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The Role of Digital Forensic Analysis in Modern Investigations

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***Abstract*— This paper explores the pivotal role of digital forensic analysis in modern criminal investigations, emphasizing its integration with traditional investigative practices and the challenges it faces in the digital age. The fusion of digital expertise with traditional forensic methods is crucial for effective crime-solving, allowing investigators to utilize a wide range of evidence from both physical and digital sources. Specialized techniques are required to handle the unique complexities of digital crime scenes, ensuring the accurate preservation and analysis of digital evidence to uncover motives and behavioral patterns behind criminal acts. As digital forensic analysis adapts to evolving challenges such as data volume and encryption, advanced tools and interdisciplinary collaboration become essential. In the legal realm, adherence to established standards and transparency in digital forensic processes are paramount for the admissibility of evidence. Digital forensic analysis is a cornerstone in modern investigations, providing critical insights for justice in an increasingly digital world.**

Keywords*— Digital Forensic Analysis, Evidence Collection, Data Privacy, Methodologies and Interdisciplinary Collaboration

I. INTRODUCTION

Forensic science, often the marriage of science and law, is a vital cornerstone of the criminal justice system. It is the art and science of applying various scientific principles, methodologies, and techniques to matters of the law, spanning a wide spectrum of disciplines. From the meticulous analysis of crime scenes to the intricate examination of digital evidence, forensic science plays a pivotal role in unraveling mysteries, solving crimes, and delivering justice.

At its essence, the term "forensic" originates from the Latin word "forensis," meaning "of or before the forum." This etymological root highlights the historical association of forensic science with legal proceedings, emphasizing its fundamental role in presenting evidence before courts of law. Today, the scope of forensic science is vast and multifaceted, encompassing disciplines such as DNA analysis, questioned documents, ballistics, toxicology, digital forensics, and beyond [1].

The breadth of forensic science is underscored by its adaptability across diverse settings and contexts. Whether in the laboratories of law enforcement agencies, government organizations' offices, or independent consultants' private practices, forensic scientists apply their expertise to unravel complex cases and shed light on obscure truths. Moreover, forensic science is utilized on the global stage to seek justice for human rights abuses, acts of war, and various international atrocities [2].

The historical evolution of forensic science is a testament to human ingenuity and innovation. From ancient civilizations utilizing fingerprints for identification to establishing formalized systems for forensic analysis in the 19th and 20th centuries, the field has continuously evolved in response to societal needs and technological advancements. Pioneering figures such as Henry Goddard, James Marsh, and Sir Francis Galton laid the groundwork for modern forensic practices, paving the way for future generations of forensic scientists [3].

In the digital age, forensic science faces new frontiers and challenges. Digital forensics has revolutionized investigative techniques, enabling analysts to uncover evidence stored within electronic devices and online platforms. Legislative measures, such as the Florida Computer Crimes Act and the Federal Computer Fraud and Abuse Act, have provided a legal framework for addressing cybercrimes and digital evidence [4].

However, amidst these advancements, forensic science grapples with the "CSI effect" – a phenomenon fueled by media portrayals that shape public perceptions and expectations of forensic investigations. This phenomenon poses challenges for forensic analysts as they strive to balance the realities of scientific inquiry with the sensationalized depictions seen on television screens [5].

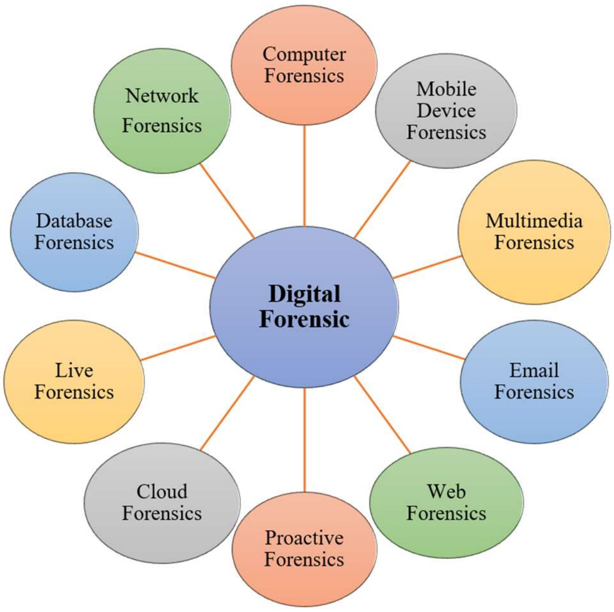

Figure 1. Classification of Digital Forensics

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Digital Forensics operates as a science, employing rigorous methodologies to investigate digital artifacts and uncover evidence while adhering to scientific principles [6]. Your approach to testing within Digital Forensics should mirror the systematic and empirical nature of the scientific method, ensuring investigations are systematic, replicable, and reliable. Applying the scientific method in Digital Forensics allows for the formulation of hypotheses, controlled experiments, and unbiased data analysis, thus upholding the standards of science and enhancing the credibility and integrity of findings, supporting the accuracy and validity of investigative outcomes.

II. Digital Forensic Analysis

In the ever-evolving landscape of criminal investigations, digital forensic analysis is crucial in unraveling complex cases and securing justice in the digital age. This section explores the multifaceted realm of digital forensic analysis, encompassing methodologies, challenges, and integrating digital expertise with traditional investigative practices [7].

A. Digital Crime Scene Analysis

Digital forensic analysis is pivotal in modern investigative endeavors, offering unique insights, methodologies, and challenges that necessitate specialized expertise. By integrating digital proficiency with traditional forensic practices, investigators can adopt a holistic approach to solving crimes in the digital age, ensuring thorough analysis and interpretation of evidence across diverse investigative domains [8].

In contemporary forensic investigations, examining digital crime scenes presents an intricate and dynamic landscape distinct from traditional physical crime scenes. While crime scene analysts are skilled in processing tangible locations, digital forensic analysts specialize in unraveling the complexities inherent in digital environments. This comprehensive section delves into the nuanced methodologies, diverse types of evidence, evolving challenges, and integration with traditional forensic practices within digital forensic analysis [9].

B. Methodologies: Bridging Physical and Digital Realms

In the realm of crime scene analysis, both physical and digital, methodologies serve as the cornerstone of investigative processes [10]. Despite the differing nature of the scenes, crime scene analysts and digital forensic analysts adhere to analogous protocols, albeit with distinct applications [11].

- *Response and Scene Securing:* Crime scene analysts are trained to swiftly respond to physical locations where crimes are suspected to have occurred. Conversely, digital forensic analysts respond to digital environments, ensuring the preservation and protection of digital data to prevent alterations or contamination.
- *Documentation:* Thorough documentation is paramount in both physical and digital investigations. Whether capturing physical evidence or documenting digital data, meticulous recording ensures the preservation of crucial details.
- *Search and Evidence Collection:* Methodical searches are conducted in both realms to locate evidence pertinent to the investigation. While crime scene analysts collect physical evidence such as fingerprints or DNA samples, digital forensic analysts focus on extracting and preserving relevant digital data.
- *Unique Aspects of Digital Forensics:* Unlocking the "Why" Behind Crimes

One of the distinctive features of digital forensic analysis lies in its capacity to uncover the rationale behind criminal actions:

- *Understanding Intent:* Digital evidence provides invaluable insights into the perpetrator's motives, thought processes, and premeditation, elucidating the underlying factors driving criminal behavior.
- *Behavioral Analysis:* Examination of digital artifacts such as internet search history, communication patterns, and documents enables the construction of intricate personality profiles, shedding light on interests, medical conditions, and potential criminal intent.

C. Types of Digital Evidence: A Multifaceted Landscape

The realm of digital evidence encompasses a diverse array of sources and artifacts, extending far beyond conventional notions:

- *Device Types:* Computers, smartphones, gaming systems, and various storage media serve as repositories for potential digital evidence, each offering unique insights into the investigation.
- *Data Categories:* From chat/email transcripts and multimedia files to financial records and internet browsing history, digital evidence spans an extensive spectrum of data categories, each holding significance in the investigative process.
- *Cloud Storage:* In addition to local storage, digital evidence may also be housed in cloud platforms, presenting challenges in retrieval and analysis but expanding the scope of potential evidence.

D. Evolving Challenges: Navigating the Digital Frontier

Digital forensic analysis confronts a myriad of evolving challenges, shaped by the rapid pace of technological advancement and the ever-expanding volume of digital data:

- *Data Volume and Complexity:* The exponential growth of digital data presents significant challenges in managing and analyzing vast amounts of information, necessitating advanced tools and techniques.
- *Encryption and Privacy:* Increasingly sophisticated encryption standards heighten the difficulty of accessing protected data, raising concerns regarding privacy and data security [12].
- *Rapid Technological Evolution:* The rapid evolution of technology necessitates continuous skill development and adaptation among digital forensic professionals to keep pace with emerging trends and techniques.

E. Integration with Traditional Forensics: A Holistic Approach to Investigation

Contrary to replacing traditional forensic methods, digital forensic analysis complements and enriches existing investigative practices:

- *Interdisciplinary Collaboration:* Collaboration among various forensic disciplines fosters a holistic approach to investigation, ensuring comprehensive analysis and interpretation of evidence.
- *Combined Evidence:* Digital evidence enhances traditional forensic findings, providing additional layers of insight and context to the investigative process.
- *Managing Expectations:* Addressing misconceptions, such as those influenced by media portrayals (CSI effect), is crucial in managing expectations and fostering a realistic understanding of digital forensic capabilities among stakeholders.

III. Legal Role Of The Digital Forensic Analyst

In contemporary legal contexts, the role of digital forensic analysts holds significant weight, particularly in the investigation of criminal activities and civil litigation. The digital landscape has become integral to modern life, and with it, the importance of digital evidence has soared. The digital forensic analyst serves as a linchpin in the process of uncovering, interpreting, and presenting this evidence in a manner that is admissible and comprehensible within legal proceedings [4].

Digital forensics is a specialized field dedicated to the systematic examination of digital devices, networks, and media to extract and analyse digital evidence. This evidence can range from emails, documents, and images to logs, metadata, and deleted files. The search for digital evidence requires a meticulous approach, employing sophisticated tools and techniques to ensure the preservation of data integrity while adhering to legal standards and protocols [13].

In legal parlance, evidence encompasses any information, data, or facts that are relevant to proving or disproving a claim or allegation. While evidence itself is not inherently a legal term, its significance in legal proceedings cannot be overstated. The identification and classification of evidence, particularly in the digital realm, raise pertinent questions about authenticity, relevance, and admissibility, underscoring the need for rigorous examination and documentation [14].

Digital forensic analysts play a pivotal role in the investigative process, collaborating closely with law enforcement agencies, legal teams, and other stakeholders. Their responsibilities encompass a wide array of tasks, including the collection, preservation, analysis, and presentation of digital evidence. Depending on the jurisdiction and organizational structure, digital forensic analysts may operate as sworn law enforcement officers or civilian specialists, each with specific legal authorities and constraints [15].

Central to the legal role of the digital forensic analyst is their function as an expert witness in court proceedings. As recognized experts in their field, digital forensic analysts provide invaluable insights and interpretations regarding complex digital evidence. Their testimony serves to elucidate technical concepts and methodologies for judges and juries, facilitating informed decision-making. The admissibility of their testimony is subject to stringent standards, ensuring that only reliable and relevant evidence is presented in court [16].

The admissibility of scientific evidence in court is governed by established legal standards, including the Frye and Daubert standards. The Frye standard emphasizes the general acceptance of a scientific technique within the relevant scientific community, while the Daubert standard focuses on the reliability and relevance of the evidence. These standards serve as gatekeeping mechanisms, safeguarding against the introduction of unreliable or unscientific evidence in legal proceedings [17].

The execution of digital forensic analysis often requires the obtainment and execution of search warrants, which grant law enforcement agencies the authority to conduct searches based on probable cause [18]. Search warrants outline the scope of the search, including the items to be searched, the individuals authorized to conduct the search, the location of the search, and the time frame within which the search must be executed. Compliance with search warrant provisions is paramount to upholding constitutional protections against unlawful search and seizure.

IV. Best Practices In Digital Forensics

In digital forensics, a field where the accuracy and reliability of evidence can make or break legal cases, adherence to best practices is paramount. These practices ensure the integrity of investigations and uphold the standards of justice and accountability. This section outlines key best practices, offering comprehensive guidance to digital forensic analysts as they navigate the complexities of their profession.

Standard Operating Procedures (SOPs): Standard operating procedures (SOPs) are the backbone of digital forensic investigations, providing a systematic framework for conducting analyses. These procedures must be meticulously documented, detailing the steps to be followed, the rationale behind each action, and any limitations or requirements that must be adhered to [14]. SOPs ensure consistency across analysts and laboratories, fostering reliability and reproducibility in investigative processes.

- *Quality Control:* Quality control mechanisms are essential safeguards against errors and inconsistencies in digital forensic analyses. Establishing an overarching program of quality, overseen by designated individuals, ensures that investigations meet rigorous standards of accuracy and reliability [19]. Accreditation serves as tangible evidence of adherence to quality protocols, bolstering the credibility of forensic analyses in legal proceedings [20].
- *Validation Testing:* Validation testing is the cornerstone of confidence in digital forensic tools and methodologies. It involves rigorous testing to verify forensic tools' functionality, reliability, and accuracy, thereby mitigating the risk of errors or inaccuracies in analyses [4]. Maintaining a comprehensive list of validated and approved tools is essential, assuring that

only reliable and effective tools are utilized in investigations.

Figure 2. Efective practice stages: Plan–Do–Check–Change

- *Proficiency Testing:* Proficiency testing is essential for both individual analysts and the systems they employ. Analysts must undergo regular proficiency tests to assess their competency and ensure they remain abreast of advancements in technology and methodology [20]. Similarly, systems and procedures should undergo testing to validate their efficacy and reliability, particularly in the face of evolving digital threats.

- *Documentation:* Thorough documentation is non-negotiable in digital forensic investigations. Every step of the inquiry must be meticulously documented, providing a clear record of the processes followed, decisions made, and evidence collected [4]. This documentation serves as a critical resource in legal proceedings, ensuring transparency, accountability, and the admissibility of evidence.

- *Training:* A robust training program is essential for cultivating the expertise and proficiency of digital forensic analysts. Qualified trainers should deliver comprehensive training covering forensic science fundamentals, investigative techniques, and courtroom testimony [20]. Training should be ongoing, with clear benchmarks and metrics to assess competency and proficiency.

- *Examination Environment:* The examination environment plays a crucial role in the integrity and security of digital evidence. Factors such as adequate power and cooling, contaminant-free workspaces, limited access, and measures to prevent cross-contamination must be meticulously managed to ensure the reliability of forensic analyses [14].

- *Examination Equipment:* The selection and configuration of examination equipment are critical considerations in digital forensic analyses. Workstations must have sufficient processing power to run forensic tools effectively while providing unfettered operating system access [20]. Additionally, the availability of peripherals, write blockers, adapters, and storage media is essential for conducting thorough investigations.

- *Preparing to Begin Analysis:* Before commencing analysis, analysts must review all relevant documentation, including search warrants, consent forms, and case summaries. This ensures a clear understanding of the scope and objectives of the investigation, preventing open-ended analyses and guiding the direction of the examination [4].

V. Discussion

The comprehensive overview presented in the "Digital Forensic Analysis in Modern Investigations" section highlights the indispensable role of digital forensic analysis in contemporary criminal investigations. By dissecting the methodologies, challenges, and integration with traditional investigative practices, this discussion sheds light on the complexities and significance of digital forensic analysis in pursuing justice.

The section emphasizes the integration of digital proficiency with traditional forensic practices, underlining the importance of a holistic approach to solving crimes in the digital age. By connecting the physical and digital realms, investigators can utilize both digital and traditional evidence to conduct comprehensive analyses and interpretations, ultimately bolstering the efficacy of investigative endeavors.

Digital crime scenes present a dynamic and intricate landscape distinct from traditional physical crime scenes. While crime scene analysts excel in processing tangible locations, digital forensic analysts specialize in navigating the complexities inherent in digital environments. This distinction underscores the need for specialized expertise and methodologies tailored to the digital realm, ensuring precision and accuracy of digital evidence's preservation, collection, and analysis.

One of the distinctive features of digital forensic analysis lies in its capacity to uncover the intent and behavioral patterns behind criminal actions. Analysts can construct intricate personality profiles by examining digital artifacts such as internet search history and communication patterns, providing insights into motives, thought processes, and potential criminal intent. This behavioral analysis adds depth to investigations, enabling investigators to understand the perpetrators and their motivations better.

Digital forensic analysis confronts many evolving challenges, ranging from the exponential growth of digital data to increasingly sophisticated encryption standards. The rapid evolution of technology necessitates continuous skill development and adaptation among digital forensic professionals to keep pace with emerging trends and techniques.

Tackling these challenges demands a proactive stance, utilizing advanced tools, meticulous methodologies, and interdisciplinary collaboration to effectively navigate the intricacies of the digital frontier.

Digital forensic analysts hold significant weight in contemporary legal contexts, particularly in investigating criminal activities and civil litigation. The admissibility of digital evidence in court proceedings is governed by established legal standards such as the Frye and Daubert standards, which serve as gatekeeping mechanisms to safeguard against the introduction of unreliable or unscientific evidence. Compliance with search warrant provisions is paramount to upholding constitutional protections against unlawful search and seizure, emphasizing the importance of adherence to legal standards and protocols in digital forensic analysis.

Adherence to best practices and quality assurance measures is paramount in digital forensic analysis to ensure the integrity and reliability of evidence. Standard operating procedures (SOPs), quality control mechanisms, validation testing, proficiency testing, thorough documentation, robust training programs, and meticulous management of the examination environment and equipment are essential components of a comprehensive approach to digital forensic analysis. These practices not only uphold the standards of justice and accountability but also bolster the credibility of forensic analyses in legal proceedings, underscoring the importance of maintaining rigor and transparency throughout the investigative process.

VI. Conclusions

This paper illuminates the critical role of digital forensic analysis in the contemporary landscape of criminal investigations. By delving into methodologies, challenges, and the fusion of digital expertise with traditional investigative practices, we underscore the complexities and significance of digital forensic analysis. Integrating digital proficiency with traditional forensic practices emerges as a key theme, emphasizing the importance of a holistic approach to solving crimes in the digital age. Connecting the physical and digital realms empowers investigators to leverage a comprehensive range of evidence, thereby augmenting the effectiveness of investigative endeavors. Furthermore, we highlight the unique nature of digital crime scenes, necessitating specialized expertise and methodologies tailored to the digital realm. This distinction underscores the importance of preserving, collecting, and analyzing digital evidence with precision and accuracy to uncover insights into motives and behavioral patterns behind criminal actions.

As digital forensic analysis confronts evolving challenges such as data volume, encryption, and rapid technological evolution, a proactive approach involving advanced tools, rigorous methodologies, and interdisciplinary collaboration becomes imperative to navigate the complexities of the digital frontier effectively. In the legal arena, the role of digital forensic analysts holds significant weight. The admissibility of digital evidence is governed by established legal standards. Compliance with search warrant provisions and adherence to legal standards and protocols underscore the importance of rigor and transparency in digital forensic analysis.

Finally, strict adherence to best practices and quality assurance measures is crucial to guarantee the integrity and reliability of evidence. From standard operating procedures to proficiency testing and thorough documentation, these practices uphold the standards of justice and accountability while bolstering the credibility of forensic analyses in legal proceedings. By embracing technological advancements, rigorous methodologies, and interdisciplinary collaboration, digital forensic analysts play a pivotal role in uncovering the truth and upholding the principles of fairness and accountability in legal proceedings.

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Metaverse for Enhancing Animal Welfare - Leveraging Sensor Technology and Ethical Considerations

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***Abstract*— The metaverse, a virtual world where real-world aspects merge with artificial intelligence, immersive experiences, and high-level digital connectivity, is increasingly being applied in animal farming. This integration offers significant opportunities for addressing climate change and promoting sustainable food production. However, it also raises several ethical issues, particularly concerning animal rights. This paper evaluates these ethical considerations, emphasizing the need for a thorough examination of how sensor technology affects animals' perception and autonomy. Key findings indicate that while metaverse technologies can enhance animal welfare through improved monitoring and optimized living conditions, they also pose risks of detachment and commodification. The design of animal-friendly environments must balance technological advancement with ethical approaches to animal welfare. Critical factors such as ethical reflection, socio-economic impact, and the ability to retrieve meaningful information must be considered to maintain sensitivity and trust in these technologies. Moreover, the paper highlights the importance of addressing inequalities in access and adoption of metaverse technologies, which can significantly benefit animal farming. The potential of the metaverse to revolutionize the agri-food sector, particularly in animal agriculture, remains vast but requires further research to fully understand its implications. This paper concludes that a conscientious and ethical approach is essential for integrating metaverse technologies into animal farming, ensuring that animal welfare and equitable practices are prioritized for a sustainable future.**

Keywords—Animal Welfare, Metaverse, Augmented Reality, Precision Livestock Farming, Ethical Farming, Sustainability, Digital agriculture

I. MODERN ANIMAL FARMING AND METAVERSE

Animal husbandry has been at the core of human existence for centuries. It provides humans with food and raw materials. The process of domestication dates back to around 10,000 years, with canines being the first to domesticate. Other animals followed in chronological order as bovines, galliformes, suids, and ovines [1. 2]. Over the centuries, the development of technology has revolutionized animal husbandry.

Technological development has increased the production and efficiency of animals. Modern animal farming features several technological advancements such as Artificial Intelligence, robotics, and automation systems among others, which have improved the daily operation on the farm [3]. Precision farming tools have played a significant role in improving animal welfare, including robotic milkers, automated gating systems, and mechanized manure removal systems which have increased productivity, reduced labor and stress in animals [4].

An excellent example of the improvement of the animal well-being is the introduction of the automated bird retrieving system in poultry farming which significantly reduced the number of keel bone fractures and lowered stress levels before slaughter. Similarly, the introduction of robotic calf feeders replaced the traditional solitary houses, thereby encouraging socialization among calves while providing the appropriate nutritional diets such as promoting cognitive growth and negating the impact of loneliness. These examples underscore the role of precision farming in addressing specific constraints in farming [5]. Nonetheless, it has elicited its fair share of issues including overcrowding, reduced access to essentials, and the use of hormones to encourage growth among others [6].

Diseases remain pre-potent to livestock with enormous implications for ecosystems and humans as well. Livestock farming contributes to the depletion and pollution of land and water resources while its waste is a significant contributor to air pollution [7]. This problem seems irreversible because of the need for livestock products. Virtual reality and other related technologies provide a possible solution to the ethics dissents in the sector. The technology is believed to cost less and improve the living situation of the animals [8]. The evolving technology has the potential to resolve most of the challenges facing modern farming. However, it should induce another ethical debate on its capacities. To cultivate and use metaverse in the sector responsibly, we must use ethical skepticism to measures such as the impacts on animal welfare, the environment, and interaction with humans. The trend can make the use of technology humbler, long-standing, and without an effect.

II. EVOLUTION OF ANIMAL FARMING AND ETHICS

The Ethical implications of modern farming approaches on an industrial scale have generated further awareness regarding the treatment of farm animals. Public demand for not only keeping animals in agriculture products in a more humane way but also in an ethically viable manner continues to grow due to issues of cruelty and sustainability resonate within the industry [9]. This led to the development of state legislative and regulatory bodies that addressed the cruelty over work animals in agriculture retrospectively. For example, the UK

Cruelty to Animals Act 1822 and U.S. legislation in 1828 tackled cruelty to animals during sea transportation [10].

The U.S. law to protect animals – ASPCA Act – in 1866 was the first significant milestone that initiated a process of integrating animal welfare in state laws. Based on these and other examples, several countries have imposed minimum standards for living for agricultural animals, as seen in the European Union, where gestation crates for sows has been banned [11]. Given the growing sociocultural industry backlash regarding animal maltreatment in agricultural establishments, the expansion of animal composures might be possible under the influence of newly developed values.

The metaverse promises a future where immersive farming experiences will enhance animal welfare and sustainable practices. Metaverse simulate natural habitats, significantly reducing the stress and isolation of animals reared in conventional farms. Consequently, the animals' health will be promoted, and they will be in a better state of well-being. Likewise, technologies such as virtual reality and augmented reality will redefine how people interact with animal welfare. For instance, they will transform animal care into farming simulations while also presenting learning experiences on best practices on welfare. Most importantly, however, is how the platforms provide consumer education on the best ethical practices of animal farming, which will impart more empathy and information to care for animals.

Building metaverse benefits human animal farming beyond just welfare; it also has advantages for the farmer and the food industry at large.

a) Resource efficiency: Metaverse will help farmers monitor and control their resource use. This guarantees optimal consumption, which will reduce wastage.

b) Infrastructure expenditure: virtual farming minimizes the area used for farming and reduces overhead and operating costs.

c) Production efficiency: farmers can edit the ideal farming conditions for the best result soil testing beneficial to plant growth which will minimize costs.

d) Environmental consideration: virtual farming minimizes the need for land expansion and reduces agriculture's environmental impact.

However, while metaverses appear to promise cost savings and ecological benefits on animal farming, it is important to consider its ethics and limitations thoroughly. New virtual reality (VR) and augmented reality (AR) technologies are revolutionizing animal farming by influencing welfare, operational efficiency, and ecological consideration.

The innovations serve a purpose in learning, training, scenario testing, health monitoring, and stress reduction and sustainable behaviorization [12-17].

This paper provides an overview of a very promising frontier but also appreciates that the research in this undertaking is still in its infancy. The theoretical path of authenticity or lack thereof that metaverse may eventually embrace to become potential alternatives to conventional animal farming is a journey that includes a lot of discussion but little academic literature from a commercial practice. Currently there are not much commercially available metaverse or virtual reality products or solutions available for animal farming applications. This makes it challenging to determine the impact of metaverse on traditional livestock farming practices.

Furthermore, the available scientific publications and literature suggestion implies that this field always strives based on the improvement of methodologies, technologies, and application strategies. Attempting to bridge theoretical knowledges and practical challenges regarding the assessment of farm animal welfare in virtual settings is inherently difficult given the interconnection between the physical condition, mental engagement, social interaction, behavior, and other aspects of wellbeing of farm animals.

One should acknowledge that the field of metaverse in animal farming remains largely exploratory, which suggests further research is essential for increased validation and collaboration across various disciplines. Consequently, a systematic comprehensive study in commercial contexts is vital for discovering the practical benefits and drawbacks of metaverse. In some potential application cases, the platforms can simulate vast outdoor spaces or natural habitats. By doing so, animals are given the opportunity to enjoy a semblance of their natural environment.

Klaas et al. [18] offered such an artificial environment and noted significant reductions in stress, as familiarity encouraged the poultry to engage in natural behaviors. A similar finding was documented by Norouzi et al. [19] who speculated that virtual settings that resemble nature can reduce stress and anxiety in animals. Furthermore, incorporating digital twins in has the potential for incorporating metaverse. It can generate a humane environment, allowing meticulous monitoring and optimization of animal health and nutrition practices. This way, customized dietary programs can be developed, and diseases can be detected in advance, reducing the reliance on antibiotics and enhancing gentle animal welfare has the potential. Metaverse are capable of reducing antibiotic use by lowering stress and enabling prompt disease diagnosis.

Virtual settings may offer a rich foundation to simulate and observe entire farming practices, enabling the measurement and creation of farming methods that are inherently and functionally safer and more reliable. Farming systems often involve the various practices that farmers undertake. Heightened Animal Welfare – Comprehensively based on the current practices, metaverse have the distinct advantage of promoting more ethical solutions to the study of the potential benefits of different approaches, reducing the need for invasive and cruel physical effects.

Public knowledge of animal welfare and ethical animal farming can be greatly expanded using advanced multi-sensory technology and VR farm trips. Critically evaluated – One major fear is the question of habituation and the effect on creatures and their behavior. Longitudinal studies indicate the possibility of initial advantages, from lowered stress to enhanced actions, quickly diminish, leaving animals insensitive and non-responsive when exposed to metaverse based virtual reality technologies [20]. For example, a poultry farm with virtual organic surroundings will initially reduce pressure by fascinating birds and by exposing birds to natural farm environment. However, over time, the learning process is robust, lowering the strain, formality, and acceptance of genuine stimuli. Similarly, livestock such as dairy cows or swine might become unsusceptible and may not remove itself complex surroundings and be bored to death.

From an ethical perspective, if metaverse are construed as a replacement for real-world experiences, use, and to a certain extent, animals will remain justified since animal meat and animal products such as dairy, eggs etc are necessary for human consumption. In this context, for instance, the use of metaverse to maximize the production of lab-grown meat might create the illusion of resolving the issue of animal exploitation by commercially producing the flesh and leaving out the broader ethical issue surrounding animals' rights.

In the industrial farming setting, the use of metaverse may not tackle the underlying causes of animal suffering. For example, this approach may make farmers feel like offering virtual reality to virtual poultry might overlook the root cause of the animal's plight. This would be construed as only superficial animal welfare enhancement and not a real substantial systemic change [21]. Metaverse have high resource and technological demands and costs, posing substantial barriers. Smallholder farmers and those from developing countries most affected by industrial farming are less likely to provide metaverse due to resource shortages [22]. This would lead to Digital Divide in terms of adoption of advanced technologies between developed countries vs developing nations and between large scale farmers vs smaller to medium scale farmers.

Overcoming Digital Divide becomes essential for further validation and adoption of metaverse tools and virtual reality platforms in the animal farming sector. Furthermore, inaccurate simulation may lead to misleading decision-making, which drives the pretense further. Lastly, the metaverse lack natural physical stimulations that may have negative physical and psychological impacts on animals [23]. As a result, even simulations need to be incorporated with physical stimulations to achieve a balanced approach [24]. Without physical activity for farm animals, the musculoskeletal health would suffer along with the lack of exposure to sunlight and wind which are correlated to the farm animals physiology and functioning and mental health.

III. SENSOR DATA AND LIVESTOCK BEHAVIOUR

The integration of sensor data and analysis of livestock behavior represents a transformative potential for animal farming, promising to advance the industry by providing real-time insights into animal health, welfare, and optimizing productivity through sustainable practices.

A. *Types of Sensors in Animal Farming*

Advancements in sensor technology have significantly enhanced the monitoring capabilities in animal farming, leading to the categorization of sensors into wearable, non-wearable, imaging, and acoustic types. Wearable sensors, such as accelerometers and heart rate monitors, are affixed directly to the animals, providing vital data on their physical state and movements. Non-wearable sensors, placed within the farm environment, track ambient conditions crucial for maintaining optimal living conditions. Imaging sensors, including various camera types (2D, 3D, 4D, Depth, Kinetic, thermal) and computer vision algorithms, capture visual data to monitor movement and posture, while acoustic sensors detect sounds that indicate stress or environmental changes. Together, these sensors offer a comprehensive overview of both animal welfare and environmental quality within farming setups.

B. *Monitoring Animal Behavior and Health*

The deployment of sensor technology significantly enhances the capacity to monitor animal behavior and health, offering invaluable insights into welfare and productivity. Movement tracking, quantifying activity pattern, physiological monitoring, and the observation of social and reproductive behaviors enable early detection of health issues, stress indicators, and welfare concerns. For example, changes in feeding and drinking patterns detected by sensors can signal health problems or stress, necessitating intervention. Moreover, the integration of machine learning algorithms with sensor data facilitates the prediction and detection of specific health conditions, allowing for timely and targeted treatments.

C. *Environmental Conditions and Livestock Impact*

Environmental sensors are pivotal in managing conditions that affect animal welfare and productivity. By monitoring the animal husbandry parameters such as the temperature, humidity, air quality, lighting, and noise levels, these sensors ensure animals reside within their comfort zones, preventing stress and promoting health. Additionally, insights into the farm house space utilization and weather conditions enable optimized management of outdoor and indoor environments, enhancing the overall well-being of livestock.

D. *Sensor Fusion and Multimodal Integration*

The fusion of sensor data with advanced technologies like predictive analytics, simulation modeling, and computer vision algorithms can significantly enhance the virtual farming experience within the metaverse. This multimodal integration facilitates immersive experiences, enabling virtual training for farmers and veterinarians and simulating various environmental impacts on animal welfare without risking real animals. Predictive analytics and personalized tools allow for the creation of immersive, interconnected virtual farming worlds, optimizing animal nutrition, behavior, and reproduction in a sustainable and ethical manner.

IV. DIGITAL REALMS - INTEGRATION OF ADVANCED TECHNOLOGIES IN CRAFTING IMMERSIVE METAVERSE

The realization of metaverse into practical applications encapsulates the deployment of sophisticated technologies and systems to craft immersive and interactive digital realms. This process integrates various components, each playing a pivotal role in bringing virtual spaces to life;

The foundation of immersive experiences is laid by VR hardware, including headsets like Oculus Rift, HTC Vive, and PlayStation VR. These devices, equipped with high-resolution displays, motion tracking, and integrated audio, immerse users in digital landscapes, effectively isolating them from the physical world [25].

Critical to the construction of metaverse is specialized software that facilitates the creation, rendering, and interaction within these spaces. Developers leverage these platforms to craft intricate digital terrains, enabling realistic graphics and user engagement within the virtual realm [26].

The essence of metaverse lies in their ability to mimic real-world settings or conjure entirely novel universes. From accurate renditions of tangible locations to imaginative domains, these digital spaces host a variety of elements, including landscapes and life-like entities, enriching user immersion and interaction [27]. Immersion is further amplified through dynamic interaction mechanisms within the virtual environment. Technologies enabling gesture recognition, hand controllers, voice commands, and full-body tracking allow users to navigate, manipulate digital objects, and engage in multifaceted actions, augmenting the realism of their virtual experience [28].

To ensure a cohesive and authentic virtual experience, advanced rendering techniques are employed for the instantaneous depiction of complex graphics and animations. Simultaneously, physics simulations reproduce real-world interactions and environmental dynamics, such as gravity and weather effects, enhancing the believability of the virtual world [29]. The collaborative and social aspect of metaverse is enabled through networking technologies, allowing users to connect, interact, and share experiences within a unified digital space. This collective participation fosters a communal sense of presence and belonging in the virtual environment [30].

The architecture of metaverse is facilitated by an array of development tools, which assist in generating 3D models, textures, animations, and the programming necessary for constructing interactive and captivating virtual spaces [31]. Through the harmonious integration of VR hardware, software, simulated components, interaction techniques, rendering capabilities, networking functions, and development tools, metaverse transcend conceptual boundaries to become tangible experiences. This convergence of technology not only materializes immersive digital worlds but also propels users into engaging, realistic, and socially connected virtual experiences, marking a significant milestone in the evolution of digital interaction and simulation [32].

V. Economic Frontiers Of The Metaverse In Animal Farming

A. *Ethical Dimensions of Virtual Integration in Animal Farming*

The emergence of the metaverse possibilities in animal farming raises ethical dilemmas concerning the commodification and objectification of animals within digital realms. Such virtualization risks detaching human empathy from the tangible realities of animal existence, potentially normalizing controversial practices like genetic modification or invasive procedures under the guise of technological advancement [33]. The virtual and augmented reality platforms could pave the way by offering the extraordinary capacity to cultivate empathy and deepen our comprehension of animal experiences by simulating their natural habitats, thereby fostering a more profound connection with the living world [34].

The economic landscape of metaverse in animal farming is nuanced, with potential for both cost reduction and heightened efficiency [35]. Virtual farming can optimize resource management, enhancing feed efficiency and health monitoring, thereby reducing operational costs and environmental impact. This could redefine productivity and profitability, offering scalable benefits from real-time analytics and precision farming techniques [36].

However, the digital divide looms large, posing significant challenges for small-scale and resource-constrained farmers [37]. The upfront investment costs required for virtual farming infrastructures may reinforce existing disparities, underscoring the urgency for accessible and inclusive technological solutions. Bridging this divide necessitates targeted support via government programs or by farmers co-op funding mechanisms and training for small-scale farmers, ensuring equitable access to the benefits of metaverse.

B. *Regulatory, Educational, and Consumer Dynamics in the Virtual Farming Ecosystem*

The regulatory landscape must evolve to address the unique challenges posed by the metaverse in animal farming. Developing comprehensive legal and ethical frameworks is crucial for governing the application of virtual technologies, safeguarding animal welfare, and ensuring responsible industry practices. Collaborative efforts among policymakers, industry stakeholders, and ethical experts are vital for crafting regulations that balance innovation with ethical accountability.

Education and training emerge as pivotal components in the transition towards virtual farming, equipping stakeholders with the requisite skills for navigating and maximizing the economic potential of digital environments. Specialized programs and resources are essential for fostering proficiency in virtual farming technologies, promoting best practices in animal welfare, and enhancing productivity within the metaverse (Figure 1). It should also be emphasized here that the regulatory bodies such as the World Organization for Animal Health (WOAH) is placing a higher emphasis on real-time surveillance and monitoring of the farm animals which calls for adoption of metaverse and virtual reality technologies in the animal farming sector.

Ethical consumerism is poised to play a transformative role in shaping industry standards through the metaverse. By offering immersive experiences that highlight sustainable and humane farming practices, metaverse can influence consumer behaviors, encouraging demand for ethically produced animal products. This shift towards ethical consumerism demands a careful balance between promoting transparency and avoiding the pitfalls of misrepresentation or greenwashing.is [7]. The digitalization of livestock farming unveils novel business opportunities, from monetizing farm-generated data to offering specialized consultancy services. Diversification of income sources can diminish dependence on conventional farming income, paving the way for more resilient and versatile business models.

TABLE 1: ECONOMIC IMPACT OF METAVERSE ON ANIMAL FARMING

Impact	Description	Potential Benefits
Cost Reduction	Optimization of the use of feed by tracking the dietary needs of individual animals which then reduces waste and increase efficiency.	More accessible and affordable animal farming, increased profitability, reduced waste.
Productivity and Efficiency	Produce more food with fewer resources by creating more efficient and sustainable farming systems.	Increased productivity and profitability, more accessible and affordable animal farming.
Sustainability	Can promote sustainability by reducing the environmental impact of traditional farming practices.	Reduced environmental impact, promotion of more ethical and sustainable farming practices.
Animal Welfare	Can help farmers monitor their animals' behavior and health, enabling early intervention and reducing stress.	Improved animal welfare, creation of value and competitive advantage
Data Analysis	Generate vast amounts of data that farmers can use to optimize their production processes, reduce waste, and increase efficiency. By analyzing data, farmers can identify areas where improvements can be made.	Increased productivity and profitability, reduced waste.
Training and Education	Investing in training and education can help farmers build the skills and knowledge necessary to effectively utilize metaverse.	Increased skills and knowledge, maximized benefits of metaverse, sustainable value creation.
Collaboration	Collaborating with other stakeholders, including animal welfare advocates, food safety experts, and technology providers, can help farmers leverage their expertise and create new opportunities for value creation.	Innovative solutions for improving animal welfare, increased productivity, promotion of sustainable agriculture.
Regulatory Compliance	Ensuring regulatory compliance is critical to the long-term sustainability of virtual livestock farming. Farmers must adhere to regulations governing animal welfare, food safety, and data privacy.	Maintained credibility, access to markets.
Technological Advancements	By adopting new technologies, such as artificial intelligence and machine learning.	Optimized production processes, reduced costs, increased efficiency.
Customer Relationships	Fostering relationships with customers is important for creating sustainable value in virtual livestock farming. By engaging with customers and providing transparent information.	Increased demand for products, trust and loyalty from customers.

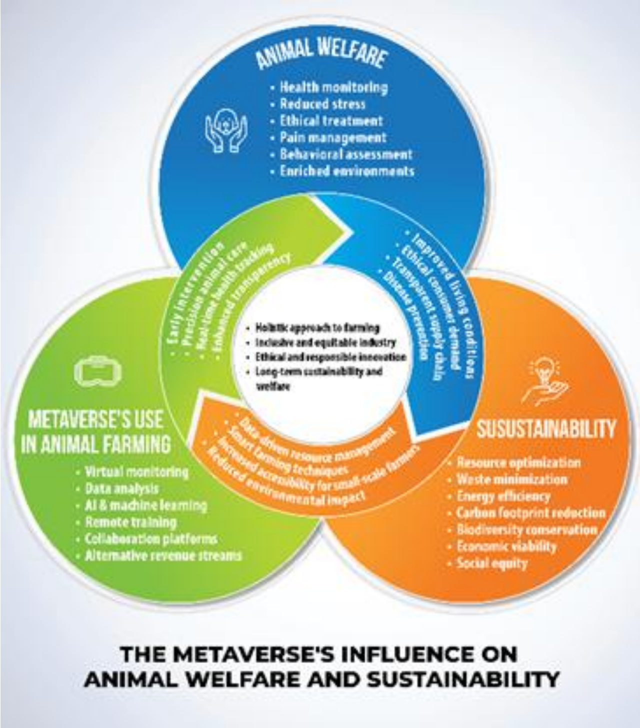

FIGURE 1. THE METAVERSE'S INFLUENCE ON ANIMAL WELFARE AND SUSTAINABILITY.

VI. SOCIAL IMPLICATIONS OF METAVERSE FOR ANIMAL FARMING

Metaverse in animal farming herald a transformative shift with wide-ranging social implications for stakeholders such as farmers, consumers, and animal welfare advocates. These technological innovations promise to democratize industry, making animal farming more accessible and profitable for entities ranging from small-scale operations to larger commercial enterprises. Additionally, these platforms can meet the growing consumer demand for sustainably produced and ethically sourced food, potentially revolutionizing the sector.

One of the most significant benefits of metaverse is the dramatic improvement in transparency and traceability within the food supply chain. By enabling detailed tracking of each animal's dietary and health history, these tools can facilitate the production of safe and ethically sound food products. Such oversight not only boosts consumer confidence, especially following food safety incidents and amidst rising concerns over animal welfare, but also allows for precise control over factors affecting animal well-being, thereby mitigating disease risks and enhancing food availability, especially in areas prone to food scarcity.

Furthermore, metaverse could redefine the distribution of value and accessibility in animal farming. They have the potential to streamline distribution channels, improve yield quality, and reduce production costs, leading to lower consumer prices and more equitable value distribution along the supply chain. Moreover, giving farmers better insights into product pricing and enabling them to negotiate fairer terms could challenge the dominance of large agribusinesses and promote fairer market practices.

The inclusive development and application of these technologies are crucial to addressing potential socio-economic impacts and ensuring the equitable distribution of benefits. Engaging a diverse array of stakeholders can help identify biases or unintended consequences, fostering a more inclusive and equitable industry. Particularly, metaverse could lower barriers to entry for small-scale and marginalized farmers, enhancing industry diversity and equity.

These platforms also provide a collaborative space for a broad spectrum of stakeholders, from marginalized farmers to industry experts, facilitating knowledge exchange and market access. By transcending language barriers, they promote global communication and collaboration. Moreover, metaverse have the potential to advance social equality and animal welfare through accessible education and training and can accommodate farmers with physical limitations, fostering a more inclusive and adaptive industry.

VII. Technology Governance In The Metaverse

Integrating metaverse into today's animal agriculture sector brings about a contradiction: it creates vast motivation for more efficiency and innovation while at the same time raising an endless number of entangled ethical and socio-economic issues. Having highlighted the centrality and significance of governance frameworks in questioning any new animal farming's ethical implications, one can argue that technology governance is crucial for a sustainable and low-risk distribution and use of these technologies.

Without proper governance, the revolution of metaverse could favor those already well-positioned in the sector – large-scale and well-resourced companies, consequently increasing inequality and marginalizing small-scale farmers. Technology governance in animal farming refers to a broad set of policies, standards, and regulations aimed at guiding the development and use of these digital technologies [38]. The aim is to address concerns of access, usability, and the impacts of VR and AR technology on animal farming regarding animal welfare, increased productivity, environmentally friendly practices, and suffering. It becomes a tool for those with the insight of developing them, enhancing access to necessary resources through democratizing access.

The growing sophistication involved in developing a human-animal dialogue raises necessary ethical concerns regarding the commodification, objectification, and desensitization of animals. It makes sure that the metaverse are not to encourage emotional disconnection but to inspire compassion, learning, and understanding of what animals endure. Some of the challenges of ethical governance in animal farming include the potential domination by agribusiness interests, insufficient regulation measures against emerging technologies, and the need for global agreement on setting standards. It requires governments, livestock industry representatives, and civil societies to come together to find governance models that dignify societal welfare to personal benefits, transparency, and global collectiveness.

Leveraging technology with strong governance in animal farming can well enhance animal welfare. The chasm between utilitarian and right-based assumptions of animal welfare – the former including lesser suffering while the later embraces animals' merits, testifies such complexity. The need for constant governance models to comply with the current societal value judgments, as indicated by transforming societal values, ethical considerations, consumer attitudes, and new scientific discoveries.

VIII. Principles And Considerations For Designing Ethical Metaverse For Animal Farming

Transition in animal agriculture enabled by metaverse demands a nuanced and ethical approach in addressing the concerns related to animal welfare, human labor, and broader socio-economic implications. At the heart of ethical virtual environment design lies the commitment to the physical and psychological well-being of animals. These spaces should meet animals' essential needs—adequate nutrition, hydration, and ample living conditions that facilitate natural behaviors and social interactions. Furthermore, it's critical that these environments are crafted to minimize stress and avoid harm, thereby creating conditions that support safety, comfort, and enrichment opportunities.

TABLE 2: PRINCIPLES FOR ETHICAL METAVERSE DESIGN IN ANIMAL FARMING

Principle	**Description**
Animal well-being	Meet the basic needs of animals such as access to food, water, space for movement, and socialization. Free from stressors and potential harm to the animals.
Accessibility	Designed to be accessible to all animals, regardless of their age, size, or breed.
Animal welfare	Designed to promote animal welfare and reduce overall suffering by providing a sense of safety and security, as well as opportunities for natural behavior and enrichment.
Human labor and employment	Ethical implications of metaverse on human labor and employment Creating equitable and just working conditions.
Human-animal interactions	Designed to promote positive interactions and relationships between humans and animals.
Transparency and accountability	Adopt an open and transparent approach to the design, operation, and management of the system, and be accountable to stakeholders, including farmers, consumers, and animal welfare advocates.
Monitoring and evaluation	Regular monitoring and evaluation should be carried out to assess the impact of metaverse on animal welfare.
Sustainability and environmental responsibility	Designers of metaverse should consider the environmental impact of the system and take measures to minimize its footprint.
Accessibility	Make livestock farming more accessible to people who live in areas where traditional farming is not possible, due to a lack of land or resources.
Innovation	Create opportunities for innovation in the livestock farming industry, leading to the development of new technologies that could improve the efficiency and effectiveness of livestock farming.
Productivity	More efficient way of managing their livestock, enabling them to monitor their animals remotely and detect issues before they become significant problems.
Human expertise	Maintaining a strong focus on human expertise and skills can be achieved through investment in training and education programs, as well as support for research and development in areas such as animal behavior, welfare, and nutrition.
Collaboration	Fostering collaboration between farmers, scientists, and other stakeholders can help ensure that new technologies and strategies are developed that reflects the needs and values of all stakeholders.

Inclusivity is a cornerstone principle, advocating for accessible environments to all animals, regardless of characteristics such as age, size, or breed. This approach rejects the valuation of some animals over others, promoting equal care and consideration for all. Moreover, beyond fulfilling basic requirements, metaverse should aim to diminish suffering and enhance the quality of life for animals. This involves designing spaces that not only protect animals but also encourage security, natural behaviors, and enrichment, ultimately improving their welfare.

The influence of metaverse on human labor in the agricultural sector cannot be overlooked. The automation of tasks historically performed by people poses challenges to employment and labor relations, necessitating forward-thinking strategies that ensure fair and sustainable work conditions, thus honoring the dignity and livelihoods of farm workers.

There is a possibility that the virtual spaces may alter human-animal interactions within farming. Designing these environments requires careful consideration of their potential impacts on these relationships, striving to nurture positive and meaningful engagements between humans and animals.

Table 2 outlines the core ethical principles and considerations vital for developing metaverse in animal farming. This framework serves as a comprehensive guide for a varied audience, including farmers, animal scientists, bioengineers, veterinarians, policymakers, consumers, and B2B clients, underlining the imperative of utilizing technology responsibly and ethically.

IX. Potential Negative Impacts Of Metaverse On Animal Welfare

While metaverse offer numerous benefits, they also present several potential negative impacts on animals. One major concern is the difficulty animals may face in distinguishing between the virtual and real worlds, leading to disorientation and stress. For example, animals might attempt to interact with virtual objects or move beyond the virtual boundaries, risking physical harm if they jump or collide with real-world obstacles. Moreover, there is a risk of animals developing addiction-like behaviors to the metaverse, where they might refuse to exit the virtual space. This dependency could lead to neglect of their need for physical interaction, exercise, and engagement in natural behaviors, ultimately affecting their physical and psychological well-being. The absence of real-world stimuli, such as sunlight, fresh air, and social interactions with other animals, can exacerbate these issues, potentially leading to deficiencies, musculoskeletal health problems, and increased stress levels.

Design issues of virtual and mixed reality platforms also pose significant challenges. Inadequate interface design might fail to account for the natural behaviors and sensory perceptions of animals, leading to confusion and frustration. For instance, metaverse that do not accurately simulate natural conditions or provide appropriate sensory feedback might stress animals rather than comfort them. Additionally, poorly designed interfaces might not be user-friendly for animal caretakers, complicating their efforts to monitor and interact with animals effectively. Furthermore, the over-reliance on metaverse might mask underlying issues in the animals' actual living conditions, preventing necessary improvements and real-world enhancements to their welfare. This reliance can create a superficial sense of well-being, where technological solutions are seen as a substitute for addressing fundamental welfare needs. In the long term, such an approach could undermine efforts to promote genuine improvements in animal farming practices and overall animal welfare.

X. A Guide To Best Practices - Enhancing Animal Welfare And Farming Efficiency Via Metaverse

Metaverse in animal farming necessitate designs that cater specifically to the dietary, habitat, and social needs of animals. These digital habitats must simulate natural environments, incorporating adequate space, temperature regulation, and appropriate lighting to foster a stress-free and safe setting. Animals should have ample room for free movement, expression of natural behaviors, and social interaction. By accommodating these needs, metaverse can significantly enhance animal welfare, reducing stress and facilitating positive interactions, including those with humans. Healthcare standards akin to those in conventional farming, such as routine health assessments and timely interventions, are critical in virtual settings. The aim is to design environments that minimize stress and discomfort, ensuring a living experience that supports the animals' physical and emotional well-being.

The creation of these spaces must account for the diverse needs and behaviors of various species, tailoring environments to promote well-being and ethical care across different animal types. Transparency in the design, operation, and oversight of metaverse is fundamental, ensuring stakeholder accountability. The integration of advanced sensor technology for continuous monitoring of animal behavior and health allows for early identification and resolution of welfare issues. Collaborative efforts with experts in animal welfare, technology, and regulation are essential to uphold animal welfare standards consistently.

Moreover, the environmental footprint of virtual farming should be a key consideration, focusing on reducing energy use, water consumption, and waste generation to minimize the agricultural sector's ecological impact. Virtual farming holds promise for expanding access to livestock farming, especially in areas where traditional practices are limited by land or resource constraints. Fostering innovation in these platforms can spur technological breakthroughs that improve farming efficiency and productivity.

Efficient management through metaverse enables remote livestock monitoring, promoting proactive issue resolution. However, the value of human expertise in understanding animal behavior, welfare, and nutrition remains paramount. Investing in training and fostering collaborative networks among stakeholders is crucial for seamlessly integrating metaverse into livestock farming.

XI. THE FUTURE OF LIVESTOCK FARMING IN THE METAVERSE - A VISION FOR SUSTAINABLE AGRICULTURE

The integration of technologies such as artificial intelligence (AI), robotics, and sensor networks is poised to revolutionize virtual farming environments. AI systems offer precise insights into animal health, behavior, and productivity, facilitating data-driven management decisions. Predictive analytics, a key component of AI, anticipates disease outbreaks, allowing for preemptive health measures that protect both animal welfare and farm efficiency [39]. Robotics enhances farming tasks, including automated milking and precision feeding [40], streamlining operations while reducing animal stress for a more humane environment.

Sensor networks provide real-time monitoring of vital signs and environmental conditions, crucial for early identification and mitigation of health issues and stressors [41]. These technologies coalesce into smart farming systems [42], delivering comprehensive analytics to inform decision-making and improve both efficiency and sustainability.

Precision Livestock Farming employs GPS and remote sensing to optimize resource use, cutting down on inputs like water and fertilizers to boost productivity and lessen environmental impacts. In the context of metaverse applications in animal farming, ethical considerations (Figure 2) must balance technological innovation with animal welfare, environmental care, and societal values. The adoption of metaverse technologies in agriculture requires a commitment to ethical practices and public trust, ensuring advancements contribute positively without compromising ecological integrity or animal health.

A multidisciplinary dialogue among stakeholders, including farmers, policymakers, and technologists, is essential for the ethical integration of metaverse technologies. This collaborative effort aims to guide responsible innovation in line with ethical standards and societal expectations. Research in metaverse applications within animal farming is expanding, indicating a future rich with opportunities for improving animal welfare, sustainability, and technological innovation. Harnessing the metaverse's potential can lead to significant advancements previously beyond our reach.

FIGURE 2. THE ETHICAL SPECTRUM OF METAVERSE IN MODERN ANIMAL FARMING

XII. CONCLUSIONS

Contemplating the future of animal farming, the introduction of metaverse, powered by sensor data, offers promising avenues for enhancing animal welfare, reducing stress, and promoting sustainable and ethical practices. However, this path is fraught with challenges, including ethical considerations, the potential impact on animal behavior, cost and accessibility issues, and the need for physical engagement. At the core of integrating metaverse into animal farming is a steadfast commitment to animal welfare, placing ethical considerations alongside diversity and equity at the forefront of deployment strategies. This approach requires a nuanced understanding of the socio-economic implications of technological adoption.

The inclusion of metaverse in animal farming presents significant challenges but also opens up opportunities to improve the lives of animals and forge a more sustainable and equitable agricultural model. By embracing technological innovations and addressing their limitations from an ethical perspective, we pave the way for a more hopeful future in animal farming. Achieving a balance between technological advancements, ethical responsibility, and sustainability goals is crucial. A conscientious and ethical approach can unlock the potential benefits of the metaverse, ensuring that animal welfare and equitable practices are prioritized. Together, we can aim for a future where animal farming not only commits to sustainability and compassion but also utilizes metaverse as a key tool in achieving such aspirations

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A Systematic Review of Application of Machine Learning in Curriculum Design Among Higher Education

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***Abstract*— Machine learning has become an increasingly popular area of research in the field of education, with potential applications in various aspects of higher education curriculum design. This study aims to review the current applications of AI in the curriculum design of higher education. We conducted an initial search for articles on the application of machine learning in curriculum design in higher education. This involved searching three core educational databases, including the Educational Research Resources Information Centre (ERIC), the British Education Index (BEI), and Education Research Complete, to identify relevant literature. Subsequently, this study performed network analysis on the included literature to gain a deeper understanding of the common themes and topics within the field. The results showed a growing trend in publishing research on the application of machine learning within the educational domain. Our review pinpointed merely 11 publications specifically targeting the application of machine learning in higher education course design, with only three being peer-reviewed articles. Through the word cloud visualization, we discerned the most prominent keywords to be AI, foreign countries, pedagogy, online courses, e-learning, and course design. Collectively, these keywords underscore the significance of AI in molding the educational landscape, as well as the expanding tendency to incorporate AI technologies into online and technology-enhanced learning experiences. Although there is a significant amount of research on the application of machine learning in education, the literature on its specific use in higher education course design still needs to be expanded. Our review identified only a small number of studies that directly focused on this topic, and among them. The network analysis generated from the included literature highlights important themes related to student learning and performance and the use of models and algorithms. However, there is still a need for further research in this area to fully understand the potential of machine learning in higher education course design. This study would contribute literature in this specific field. The review can update teacher's awareness of using machine learning in teaching practice. Additionally, it implies more and more researchers conduct related research in this area. Future studies should consider the limitations of the existing literature and explore new approaches to incorporate machine learning into curriculum design to improve student learning outcomes.**

Keywords*—*Machine Learning, Computer System, Curriculum Design, Review

I. INTRODUCTION

Several sources define curriculum design. According to McKimm, curriculum is sometimes misunderstood for the syllabus when it is actually the planned sequence of learning experiences leading to defined outcomes. The International Education Association of Australia defines it broadly as "*anything that shapes the student's learning experience*" [1,2]. Curriculum design entails integrating educational philosophy and theory into practical and coherent learning experiences in a school or educational institution. This involves assessing students' needs, teachers' skills, and the learning environment [3]. Content, teaching and learning methods, assessment, and evaluation must be organized logically and consistently.

Various theories have been proposed regarding curriculum design. As depicted in Figure 1[4], the central circle represents the core goals of curriculum design, which are crucial in determining the purpose of a course and the outcomes students can expect. Surrounding the core are Content and Sequencing, Format and Presentation of Material, and Monitoring and Assessment. The three circles connected to the core represent principles, needs, and environment.

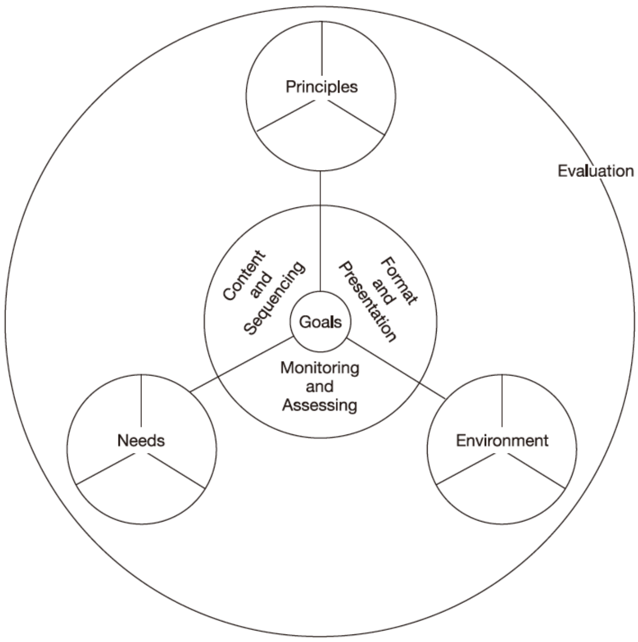

Figure 1. A model of the parts of the curriculum design process [4]

In terms of principles, four examples include learners should obtain an immediate and useful return on their learning, avoid interference, employ thoughtful processing, and engage in fluency practice. Learners' needs analysis primarily focuses on the curriculum goals and its content of a course. It is to examine what learners have already learned and what they still need to learn in the following classes. This analysis ensures that the course contains the relevant and supportive learning materials. The effective learners' needs analysis involves inquiring about the correct questions and finding out the corresponding answers in the most efficient approach.

Environment analysis [4] examines factors that strongly influence decisions about the course goals, content, teaching methods, and assessment. These factors can arise from the learners, teachers, and the overall teaching and learning situation. In the outer circle, evaluation assesses all aspects of curriculum design to determine if the course is optimal (which is why the outer circle encompasses all elements of the curriculum design process). Evaluation entails examining both the course outcomes and the planning and implementation of the course [5]

Chang et al. propose a five-stage analysis method for curriculum design consisting of Extract, Transform, Load (ETL), Analysis, Visualization, Intervention, and Expansion & Refinement [6]. In the first stage, ETL, school data is extracted and transformed for analysis. Student grades are then analysed using descriptive statistics, inferential statistics, and data mining to identify trends, correlations, and patterns. Visualization is used to represent these trends and phenomena in data or analysed results using tools such as 3D graphs, tables, charts, geographical maps, or association networks. Domain knowledge is required to create interventions, which are submitted to the committee for further improvements in curriculum design. Finally, actions are taken from different dimensions, such as data modelling and data collection from social media, to expand and refine the curriculum design.

The process of curriculum design is complex and multifaceted, involving careful planning, implementation, and evaluation to create effective educational programs [6]. This process is particularly nuanced when integrating modern technologies such as Artificial Intelligence (AI) and adopting interdisciplinary approaches. Curriculum design includes several critical stages. It needs assessment, goal setting, content selection, organization, implementation, and evaluation [3,6]. Needs assessment identifies the educational requirements and gaps, while goal setting defines the objectives that the curriculum aims to achieve. Content selection and organization involve choosing relevant materials and structuring them coherently to facilitate learning. Implementation focuses on delivering the curriculum effectively, and evaluation assesses the program's success and areas for improvement. In summary, curriculum design is a purposeful development of educational content, instructional techniques, learning experiences, and assessment procedures. Various frameworks and analysis methods are proposed to guide curriculum designers in creating effective courses for learners.

Machine learning is an artificial intelligence technology that enables computer systems to learn from experience and make predictions [7]. It is a subset of AI in which algorithms and statistical models to analyse are used to evaluate and interpret, allowing the machine to learn and develop on its own [7] Machine learning algorithms are built to operate with enormous volumes of data and may spot patterns and correlations in data that people would find difficult or impossible to discern.

Machine learning began in the 1950s with artificial intelligence [8, 9]. Researchers created algorithms and models that could play chess or solve math issues [10]. However, these early models did not learn from experience, a critical machine learning trait [11]. Researchers created data-learning algorithms and models. Late 1960s–early 1970s [12]. Machine learning was born, and researchers and practitioners immediately adopted it [12]. Throughout the next few decades, academics developed decision trees, neural networks, and supported vector machines to advance machine learning [13]. Big data and the inability of powerful computer system in the 1990s and 2000s boosted machine learning [14]. These advances let researchers develop larger, more complex models for picture and speech recognition [15]. Recommendation systems and fraud detection have helped machine learning grow [16]. Researchers and practitioners are creating deep learning and reinforcement learning algorithms and models to further machine learning [17]. These models are used in a wide range of applications, including computer vision, natural language processing, and robotics.

Machines learning algorithms are classified into numerous types, including supervised learning, unsupervised learning, semi-supervised learning, and reinforcement learning. Supervised learning algorithms are used for classification and regression tasks and are learned using labelled data. Supervised learning involves training algorithms on labelled datasets to predict outputs for given inputs. Examples of such algorithms include linear regression, logistic regression, decision trees, and random forests [18].

Unsupervised learning includes k-means clustering, principal component analysis (PCA), and deep neural networks [19]. Reinforcement learning is a sort of machine learning in which the algorithm discovers new information through trial and error [20]. Semi-supervised learning is a blend of supervised and unsupervised learning. The algorithm is trained on a mixture of labelled and unlabelled data, using the labelled data to make predictions and the unlabelled data to identify patterns and structures [21].

Each type of machine learning algorithm has its own strengths and weaknesses [22, 23], and the choice of which one to use depends on the specific problem at hand. Some of the most used machine learning algorithms include decision trees, support vector machines, k-nearest neighbours, Naive Bayes, and artificial neural networks. Deep learning algorithms, such as convolutional neural networks and recurrent neural networks, have grown in recent years popular due to their capacity to learn from massive volumes of data [24].

Regardless of the specific type of algorithm used, machine learning has the potential to greatly improve the accuracy and efficiency of decision-making in many applications, including in the field of education and curriculum design [25, 26]. In the age of big data, learning analytic has become increasingly important, as institutional experts use complex formulas to decide admissions and improve student retention and success [27]. This method combines data, statistics, and predictions to provide helpful information [28].

Machine learning algorithms find patterns in student data like exam results, attendance, and feedback [29]. This data can be utilized to create individualized learning programs and give students real-time feedback to track their progress and alter their learning tactics. Machine learning has made education dynamic and data-driven, allowing educators to make informed decisions regarding student performance and tailor courses based on data. Machine learning can automate time-consuming procedures, freeing educators to focus on more important instructional responsibilities [30].

Students who receive one-on-one tutoring demonstrate performance improvements equivalent to two standard deviations compared to those participating in conventional educational methods [31].

Machine learning has emerged as a critical component in personalized learning, altering educational delivery to accommodate individual needs and preferences [32, 33] and creating separate learning pathways for students [34]. Educators may now develop adaptive learning systems that suit to each student's unique learning style, pace, and talents by leveraging the capabilities of machine learning algorithms, resulting in a more focused and efficient educational experience [35].

Machine learning in personalized learning encompasses intelligent teaching systems, autonomous learning material, learning progress organization, and group cooperative learning [36]. It evaluates curricular resources and enables adaptive learning and recommendation engines to advance learning analytics. These platforms analyse vast volumes of student performance, engagement, and learning preferences. Analysing this data reveals patterns and trends, enabling customised learning paths for each learner [37]. Machine learning algorithms can assess student performance, interests, and preferences, recommending relevant and engaging learning materials like articles, videos, and quizzes [38]. This ensures that students receive content that is appropriate for their ability level and matches with their interests, ensuring that students remain motivated and engaged throughout the learning process.

Machine learning can also be employed to evaluate and predict student performance [39]. Analysing historical data allows algorithms to identify patterns and trends in student performance, which can be used to forecast future performance [40]. This information helps identify at-risk students and provide targeted interventions, ensuring necessary support for success.

Numerous machine learning-based systems have been developed for personalized learning, such as Adaptive Learning Systems, E-learning Systems, Intelligent Tutoring Systems (iDRIVE, CSAL, AutoTutor Operation ARA/ARIES), Dyslexia Adaptive E-Learning Management System (DAELMS), and Adaptive Self-regulated Learning Questionnaire (ASRQ), all of which cater to personalized learning experiences [41-45].

Real-time feedback relies on machine learning. Machine learning algorithms examine data, find trends, and provide quick feedback to improve performance. Machine learning can assess student performance, track engagement, and identify misconceptions, enabling tailored guidance and support. Real-time feedback helps students identify problems, improve their comprehension, and improve learning results. This feedback can also help teachers better meet students' needs.

Machine learning-based instructional software provides real-time feedback to pupils. Kaburlasos et al. [46] proposed a prototype software platform named Platform for Adaptive and Reliable Evaluation of Students (PARES) for student testing and evaluation. Ross et al. [47] used consumer RGB-D sensor data to classify students as attentive or inattentive using machine learning methods (K-means and SVM). Nguyen et al. [48] suggest dense solution space sampling in highly organized MOOC homework assignments for large-scale feedback. Hence, the researchers proposed "code words" to classify online assignment submissions. They constructed a searchable index using this terminology to quickly search the enormous dataset of student homework submissions [48]. Sivakumar et al. [49] suggested a new method for assessing Twitter API student feedback by detecting semantic relatedness between aspect terms and student opinion phrases. Uskov et al. [50] reported on a Bradley University (Peoria, IL, USA) research and development effort that set up and benchmarked eight machine learning algorithms for predictive learning analytics to forecast student academic success in a course. Lastly, Wu et al. [51] addressed the "zero-shot" feedback difficulty with a human-in-the-loop "rubric sampling" strategy.

Data-driven teaching, which utilizes machine learning algorithms to analyse student performance data, enables educators to make informed decisions, personalize learning experiences, and optimize instructional strategies. In particular, adaptive dialogue systems and natural language generation, studied by Rieser et al. [52] represent a data-driven methodology for dialogue management.

Through the analysis of vast amounts of data, such as historical grades, attendance records, and engagement metrics, machine learning algorithms can identify patterns and correlations that may impact academic success, as evidenced by Iqbal et al. [53] and Adnan et al. [54]. This information allows educators to identify at-risk students and provide targeted interventions and support to improve performance and reduce dropout rates. By leveraging this data, educators can refine their teaching techniques, adapt curricula, and implement best practices to enhance learning outcomes [55].

Vrakas et al. [56] showcased PASER, an innovative system that automatically synthesizes curricula by employing AI Planning and Machine Learning techniques. This is based on an ontology of educational resources metadata, which has the potential to revolutionize curriculum development. In the realm of game-based learning, Wallace et al. [57] described two projects from the MLeXAI, demonstrating the potential for AI and machine learning to enhance educational gaming experiences. The IBM AutoAI Playground, as described by Wang et al. [58] is a pioneering system that empowers non-technical users to define and customize their business goals, showcasing the increasing accessibility of AI technology. Lastly, Chamunyonga et al. [59] reviewed AI and ML applications in radiation therapy courses and suggested considerations for enhancing radiation therapy curricula.

II. METHOD

We undertook a thorough and extensive review of peer-reviewed literature that focuses on the application of machine learning in higher education course design. As an integrative review, we aimed to include a wide range of research designs to gain a comprehensive understanding of this emerging field. By including studies that employ different research methods and approaches, we were able to synthesize a diverse range of perspectives and insights on the use of machine learning in higher education. This allowed us to explore not only the benefits and challenges of incorporating machine learning into course design, but also the various ways in which it can be applied and the potential implications for teaching and learning.

A. A preliminary search in Web of Science for the use of machine learning in education

To generate an overview of the use of machine learning in education over the past 20 years, we conducted a systematic search of (database) using the preliminary search term (“education”, “machine learning”) up to July 2024. After filtering the results based on inclusion and exclusion criteria, we extracted data on the number of articles published each year that focused on machine learning in education. We then plotted these data points on a line graph to visualize the trends in publication frequency over time.

B. Data Sources and Search Strategy

We searched the Education Research Information centre , British education index, and Education Research Complete and Web of Science (WoS)to identify articles addressing machine learning in higher education course design. We developed the search strategy in collaboration with an academic health sciences librarian. The key search terms were ("machine learning") AND ("curriculum design" OR "higher education").

C. Selection of Articles for Review

We conducted a screening process by reviewing the titles and abstracts of all identified articles using the previously established search criteria and subsequently applying the exclusion criteria. Any articles deemed relevant or inconclusive were then assessed in their entirety by reading the full text.

D. Data Extraction

All eligible publications underwent a meticulous evaluation process, from which relevant data was extracted. The extracted data encompassed various aspects such as authorship, year of publication, study type, study quality, participants, subject matter, participant numbers, study objectives, and main findings.

E. Data analysis

This study utilized VOSviewer that allowed to construct and visualize networks by inputting the full text of all relevant articles identified in our review. This software did network visualization-keywords analysis, density visualization-keywords analysis and overlay visualization-abstract and keywords analysis. It analysed the frequency and network relations of keywords and abstracts used in the selected articles. It generated a visual representation of the most frequently occurring keywords and relationships among keywords groups in the form of a keywords network.

III. RESULT

A. A preliminary search in Web of Science for the use of machine learning in education

Figure 2 showed a year-by-year breakdown of the number of publications related to machine learning in the education field from 2003 to 2024. The numbers show a gradual increase in publications from 1,201 in 2003 to 1,9482 in 2018. A particularly striking aspect of the data is the significant surge in publications from 2018 to 2020, with the numbers almost quadrupling from 29,955 in 2019 to 60,435 in 2021. The trend continues to grow in the following years, with 72,900 publications in 2022 and 44,940 in July 2024.

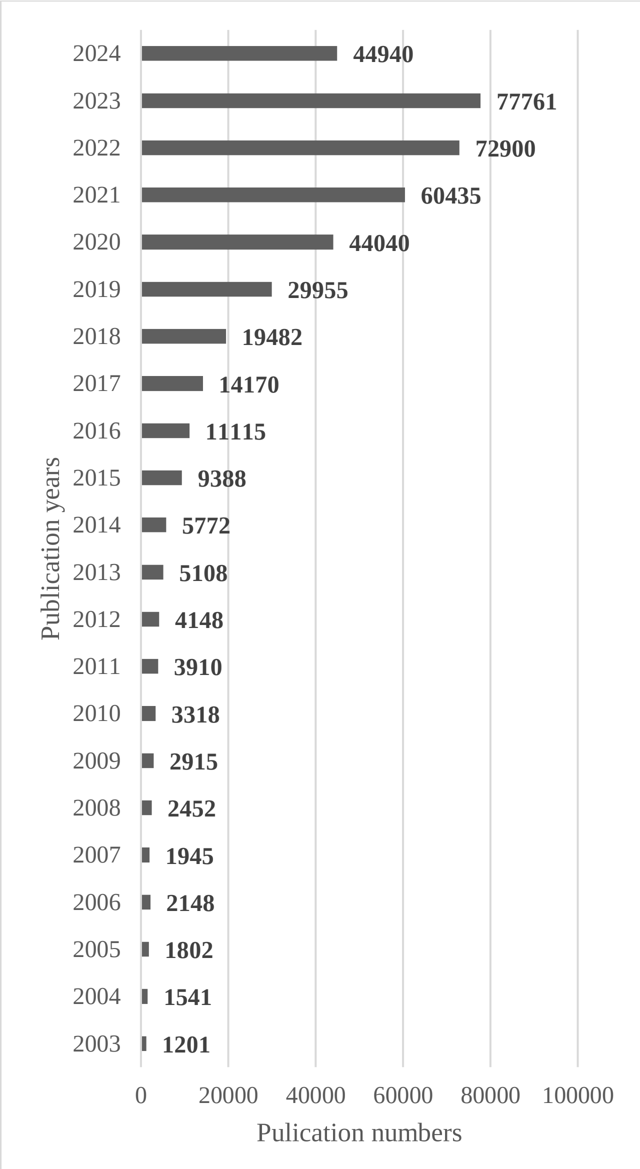

Figure 2. Number of publications on machine learning in education

B. Inclusion and exclusion criteria and searching results

The inclusion and exclusion criteria were shown step by step in Figure 3. The exclusion criteria mainly includes identification, screening, eligibility.

- The inclusion criteria were as follows:
  - The study must focus on the application of machine learning in higher education course design.
  - The study must be published in a peer-reviewed journal or conference proceedings.
  - The study must be published in English.
  - The study must be conducted within the last 20 years to ensure relevance to current practices.
- The exclusion criteria were as follows:

Articles on other aspects of education apart from higher education

  - Articles on use of technology (such as online lectures and computer-based education) without incorporation of machine learning (or AI), or articles with only a brief mention of machine learning usage.
  - Full texts of articles available in languages other than English

Our search initially yielded 426,261 publications, which were reduced to 21,140 after removing duplicates. We excluded 405,021 duplicates, 18.267 irrelevant articles, 1,942 non-full text ones, 835 articles that did not pertain to machine learning and curriculum design in higher education and 68 papers not mentioned pedagogical application. Out of the remaining 41 articles, we included 28 relevant publications in our review, which provided valuable insights into the application of machine learning in higher education course design (Figure 3).

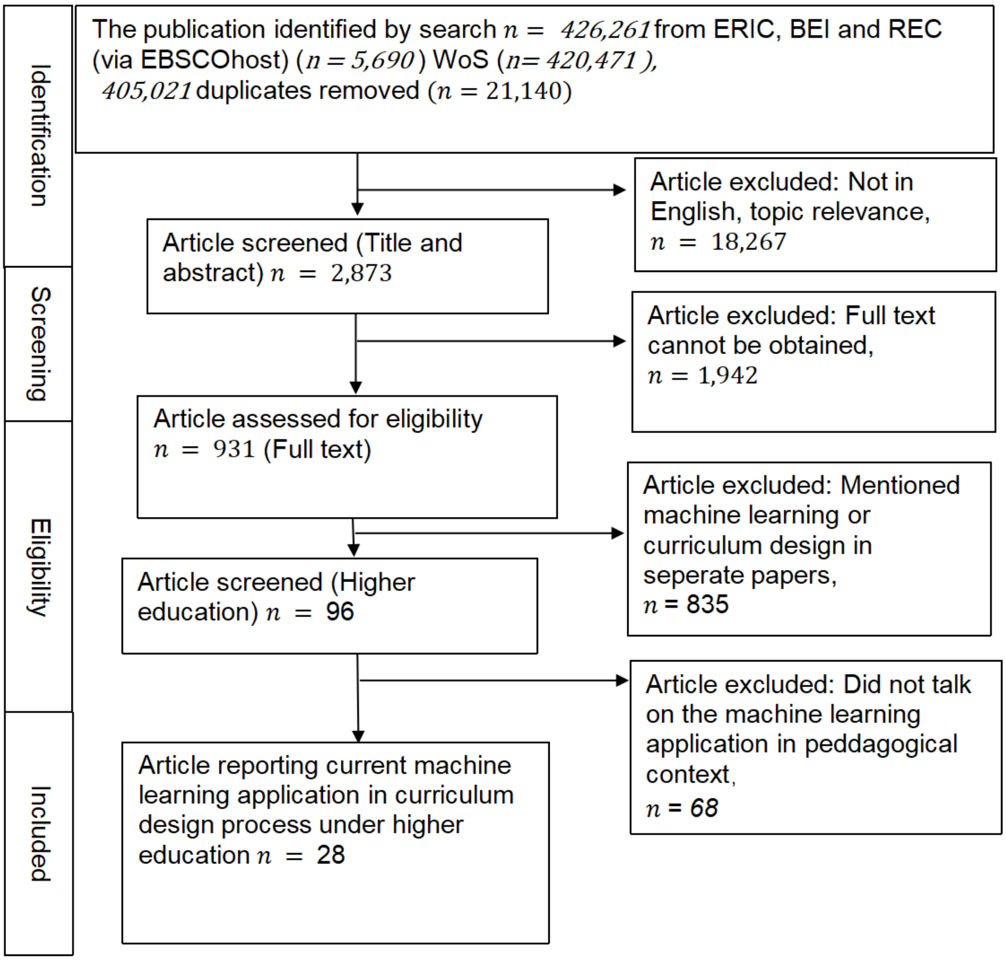

Figure 3. Prisma diagram of included articles in the scoping review.

Based on our review, out of the 11 relevant publications, 3 were peer-reviewed articles, 1 was a review article, and the remaining were conference proceedings. Three of the studies were quantitative research, while one was a qualitative and quantitative research study. The peer-reviewed articles were conducted by Wallace, Maccartney and Russell [57] on game-based AI projects, Musso [60] on predicting student academic performance using ANN. The review article by Kowalska et al., [65] provided a case study of using machine learning-driven classification for analysis of the disparities between categorized learning outcomes. Stadelmann [68] on evaluating the effectiveness of a didactic concept for teaching AI and ML. For a more comprehensive overview of machine learning in higher education curriculum design, the whole selected article in Table 1.

Table 1. The summary of included studies

Studies	Application in curriculum design
Wallace, Meccartney and Russell [57]	Predicting student academic performance compared to traditional methods like discriminant analysis.
Musso and Mariel [60]	The artificial neural networks (ANN) demonstrated higher accuracy in predicting student academic performance compared to traditional methods like discriminant analysis.
Balcioglu and Artar [61]	Predicting academic performance of students with machine learning.
Nawaz et al . [62]	Leveraging machine learning for student survey: actionable insights from textual feedback to enhance quality of teaching and learning.
Dennehy et al. [63]	Adopting learning analytics to inform postgraduate curriculum design: recommendations and research agenda.
Supraja [64]	The research proposes an intelligent model to automatically label practice opportunities (assessment questions) according to the learning outcomes intended by course designers.
(Kowalska et al., [65]	Using machine learning-driven classification for analysis of the disparities between categorized learning outcomes.
Karala rea al. [66]	Predicting students at risk of academic failure using ensemble model during pandemic in a distance learning system.
Chang et al. [67]	The extreme learning machine (ELM) technique evaluates designs integrated into the suitable student monitoring model weighted score (WS) and exam results.
StadelmaN [68]	Providing specific recommendations for adopting technical curricula in various teaching conditions (on-site, hybrid, or online).
Almufarreh et al. [73]	Academic teaching quality framework and performance evaluation using machine learning.
Çağataylı & Çelebi [74]	Estimating academic success in higher education using big five personality traits, a machine learning approach.
Chang et al. [75]	Integration of artificial intelligence and machine learning content in technology and science curriculum.
Villegas-Ch et al. [76]	Machine learning techniques for quality management in teaching learning process in higher education by predicting the student's academic performance.
Ilic et al. [77]	Mchine learning for performance analysis to make changes in higher education.
Go et al. [78]	Machine learning in processing students' e-learning satisfaction.
Elsharkawy e al. [79]	Employability prediction of information technology graduates using machine learning algorithms.
Dipierro and Dewitte [80]	Machine learning approach in analysing effective signals of learning.
Sghir et al. [81]	Predictive learning Go.
Sanchez et al. [82]	Machine learning techniques for quality management in teaching learning process in higher education by predicting the student's academic performance.
Ureel et al. [83]	Active Machine Learning for Chemical Engineers with design learning.
Ibarra-Vazquez et al. [84]	Forecasting gender in open education competencies.
Pelzer & Turner [85]	Generating an interactive machine teacher online to interact with students.
Bruno et al. [86]	Designing a transnational curriculum.
Shang et al. [87]	Interactive teaching using human-machine interaction for higher education systems.
Xiao & Hu. [88]	Using machine learning models to analyse online learning performance.
Kondoyanni et al. [89]	Adding machine-learning functionality to real equipment for water preservation in higher education.
Sheridan and Gigliotti. [90]	Designing online teaching curriculum to optimise learning for all students in higher education.

C. Networks analysis

Figure 4-6 showed a range of keywords, each with their respective attributes, obtained from a word cloud visualization. The keywords are organized into distinct clusters and possess associated weights, average publication years, and total link strengths. These keywords offer insight into various topics and themes connected to machine learning (Artificial intelligence) and education.

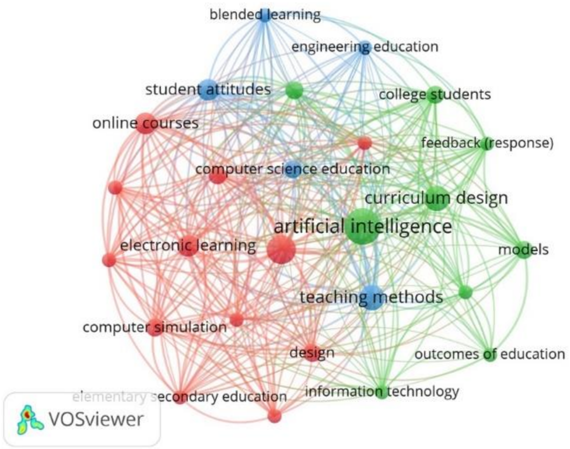

Figure 4. Network visualization-keywords analysis

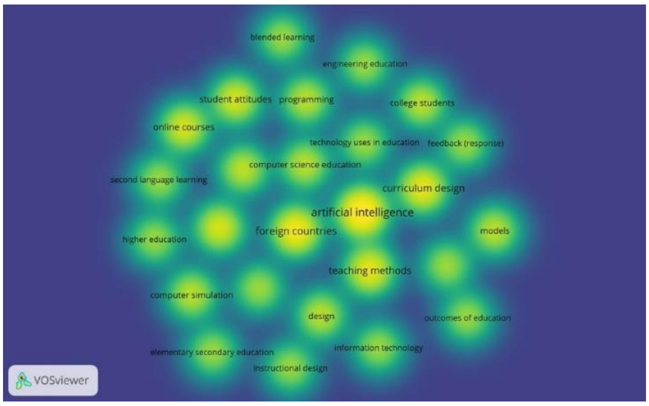

Figure 5. Density visualization-keywords analysis

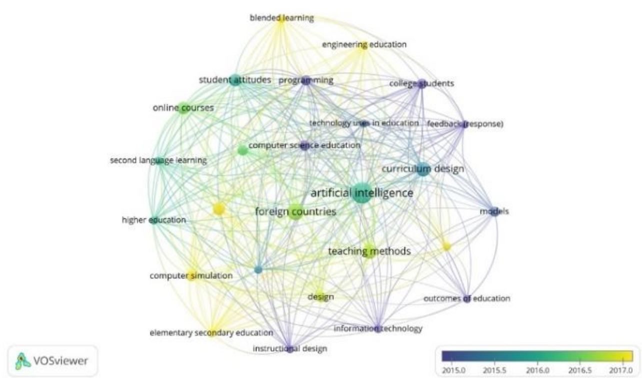

Figure 6. Overlay visualization-abstract and keywords analysis

The word cloud analysis results highlight various key topics in the dataset, including artificial intelligence with an average publication year of 2016 and 10 occurrences, foreign countries with 8 occurrences and an average publication year of 2016.625, and teaching methods with 7 occurrences and an average publication year of 2016.7143. Online courses also feature prominently with 6 occurrences and an average publication year of 2016.5. Other significant topics are electronic learning, curriculum design, student attitudes, educational technology, computer simulation, computer science education, programming, and design. Further areas of interest include faculty development, higher education, second language learning, technology uses in education, college students, elementary secondary education, feedback (response), instructional design, blended learning, information technology, models, engineering education, undergraduate students, and outcomes of education (Table 2).

Artificial intelligence, exhibiting a high total link strength of 117, signifies the importance of AI in the research landscape. Foreign countries as a keyword indicate the desire to examine AI applications and educational practices across different nations. The presence of teaching methods emphasizes the focus on innovative and effective instructional approaches utilizing AI technologies. Online courses suggest a burgeoning trend toward integrating AI technologies into virtual education and e-learning platforms. Similarly, electronic learning underscores the importance of technology-enhanced learning experiences. Curriculum design highlights the strong interest in incorporating AI technologies and principles into educational curriculum development. Lastly, the inclusion of student attitudes implies that researchers are keen on understanding students' viewpoints and experiences with AI technologies in education.

Table 2. Strength of relationships between High-frequency words

label	x	y	cluster	Weight <Links>	Weight <Occurrences>	score<Avg. pub. year>	weight<Total link strength>
artificial intelligence	0.2602	-0.0065	2	25	10	2016	117
foreign countries	-0.1136	-0.1122	1	25	8	2016.625	104
teaching methods	0.3014	-0.3335	3	25	7	2016.7143	94
online courses	-0.7425	0.4685	1	25	6	2016.5	91
electronic learning	-0.5441	-0.0949	1	25	6	2017.3333	88
curriculum design	0.602	0.1265	2	25	7	2015.5714	87
student attitudes	-0.4519	0.6246	3	25	6	2015.8333	83
educational technology	-0.4098	0.2337	1	25	5	2016.4	76
computer simulation	-0.7003	-0.4703	1	25	5	2017	73
computer science education	-0.0629	0.2589	3	25	5	2014.8	72
programming	-0.0561	0.6234	2	25	5	2014.6	71
design	0.0286	-0.5872	1	25	5	2016.8	69
faculty development	-0.3211	-0.4362	1	25	4	2015.5	68
higher education	-0.9092	-0.1608	1	25	4	2016	67
second language learning	-0.8836	0.1721	1	25	4	2016	67
technology uses in education	0.2722	0.3808	1	25	4	2015.25	65
college students	0.5941	0.6052	2	25	5	2013	64
elementary secondary education	-0.5832	-0.7933	1	25	4	2017.25	61
feedback (response)	0.8373	0.3776	2	25	4	2014.75	59
instructional design	-0.1444	-0.881	1	25	4	2014.5	57
blended learning	-0.1893	0.9702	3	24	4	2017	54
information technology	0.3511	-0.7686	2	25	4	2014.25	50
models	1.0047	-0.1112	2	25	5	2015.2	50
engineering education	0.2733	0.8217	3	25	4	2017.25	48
undergraduate students	0.7362	-0.3079	2	25	4	2017	43
outcomes of education	0.8508	-0.5993	2	24	4	2015	38

IV. DISCUSSION

This paper examines the roles and benefits of machine learning in higher education course design, as well as its potential drawbacks. We conducted a narrative review of the literature on the application of machine learning in course design. (1) Recent articles on machine learning in education have increased dramatically. (2) Just 11 relevant publications focused on machine learning in higher education course design, three of which were peer-reviewed. (3) Our review's word cloud includes "Artificial intelligence," "International countries," "teaching methods," "Internet courses," and "Curriculum design."

Recent literature on machine learning in education shows its promise and growing attention. From 2003 to 2023, machine learning education articles increased significantly (Figure 2). Machine learning in education is expanding in popularity and importance. Between 2018 and 2020, publications increased significantly, suggesting that machine learning became a more important topic in education research. In 2021 and 2022, machine learning research in education increased, indicating future advances and applications. As technology advances, machine learning can help educators better understand student learning behaviours [69] diagnose student learning problems [70] and provide personalized learning experiences and support [71], thereby improving learning outcomes and the quality of education [72]. At the same time, machine learning can also help educators better understand students' learning processes by mining data to discover patterns and patterns hidden in the data and provide data-based teaching and learning decisions and predictions [73]. In addition, the growing body of literature on the application of machine learning to education reflects educators' interest and enthusiasm for emerging technologies. They want to apply new technologies such as machine learning to improve the quality of education and learning outcomes, as well as to provide better learning experiences and support for students. This trend is also driving the deepening and growing use of machine learning in education.

V. CONCLUSION

Although an increasing study indicate more interesting focus on application on machine learning, the studies focus on higher education course design were few. Based on the results of our search, we identified a total of 28 relevant publications that provided valuable insights into the application of machine learning in higher education course design. These publications included peer-reviewed articles and a review article. Possible explanations for the relatively few studies on the application of machine learning in higher education course design may include the relatively recent emergence of machine learning techniques and their complexity, the need for specialized expertise in both machine learning and higher education, and the potential costs associated with implementing machine learning in education.

The 28 relevant publications identified in our review provide valuable insights into the application of machine learning in higher education curriculum design. Based on these included articles, machine learning (ML) is revolutionizing curriculum design in higher education by enhancing each stage of the process, from needs assessment to evaluation, especially for students' learning outcome evaluation including academic performance [57, 60, 61, 73, 76, 77, 82, 88] and learning behaviour perdition [63, 81]. It enables data-driven identification of educational gaps [78], personalized goal setting, and tailored content selection, thereby improving the relevance and effectiveness of educational programs. Additionally, it has significant trend to apply machine learning in generating an interactive machine teacher online to interact with students [85]. ML facilitates the organization of coherent learning pathways and adaptive implementation through intelligent tutoring systems, ensuring continuous support and engagement. It also automates evaluation, providing timely insights for curriculum refinement. Despite challenges such as data privacy, bias, infrastructure needs, and stakeholder acceptance, the benefits of ML in creating personalized, efficient, and data-driven educational experiences are substantial, promising significant improvements in student outcomes and satisfaction [78]. The machine learning can also help Forecasting gender in open education competencies [84]. Overall, it has improved individual massive curriculum design from students' learning needs collection, analysis, conclusion to prediction, which has significant positive impact on learning and teaching effectiveness from this review. However, its accuracy of making analysis and conclusion needs to be improved.

VI. Limitations And Recommendations

However, there are some limitations. Firstly, there is a lack of consistency in the study design and methodology across the studies, making it difficult to compare and generalize findings. Additionally, most studies have a small sample size, which may limit the generalizability of the results. Secondly, the studies are primarily focused on the technical aspects of machine learning and its application in course design, with less attention given to the pedagogical implications and effectiveness of these approaches. More research is needed to understand how machine learning can improve teaching and learning outcomes in higher education. Thirdly, the majority of the studies are focused on undergraduate education, with little attention given to graduate or postgraduate education. This is an important area for future research, as the application of machine learning in advanced education may have different challenges and opportunities. Lastly, many of the studies are focused on specific technical areas, such as AI or neural networks, leaving out other areas where machine learning could be applied in course design, such as natural language processing or computer vision. Therefore, future research could explore the potential applications of machine learning in these areas. Overall, while the studies reviewed provide valuable insights into the application of machine learning in higher education course design, there are limitations and areas for future research that need to be addressed.

Conflict Of Interest

The author declares that there is no conflict of interest.

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Digital Health: The Critical Value of Mobile Technology for the Health Sector, Different Application Examples from the World and Current Trends

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Abstract— **The internet technology, which began to integrate into our lives rapidly by the end of the 1990s, underwent significant transformations with the advent of mobile technology in the 2000s. Initially accessible through desktop or notebook computers, the internet has evolved to become an integral part of virtually every aspect of our lives as mobile technology advanced throughout the 2000s. The purpose of this study is to examine the role of mobile technologies within current health technologies, investigate the necessary competencies, evaluate mobile technology developments both in Türkiye and globally, and assess the information technology infrastructure, competencies, and skills required by the sector. Our research details various and specific mobile applications from numerous countries. Findings indicate that mobile technology has established itself much more rapidly and effectively in countries with strong internet infrastructure. Mobile health services are perceived as highly valuable by citizens. The real quality and effectiveness of mobile technology depend on its acceptance and swift implementation by users. Gamification is an important tool in the adoption of mobile health applications. These applications can enhance motivation by enabling both doctors to monitor patient care services and patients to track their own health. A good mobile health system should be accepted by both patients and doctors. In countries like Türkiye, where the health system is largely supported by the state, it is seen as necessary for the Ministry of Health to prioritize mobile services to establish a robust mobile health system. Furthermore, to effectively structure mobile services, it is essential to focus on the right problems and identify issues in order of priority. Literature review reveals that various mobile applications have been implemented in fields such as dermatology, orthopedics, ophthalmology, neurosurgery, and clinical pathology. Mobile technologies offer significant cost advantages in the delivery of health services. As the population ages in European Union countries, national governments are seeking ways to reduce healthcare costs. Mobile health is considered a solution to transform the delivery of health services and reduce costs through viable new care models for both industrialized and developing countries. Moreover, it has been observed that mobile applications provide significant benefits for the elderly, particularly in developed countries such as Germany and Sweden. Our study provides a comprehensive assessment of mobile technology in the healthcare sector, highlights prominent applications from Türkiye and around the world, and offers an extensive evaluation for field readers.**

Keywords*— *Health sector, digital health, digital transformation, mobile technology, current trends

I. INTRODUCTION

The primary social responsibility of states, regardless of their position or social status, is to provide their citizens with the opportunity to receive timely, high-quality medical care at affordable prices. The advancements in health technologies and their successful implementation in health services in many countries have accelerated the development of fundamentally new medical care organization methods and techniques for society [1]. Ensuring that every individual in need of health services can access these services promptly and equitably, without time and location constraints, and maintaining the efficiency and effectiveness of these services is crucial for both individuals and public authorities [2]. Electronic health (e-health) is defined as “the use of information and communication technologies in health services for the prevention, diagnosis, and treatment of diseases, monitoring, and management of health.” The "e" in e-health symbolizes that health services are “electronic, digital, internet-based, efficient, fast, information-focused, and technological” [2]. Recently, as the hardware capacities of smartphones and other mobile devices have advanced, e-health functionalities have become increasingly available on mobile platforms, making

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mobile health (m-health) applications a significant subset of e-health applications [3]. The power and reach of mobile communication offer considerable versatility and benefits for delivering high-quality, low-cost health services [4]. Mobile health services are among these. Mobile health applications are seen as a preferred approach to encouraging individuals in self-care skills, reducing complications and health costs, and improving individual well-being. The effectiveness of mobile health in managing chronic conditions, as well as in interventions like disease adaptation and self-monitoring ability, has been demonstrated. In this context, mobile health shows promise in the care and management of diseases [5].

Mobile applications serve as strategic tools in correcting and improving the health-threatening erroneous behaviors developed by individuals due to their habits [6,7,8]. Examples of mobile health applications include fitness and health [9; 10], quit smoking [11,12], live healthy [13], nutrition [8;14], instant heart rate monitor [15,16], e-pulse /pulse tracking [17, 18], and the central hospital appointment system [19]. This study focuses on mobile technologies and mobile applications, providing comprehensive discussions and research on mobile technology within the health sector, highlighting interesting and noteworthy applications from Türkiye and around the world that can offer readers a different perspective on the field. Currie & Seddon [20] suggested that for the European Union to achieve its goal of increasing citizen engagement in health services, mobile technology should be part of a broader social innovation. They also argued that public health culture would only change by developing a health infrastructure supported by these applications. As researchers, we aimed to present a comprehensive mobile technology perspective for state institutions, recognizing this reality. The following sections detail the health sector, digital health, and mobile technology conceptually, with comprehensive literature information and compilation on examples of mobile technology applications in the health sector in Türkiye and globally. The discussion and conclusion sections elaborate on the key topics highlighted in the literature concerning the health sector. Upon reviewing the literature, it is noted that there has been no research of this scope and dimension on mobile technologies in the health sector, and our study is expected to fill this significant gap.

II. MATERIALS AND METHOD

This study is a comprehensive review study carried out with traditional methods. It centers on the healthcare sector, illustrating how the development of mobile technology and the diversification of mobile technology products and applications over time have transformed our ways of working. The study examines the role of mobile technologies within current healthcare technologies, investigates the required competencies, evaluates mobile technology developments in the sector in both Türkiye and globally, and addresses the necessary competencies and capabilities alongside the information technology infrastructure needed by the sector. In this context, over 900 research articles, review papers, institutional reports, and book chapters were assessed via Google Scholar.

To access research and reports on mobile applications in Türkiye via Google Scholar, initial searches were conducted using the terms "mobil teknoloji ve sağlık sektörü", "mobil teknoloji ve Türkiye" and "mobil sağlık uygulamaları". Further searches were performed using the English terms "mobile technology and digital health" and "mobile applications in health sector." Additionally, health applications were examined through Google Android Market and Apple Store on a country-specific basis, and institutional applications were included in the paper. This approach aimed to provide policymakers with insights into mobile applications developed by various health institutions across different countries. Applications and best practices that could enrich the study were incorporated into the overall context, thereby offering a comprehensive view.

III. HEALTHCARE SECTOR, DIGITAL HEALTH, AND MOBILE TECHNOLOGY

Technology is rapidly advancing today. The healthcare field is also benefiting from these advancements and moving some services to virtual platforms [21]. The use of informatics in healthcare increases efficiency and quality of service while reducing medication, data, and medical errors [8,22]. In this context, digital technologies are gaining importance every day. Digital health enables unprecedented changes throughout the entire healthcare system by redefining and expanding the boundaries between patients, consumers, citizens, healthcare workers, investors, organizations, and similar structures [23,24]. Mobile technologies have become one of the most crucial and critical technologies enabling the digitalization of the healthcare sector. In recent years, mobile technologies have also found a place in the healthcare sector through wearable technologies. The use of mobile and wearable health technologies highlights the temporal, spatial, and interpersonal nature of health monitoring. Health-related data can be easily and frequently collected from users' mobile devices when they log into the relevant application. These devices offer a unique opportunity not only for users but also for health and public health workers to monitor and measure individuals' health-related habits [19,25]. Additionally, mobile technology provides unique opportunities to increase patient engagement, reduce healthcare costs, and improve outcomes [26].

Mobile technology is advancing in countless directions, and particularly in medicine, it has become an attractive area for mobile technology innovators [27]. The benefits of adapting mobile technologies to healthcare institution processes are broad, ranging from communication and cost to patient care and error reduction [28]. With the developments in information technologies used in healthcare services, especially portable devices, digital video broadcasts, database technologies, and interaction with electronic health records and health information systems have been facilitated [29]. In addition, today, mobile technology, IoT, artificial intelligence, wearable sensors, big data, blockchain and cloud computing have become prominent technologies in the healthcare sector [30,31,32]. These developments have influenced the delivery of healthcare services

In their study, Banderker & Van Belle [33] expressed the adoption factors for mobile technologies as follows: job relevance, usefulness, perceived user resources, and device features, and additionally, patient impact, support from the national government, and hospital management. Digital, mobile, and telecommunication technologies differentiate the way people communicate in daily life. Various applications allow patients to communicate with physicians, access test results, and schedule medical appointments. More interestingly, with the advancing technology, physicians can now diagnose and even treat patients remotely [34]. Metaverse technology has also become prominent in fields such as medicine, nursing, public health, midwifery, and dentistry [35,36].

E-health reduces dependency on hospitals and decreases the in-person use of hospitals through mobile applications that can provide 24/7 service and are easily accessible to everyone [2]. According to Eysenbach [37], e-health is a new field where medical informatics, public health, and business converge through the internet and related technologies to deliver or improve healthcare services and information. In a broader sense, the term not only refers to a technical development but also characterizes a mindset, an approach, a commitment to networked, global thinking, and the use of information and communication technologies to improve healthcare locally, regionally, and worldwide. Additionally, he outlined the 10 Es of e-health: Efficiency, enhancing quality of care, evidence-based, empowerment of consumers and patients, encouragement, education, enabling information, extending the scope of healthcare, ethics, and equity.

Mobile health applications, ranging from simple SMS messages used to raise awareness and provide guidance on diseases to video teleconsultation and tele-visit applications, scheduling appointments via mobile phone or website, sending medical data from portable or wearable devices, conducting color blindness tests through smartphone applications, and remote chronic disease management, are increasingly prevalent in both developing and developed countries [38]. Mobile technologies, which refer to wireless devices and sensors that are accessible, wearable, and portable by consumers in daily activities, are defined as cost-effective tools [39]. Today, with the advent of wireless and mobile technologies, individuals and organizations can perform their activities anytime and anywhere [40]. Mobile services have also transformed the delivery of government services, bringing us face-to-face with the concept of mobile government (m-government). Mobile government refers to a series of public applications and services delivered to citizens through wireless and mobile technologies [41]. Mobile government is also referred to as mobile governance (m-governance) in the literature and represents a new channel or access method to deliver electronic government services to all citizens. M-governance provides an additional access tool for e-government and processes by using wireless and mobile technologies to deliver services via mobile devices [42].

Mobile government changes the way information is exchanged between the state and citizens, creating a new communication channel by delivering government services transparently anytime and anywhere, and eliminating the traditional organizational structure of the state [43]. In recent years, m-government has gained increasing interest, particularly among developed countries, as a mechanism to reduce costs, increase efficiency, and improve public access to government services [44]. Especially in rural areas, access to electronic government services has a significant impact [42].

Today, through smartphone applications, we can measure physiological values such as blood pressure [45, 46], blood glucose levels [47, 48], and heart rate [49, 50], and even view conditions such as skin cancer [51, 52] and middle ear infections (otitis) [53, 54, 55]. Sensors developed for hundreds of medical values, such as lung functions [56, 57, 58], mood [59, 60], eye pressure [61, 62], movement disorders [63, 64], and brain waves [65, 66], are being used or tested in clinical measurements. The remarkable technological progress observed in hardware development and innovation processes in just the past few years is astonishing. Blood pressure, heart rhythm and rate, blood oxygen saturation, respiratory rate, and body temperature can now be monitored continuously and non-invasively [67, 68, 69, 70, 71, 72]. This capability allows many patients not only to measure their own values but also to perform appropriate activities related to their diseases, adhere to their diets, and avoid harmful things at home, work, and during travel [7, 8, 73, 74]. They can easily do this by simply pressing the "measure" or "start" button on their smartphone screens. Continuous measurement during sleep or in stressful environments will provide us with highly valuable medical data [38].

IV. Application Examples of Mobile Technology in The Healthcare Sector in Türkiye

Among the significant policy implementations conducted by the Ministry of Health in Türkiye from 2002 to the present, the Health Transformation Program holds a prominent position. Various pilot applications conducted nationwide until 2013 paved the way for the full implementation of these initiatives under this program title. Structural and functional changes have been experienced across the entire healthcare system, primarily benefiting healthcare workers and all stakeholders in the community. The primary goal of this program is to maintain the overall health of patients through preventive measures, sustain a healthy population, ensure improved recovery conditions for patients, and maximize access to healthcare services under equitable conditions for all citizens [75].

The widespread adoption of mobile technologies today is helping pave the way for a new paradigm where individuals can access their health information at all times. Portable and wearable technologies are increasingly utilized to collect data on individuals' physiology, psychology, and behaviors. This valuable information can be used to reduce health risks, optimize disease complications, raise awareness about self-care, understand health determinants, or gain new perspectives on factors contributing to illness [5]. Mobile phones have proven useful as instant communication channels for transmitting demographic, clinical, research, and advancement data to healthcare providers and providing timely, reliable advice to healthcare seekers [76].

In Türkiye, efforts in the field of e-health systems have also begun. The Ministry of Health initiated infrastructure and system establishment efforts related to telemedicine in 2007 and, as of 2016, has been implementing practical applications such as "e-nabız (e-Pulse), e-randevu (e-Appointment), electronic health records, doctor information database, online appointment system, and digital hospitals"[2]. Additionally, the Ministry of Health's strategic plan for 2013-2017 includes goals related to the use of "telemedicine and electronic information systems" in healthcare services[2].

Mobile communication technologies are effectively utilized in the field of telemedicine [77]. For example, in Türkiye, mobile technology has facilitated access to critical areas for patients such as hospital appointments, medication schedule tracking, and allergy control. For citizens with limited or difficult access to the internet, the development of the 182 Central Physician Appointment System has provided a direct communication channel for them to consult and specify their desired area of treatment at hospitals via voice communication with an advisor. Despite still being a new technology area for our country, these innovations in the healthcare sector have benefited from advancements made in other countries [43].

Various studies have been conducted in collaboration with different units to explore potential mobile application ideas, some of which are listed below [38, 78]:

- *Aile Hekimim Kim (Who is My Family Physician? With Map Support)*: An intelligent smartphone application that allows individuals to find their family physicians.
- *enVision Mobile*: Healthcare professionals can perform their tasks within the Electronic Document Management System (EBYS) software using the enVision Mobile application on their mobile phones.
- *Ministry of Health Mobile Application*: A mobile device application that allows users to read current Ministry news and calculate their body mass index by entering their weight and height to raise awareness about obesity.
- *Personal Electronic Health Record*: An application that enables individuals to access their medical data via smartphones, tablets, and the web, and authorize visits to their doctors.
- *Nearest Hospital and Nearest Pharmacy*: An intelligent smartphone application that helps individuals locate nearby pharmacies and hospitals.
- *Emergency Pharmacy*: An application that shows the nearest emergency pharmacies on a map.
- *General Information Mobile Health Application about Diseases and Symptoms*: A mobile health application that provides general information about diseases and their symptoms.
- *Application Regarding Drug Indications*: An application that provides information about drug indications.
- *E-Nabız (E-Pulse)*: A personal health record system created by the Ministry of Health in early 2015, allowing citizens to access their medical data, authorize doctor visits, and manage their health records through smartphones, tablets, and the web.

Social Security Institution (SGK) Mobile Applications:

- *SGK Mobile Library*: A mobile application providing access to SGK publications.
- *SGK Children's Application*: An informative application about SGK and its activities.
- *SGK TV Application*: An informative application about SGK and its activities.
- *Service Statement 4/A*: A mobile application for querying 4A services.
- *When Can I Retire?*: A mobile application for querying retirement conditions.

Tezcan [38] emphasized that the widespread adoption of mobile health applications in Türkiye would benefit the country due to its positive impact on both health preservation and healthcare expenditures. He listed the benefits as follows:

- Through SMS notifications, informative campaigns can be conducted in rural areas, focusing on epidemic prevention, maternal and child health, pregnancy monitoring, vaccination, and raising awareness.
- Locally developed user-friendly smartphone applications and gamification software can educate future generations, especially children and youth, to become more health-conscious individuals with higher awareness. This could contribute to improving the general health literacy index, which is currently measured at 30.4 out of 50, with 64.6% of the population falling into inadequate or problematic health literacy categories in Türkiye.
- Remote disease management applications can provide continuous, higher-quality healthcare services to the 22 million chronic patients living in Türkiye.
- Portable and wearable devices/sensors developed in Türkiye can significantly contribute to employment and production goals aligned with Türkiye's 2023 objectives.

One of the significant steps towards digitalizing the healthcare system in Türkiye was the emphasis on e-health applications in the 2013-2017 Strategic Plan to enhance citizen satisfaction and efficiency. Within this program framework, numerous e-health applications have been implemented under various headings. With the increasing use of technological devices, the Ministry of Health monitors the development of applications for mobile devices through the Mobile Applications Unit of the General Directorate of Health Information Systems and coordinates this process with the unit for wearable technological health products. Citizens can access the applications developed for them through the Apple Store and Google Play Store mobile markets, while Ministry of Health-affiliated users can access these applications via the T.C. Ministry of Health Mobile Market using their health user addresses [79].

Looking at e-health applications in Türkiye, the following systems stand out:

- The Drug Tracking System, created to prevent counterfeit drug coupons and ensure the effective and affordable distribution of drugs to all citizens.
- The electronic prescription (e-prescription) application, implemented for similar purposes.
- The MEDULA system managed by the Social Security Institution (SGK), which electronically manages all information flow regarding hospitals, pharmacies, and individuals.
- The Organ Transplant Information System.
- The Family Medicine Information System.
- The Central Hospital Appointment System, known colloquially as "Alo182".
- The core resource management system where all Ministry of Health resources are recorded and used for planning and management.
- The Health-Net platform, an electronic data storage system that forms the basis for all these e-health applications in Türkiye [80].

V. Mobile Technology Application Examples in The European Continent Focusing on The Health Sector

Health systems are concerned with disease prevention, early diagnosis, diagnosis, research, and timely, affordable, and safe treatment. Communication is key to delivering services in the healthcare sector, establishing connections between service providers and patients. In the recent past, mobile technology has provided various communication platforms for the healthcare system [81]. Similar efforts are also underway in the European Union. The increased use of mobile phones is expected to save over 100 billion euros in healthcare services across Europe by 2017 and increase gross domestic product by 93 billion euros. Mobile health is expected to reduce annual healthcare spending in the European Union by 18%, as well as reduce care costs for chronic conditions by 30% to 35% through improved treatment compliance and remote patient monitoring [20].

The European Union's Horizon 2020 research and innovation program, which began in 2014, is a program where many mobile health projects can be funded. One of the focus areas of Horizon 2020 is 'Personalized Health and Care'. It supports the concept of "empowering citizens" based on taking responsibility for health and disease and improving health. Below are explained four projects benefiting from mobile health funds [82]:

- *Nephron Plus/Artificial Kidney:* Chronic kidney disease is a condition observed in one out of every ten people at a certain age. Life is difficult and treatment is complex for patients suffering from kidney failure. The NephronPlus project has received 5 million euros from the European Union funds. The project aims to develop a wearable artificial kidney to remotely monitor symptoms related to the disease via smartphones and to facilitate the lives of patients.
- *GlukoTab/Easier Work, Better Care:* In hospital settings, issues can arise during shifts between doctors and nurses in terms of information flow. Supported by EU funding, the REACTION project has developed GlucoTab, a mobile system that enhances medical information flow in hospitals. The system monitors values such as blood glucose levels, nutrient intake, administered medications, and insulin sensitivity through sensors, providing treatment recommendations. The collected data is stored on a server and shared on tablets of healthcare providers.
- *MobiGuide/Guiding Chronic Patients:* Supported by EU funding, the MobiGuide project has developed an intelligent mobile system that guides chronic patients. The research focuses on heart patients (those with atrial fibrillation) and women who have experienced problems during pregnancy (such as hypertension and diabetes). The patient wears sensors that monitor biosignals (such as heart rate, blood pressure), which are sent to a smartphone and then transmitted to a robust database. The collected data is analyzed by the MobiGuide decision support device according to the patient's clinical data history. The device alerts the patient to what needs to be done or asks questions when additional information is needed. The system then provides recommendations for lifestyle changes or contacts caregivers. All treatment recommendations are sent to the caregiver. Ultimately, the system will be suitable for all chronic and acute conditions.
- *Interstress/Dealing with Stress:* Developed to escape to a tropical island in a three-dimensional virtual reality environment, Interstress is a program designed to learn and apply effective relaxation techniques via smartphones or tablets. The main objective is to reduce stress and improve health using appropriate biosensors.

To give another example from the mobile technology networks used in the field of healthcare in European Union countries, many applications called "myskinpal and firstderm", compatible with smartphones, have been developed in the Netherlands to diagnose and treat skin diseases. For example, after you take a photo of your skin problem where you notice a difference in your body, you can write down the area in which it is, its symptoms, how long it has existed and your personal information and send it to the dermatologists in the system through the application. Experts can analyze based on the photos and information you send and give you feedback such as "There is a serious situation, visit the nearest hospital" or "There is no serious situation, use these medications and continue your life." Some of these applications are paid (around $20) and some are completely free. The Dutch government, which received positive feedback from this application, developed the application and created some new applications. These applications can analyze and diagnose your skin problems before presenting your skin problem to a doctor. Put this into practice; wound, blemish, skin tone change, irritated area, etc. He does so by uploading his photo. In this way, the Dutch government both provided public services to citizens and reduced the workload of healthcare professionals [2].

When we examine mobile technologies through the Apple Store and Android Market, focusing on the UK, we come across the following applications:

- *NHS App:* Usage: The NHS App provides basic healthcare services such as obtaining medical assistance, scheduling appointments, and renewing prescriptions for users. Services: Access to health records, updating patient information, easy access to healthcare services, emergency guide. Purpose: To enhance digital access to NHS services, improve patient experience, and make healthcare more accessible [83].
- *NHS COVID-19 (inactive):* Usage: Used during the COVID-19 pandemic for users to monitor symptoms, track contacts, and receive test results. Services: Symptom monitoring, COVID-19 contact tracing, access to test results, current health information and guidance. Purpose: Pandemic management, controlling transmission by alerting those in contact with infected individuals, safeguarding public health [84].
- *NHS Couch to 5K:* Usage: Encourages users to increase their physical activity levels through running. Services: Running training from beginner level, motivational content, progress tracking. Purpose: To reduce health issues like obesity and cardiovascular diseases, improve public health, promote physical activity [85].
- *Smokefree:* Usage: Supports users in quitting smoking. Services: Smoking cessation plans, progress tracking, information on the health effects of smoking. Purpose: To reduce smoking addiction, decrease smoking prevalence in society, improve public health [86].
- *Drink Free Days:* Usage: Encourages reducing alcohol consumption. Services: Monitoring alcohol intake, promoting healthy drinking habits, motivational content. Purpose: To reduce alcohol addiction, mitigate the negative health effects of alcohol, promote healthy lifestyles [87].
- *Mindfulness UK:* Usage: Offers meditation and mindfulness exercises for stress management and mental health. Services: Daily mindfulness exercises, stress reduction techniques, mental health resources. Purpose: To improve users' mental health, enhance coping skills for stress, increase overall well-being [88].
- *Everymind:* Usage: Provides information on mental health topics and directs users to supportive resources. Services: Mental health tips, stress coping strategies, mental health assessments. Purpose: To raise awareness of mental health in society, help users maintain and improve their mental health [89].
- *GoodSAM Responder:* Usage: Matches first aid providers with those in need during emergencies. Services: CPR training, emergency guide, participation in local emergency teams. Purpose: To expedite emergency assistance, enhance community emergency response capabilities, save lives [90].
- *Blood Donor:* Usage: Promotes blood donation campaigns and directs users to nearby donation centers. Services: Blood donation appointments, information and guidance on blood donation, donor appreciation program. Purpose: To raise awareness about blood donation, strengthen blood stocks, meet blood demand during emergencies [91].

When we examine mobile technologies through Apple Store and Android Market focusing on Sweden, the following applications emerge:

- *1177 Vårdguiden:* Usage: Provides access to healthcare services and offers consultation for health issues. Services: Symptom control, healthcare guidance, appointment scheduling, medical advice. Purpose: To facilitate easy access to healthcare services for the public, provide guidance in emergencies [92].
- *Kry - Erfaren vårdpersonal:* Usage: Offers online doctor appointments and healthcare consultation via a telemedicine platform. Services: Telemedical examinations, prescription renewal, medical reporting. Purpose: To facilitate access to healthcare services, enhance patient satisfaction, digitize healthcare [93].
- *Min Doktor – Vård & vaccin:* Usage: Provides telemedicine services and allows users to have online doctor consultations. Services: Remote medical examinations, patient management, healthcare information. Purpose: To facilitate access to healthcare services, optimize healthcare delivery, improve patient experience [94].

Another application developed alongside these applications is Adrenals.eu, a portal created for mHealth purposes by the non-profit organization BijinierNET based in the Netherlands, which provides information and products online for adrenal gland patients, caregivers, and healthcare professionals [2]. In the Netherlands, the AdrenalNET/BijnierNET portal offers basic information on adrenal disorders such as adrenal insufficiency, Cushing's syndrome, congenital adrenal hyperplasia, primary aldosteronism, pheochromocytoma, and adrenocortical carcinoma [82].

In Germany, a pioneering country in the healthcare sector, telemedicine applications began earlier compared to many other countries. The operation of telemedicine is defined as the use of modern information and communication technologies in medical diagnosis, treatment, and consultation across a wide geographical area. The gradual development of telemedicine is hindered in Germany due to concerns such as data protection/security, resulting in insufficient representation in reimbursement and application lists. Mobile governance is transforming the exchange of information between the state, government, and citizens, providing transparent access to government services anytime and anywhere, thereby establishing a new communication channel between the state and its citizens and disrupting the traditional organizational structure of the state [43]. With the advancement of telemedicine, innovations and research and development continue in this field due to the convenience of digital services.

Mobile government has garnered increasing interest as a mechanism to reduce costs, enhance effectiveness, and improve public access to government services, especially among advanced countries in recent years [44]. It is acknowledged that each country uses mobile technology as a tool to provide services, depending on the accessibility levels to these services based on the welfare levels of their own citizens. There are significant differences among Member States of the European Union, with some countries being highly advanced in health information technologies (e.g., Denmark, Sweden, and the Netherlands), while many Central and Eastern European countries lag behind [95]. Mobile broadband has grown faster in developing countries, with economic growth expected to have a positive impact, experiencing a compound annual growth rate of over 200% since 2009 [96]. The introduction of new products and services by large firms and startups serves as another driving force, yet filling the healthcare market with mobile applications requires effective adoption and dissemination strategies, where health organizations and consumers recognize the importance and benefits of transitioning to mHealth [20, 97].

VI. Mobile Technology Application Examples Focusing on The Health Sector in Other Countries in The World

New technologies have enabled users to access information they need at an unprecedented rate in human history. This reality has encouraged major healthcare organizations to promote thinking, change, and restructuring in their traditional management styles. Additionally, organizations have been prompted to incorporate more flexible and interactive elements into their business models in line with current health trends [98]. This transformation and evolution is a phenomenon occurring across all countries worldwide. In the field of health, mobile technology has significantly contributed to time management and cost reduction for healthcare services at every level, from hospital visits to individual appointments with doctors, thereby greatly enhancing convenience [81]. Mobile health examples have been diverse and increasing in variety since their inception in 2003 globally. According to a report on mobile health published by the World Health Organization in 2011, 83% of member countries had implemented at least one mobile health initiative/project, whereas 19 countries had not implemented any mobile health projects. Moreover, over the past approximately 20 years and currently, mobile health has been used for various purposes in both developed and developing countries. In developed countries, it is predominantly used for remote disease management, wellness/fitness activities, and electronic patient data transfer, focusing more on technology use. In contrast, in developing countries (African countries, India, and Far East countries), it is used more for mobile phone-based information dissemination, raising awareness about diseases, and disease prevention [38].

On average, individuals spend 3 hours and 15 minutes on their phones daily. They check their phones approximately 58 times per day on average. Filipinos spend the most time on their phones daily. Japanese citizens spend less than half of the global average time on their smartphones. It is claimed that three-quarters of Generation Z spend a lot of time on their smartphones. According to recent data, an average person spends 4 hours and 37 minutes on their phone daily. This equates to more than one day per week or six days per month. Over the course of a year, this amounts to approximately 70 days spent looking at a phone. There is a correlation between generation and screen time: Generation Z (Average Daily Screen Time: 6 hours 5 minutes, Percentage Feeling Dependent: 56%), Generation Y (Average Daily Screen Time: 4 hours 36 minutes, Percentage Feeling Dependent: 48%), Generation X (Average Daily Screen Time: 4 hours 9 minutes, Percentage Feeling Dependent: 44%), Baby Boomers (Average Daily Screen Time: 3 hours 31 minutes, Percentage Feeling Dependent: 29%) [99].

We are at a turning point in health policies in this era. It is becoming increasingly clear that changes in the current healthcare system will not be sufficient to maintain and improve our health at this historic juncture. Many reasons can be cited for this, including rising rates of chronic diseases, obesity, and mental health problems. This situation proves the need for a fundamentally new mindset in health policies [100]. Many countries support these developments in different ways. Mobile health technology or mHealth, according to a study, is currently used by 83% of doctors in the United States to provide patient care. Mobile health is an emerging technology rapidly transforming healthcare services, enhancing the quality and efficiency of healthcare. mHealth encompasses various health technologies of vital importance [101]. Additionally, the deployment of mobile applications in the healthcare sector through gamification has become increasingly popular. Gamification provides users with an active experiential process, encouraging greater participation in the application. This process is tailored to the user's choices and preferences. It is observed in the literature that motivating individuals plays a significant role in gamification. Designers play a crucial role in ensuring that individuals do not become bored with the process and complete tasks. Examples of mobile health applications offered through gamification design include [3,78]:

- *Abbott Pharmaceuticals* has developed an application in the field of pediatrics for healthcare professionals, which utilizes gamification methods to present three primary approaches. The first is conditional progression, where users cannot advance to other modules without fulfilling a specific condition within the system. The second approach involves displaying movements.

- *Change Talk, Childhood Obesity, and Overweight:* This application has been developed to facilitate more effective communication between patients diagnosed with childhood obesity and their families. Its aim is to enhance patient motivation and promote behavioral changes in health. The application is structured around interactions between a virtual pediatrician (healthcare worker), the child obesity patient, and the mother, with behaviors varying based on the pediatrician's questions.

- *Google's Smart Contact Lens:* This technological innovation by Google measures glucose levels from tears and sends them to doctors around the clock.

- *CogCubed - Cognitive Games for Health*: This application is designed to assist in diagnosing attention deficit hyperactivity disorder (ADHD) in children and adults. A professional analyzes the user's behavior while playing games to determine their susceptibility to ADHD.

- *MangoHealth:* This application helps patients taking medication to manage their own health. Features include medication reminders, drug information, and health history. Users can earn points by adhering to their medication schedules, which can be converted into donations or gift cards if desired.

- *Project Evo*: Developed jointly by Akili Interactive Labs and Pfizer, this project is designed for Alzheimer's patients. Its goal is to detect susceptibility to Alzheimer's disease, and the application is developed based on clinical research.

- *Spread the Message Stop the Virus*: Implemented by the Royal Netherlands University in 2008 and 2009 in Uganda, this project targeted 15,000 active mobile users in the Mbarara region. Its aim was to raise awareness about HIV/AIDS and encourage counseling. Thousands of mobile phone users responded to an HIV/AIDS test via SMS and received messages to educate them on the topic.

- *SMS to Monitor Malaria in Remote Areas*: A pilot project organized by the Uganda Ministry of Health and Innovative New Diagnostics Foundation. Its objective is to enable health workers to report malaria results to each other via SMS, facilitating rapid disease monitoring in the field.

- *X out TB Project:* Conducted by the Massachusetts Institute of Technology in Nicaragua, this project aims to increase treatment chances for tuberculosis patients by monitoring medication adherence and requiring patients to report the code written on their urine analysis box via mobile phone.

- *Wired Mothers*: A project initiated by the University of Copenhagen in collaboration with the Ministry of Health and Social Welfare in Tanzania. It aims to reduce maternal and newborn deaths by encouraging pregnant women to attend routine prenatal care appointments, fulfill qualified birthing attendants, and access postnatal care through SMS reminders.

- *Real-Time Biosurveillance Program*: An early warning system based in India and Sri Lanka to prevent epidemic outbreaks, where village nurses enter disease statuses into a software via mobile phones.

- *Text4 Baby*: Developed to support Hispanic American pregnant and expectant mothers regarding pregnancy. The application sends messages to pregnant women regarding pregnancy details such as month and age, providing pregnancy-related tips at least three times a week.

- *Skin Scan*: A nevus analysis program that categorizes moles into low, medium, or high-risk categories. A photo of the nevus is taken and uploaded to a mobile phone. If atypical features are detected in the photo analysis, the user is directed to a dermatologist.

When we examine mobile technologies through the Apple Store and Android Market, focusing on the United States, we encounter the following applications:

- *CDC (Centers for Disease Control and Prevention):* Usage: Provides a wide range of health services including disease control, epidemiological data monitoring, health education and information dissemination, and emergency response management. Purpose: Established to control diseases in the United States and globally, gather epidemiological data, develop health policies, and educate the public on health issues. Service Areas: Government, healthcare professionals, researchers, and the general public [102].

- *VA: Health and Benefits:* Usage: Offers specialized services for veterans in the United States, including access to healthcare services, medical records, appointment management, and medication management. Purpose: Aimed at improving access to healthcare services for VA patients, enhancing medical care, and meeting the health needs of veterans. Service Areas: Veterans, VA healthcare service providers [103].

- *MyChart:* Usage: Provides patient portal services facilitating communication between healthcare providers and patients, with features such as access to medical records, appointment management, and prescription renewals.Purpose: Designed to streamline communication between healthcare providers and patients, improve patient management, and increase access to healthcare services. Service Areas: Healthcare providers, caregivers, patients [104].

- *HealthTap:* Usage: Offers online health consultation services including instant doctor consultations, asking health questions, access to health information, and messaging with doctors. Purpose: Facilitates online communication between users and doctors, raises health awareness, and enhances access to healthcare services. Service Areas: General public, health advisors, doctors, healthcare providers [105].

When we examine mobile technologies through the Apple Store and Android Market, focusing on Australia, the following applications appear:

- *COVIDSafe (inactive):* Usage: Used for contact tracing and pandemic management during the COVID-19 pandemic. Services: Tracks user contacts with infected individuals, provides information to health authorities. Purpose: Controls the spread of the pandemic, protects community health, prevents disease transmission through contact tracing [106].

- *My Health Records:* Usage: Allows users electronic access to their health records. Services: Access to medical history, prescription information, access to laboratory results, coordination of healthcare services.

Purpose: Facilitates access to healthcare services, centralizes and shares health information in a centralized database [107].

- *HealthDirect:* Usage: Provides access to health information and directs users to healthcare services. Services:Symptom checking, searching for healthcare services, guidance for emergencies. Purpose: Ensures public access to accurate health information, directs to healthcare services, provides emergency guidance [108].
- *QuitNow:* Usage: Supports users in the process of quitting smoking. Services: Smoking cessation plans, progress monitoring, motivational content. Purpose: Reduces smoking addiction, promotes healthy lifestyles, improves public health [109].
- *MyQuitBuddy:* Usage: Supportive application for smoking cessation. Services: Smoking cessation plans, progress monitoring, access to health information and support groups. Purpose: Provides support for smoking cessation, enhances motivation, raises awareness about health effects [110].

When we examine mobile technologies through the Apple Store and Android Market, focusing on Canada, the following applications appear:

- *Maple – Online Doctors 24/7:* Description: Maple, a mobile application supported by the Canadian government, enables users to communicate with healthcare providers via voice or text messaging and video calls at any time of the day. Users can schedule virtual health appointments, obtain illness reports, prescriptions, medical advice, request laboratory tests, and much more [111].
- *CANImmunize:* Description: ImmunizeCA, supported by the Canadian Ministry of Health, helps users update their vaccination records, track vaccination schedules, and receive vaccination reminders [112].

Mobile technology creates value across three fundamental pillars: productivity, coordination, and transformation. Mobile applications are becoming increasingly important in education in many countries, not only proving beneficial but also offering students an enjoyable and interactive learning experience. For a successful mobile product launch, a well-established systematic process that is controlled, efficient, and precise is essential [113]. Governments in developing countries are making increasing efforts to provide citizens, businesses, and public officials with greater access to information and services via wireless devices [114].

The digital health technology market is a continuously growing sector attracting significant investment. Investors naturally gravitate towards this field, with companies like Apple, Google, and Samsung focusing on the development of mobile medical applications, particularly those measuring blood sugar levels. IBM is increasing its research and development investments in image recognition and medical assistants/robots. Google is creating data collection and analytics pools to support medical solutions, while Microsoft is conducting feasibility studies in areas such as speech recognition and cloud technologies. The Russian company MegaFon has launched the video consultation service "MegaFon.Health," positioning itself as a partner in organizing health services within the healthcare system [115].

Health and safety inspectors can now file reports in real-time from the field using handheld computers or terminals, eliminating the need to re-enter data collected on paper forms when returning to the office. Meanwhile, citizens can save time and energy by accessing the Internet and government networks more easily via mobile phones and other wireless devices. For example, in Malaysia, citizens can verify voting information such as parliamentary and state electoral districts using SMS (Short Message Service). Alternatively, citizens can request real-time information to be sent to their mobile phones, PDAs, or pager devices via email or SMS. Another example is the California state government, which has established a webpage where citizens can register to receive wireless PDA and mobile phone notification services for energy alerts, lottery results, traffic updates, and articles from the Governor's press office. m-Government not only enhances efficiency but also facilitates citizen activism. In the Philippines, citizens can report smoke-emitting public buses and other vehicles via SMS to aid in the enforcement of anti-pollution laws. SMS is also used to involve citizens in crime and drug control efforts [42]. All these examples can be interpreted and diversified for the healthcare sector as well.

VII. Discussion and Conclusion

In our study, we identified the importance of a robust mobile health system, particularly for countries like Türkiye where the healthcare system is heavily supported by the state. Therefore, discussing mobile health under the concept of e-government within mobile government services was deemed to be a correct approach. Additionally, it was observed that for mobile services to be structured most effectively, they must address the right problems. The acceptance of a good mobile health system by both patients and doctors is crucial [33]. They pointed out that mobile information and communication technologies in the public health sector promise to improve the quality of health services, but this potential can only be realized if individuals decide to adopt new technologies.

During the development of mobile applications, we also found that information security and personal data privacy must be considered, and user roles must be well-defined. One of the most critical aspects to consider in mobile health projects is that technology alone is not sufficient in applications and solutions. Mobile health projects are equally complex as other healthcare projects. The significant difference lies in their ability to be largely accessed remotely and heavily utilize communication and information technologies. Therefore, a well-trained human resource is critical in this regard. Individuals who are aware of current information technology trends and anticipate how technology will affect their profession can play a key role in effectively utilizing relevant technologies [116, 117]. It is also considered highly beneficial to add at least one or two courses related to current health technologies and information technologies to programs in fields related to the healthcare sector such as medicine, dentistry, pharmacy, and nursing.

The effectiveness of the technology used is limited to the system you are affiliated with and the people you connect. While mobile applications and tools are developed for specific purposes, their adoption and acceptance by doctors are essential. Without sufficient doctor support and usage, there is no chance for any information technology (neither electronic health records nor mobility) to succeed [38]. Mobile health applications can enable both doctors to monitor patient care services and patients to monitor their own health, thereby increasing motivation. Gamification can be effectively used as a tool in mobile health applications [3]. The attitudes of doctors and patients towards mobile applications will provide important insights for hospital administrators, policymakers, and public health regulators regarding the impact and value of mobile tools in healthcare services.

Like in all fields, the use of information systems in healthcare is becoming widespread. Hospital information systems are used in public hospitals to securely maintain records related to patients and hospitals, improve appointment scheduling, hospital management, decision support, and workflow processes, thereby increasing efficiency and productivity, minimizing error rates, enhancing service quality, reducing service costs, and ensuring patient satisfaction[118]. Mobile information and communication technologies can help bridge these gaps due to the minimal and even zero operational costs in the mobile environment [119]. Healthcare services hold significant potential in this regard. Therefore, developing applications at this point can provide important cost advantages to institutions in the delivery of healthcare services. It is considered that health policy makers showing effective management at this point and paying attention to mobile technology will be an important input to increase patient satisfaction.

Various mobile applications have been implemented in many fields such as dermatology, orthopedics, ophthalmology, neurosurgery, and clinical pathology. Applications are comprehensive in increasing patient participation through mobile technology, self-monitoring by patients, facilitating clinical algorithm calculations, and bridging resource-poor environments with experts [120]. Moreover, it has been observed that mobile applications are of great advantage for the elderly in developed countries, especially in European Union countries such as Germany and Sweden. Bhavnani et al. [121] stated that perceptions of medical, governmental, and financial institutions support the concept that mobile health can meet increasing demands from an aging population and rising healthcare costs. Our interest in mobile health focuses on potential benefits to society and citizens when information and communication technology is used to change health culture. With an aging population across European Union countries, national governments are seeking ways to reduce healthcare costs. Mobile health is introduced as a solution to change the delivery of healthcare services through new care models applicable to industrialized and developing countries [122]. Mobilizing citizens in the innovation process, with adequate capacity to scale innovation, will accelerate economic growth and social equality [123]. Examples include mobile health technologies such as telemedicine, health applications for mobile phones, and remotely monitored medical devices, which show how citizens or patients can be more involved in healthcare services [20].

In the public sector, whether for healthcare services, education, or other services, when there is a need for mobile technology and your institution does not have the opportunity to develop such an application internally, particular attention should be paid to the procurement process. If your own software development team does not have sufficient expertise in developing such tools, outsourcing can also be pursued to avoid potential security issues in subsequent stages. It is essential to enter into a very good contract with relevant companies during the procurement process of such software. The contract must explicitly safeguard data privacy and the use of personal data under special laws and regulations. In addition, responsibilities arising from service interruptions or data manipulation must be clearly stipulated. Of course, mobile services are mostly presented as part of public health services by the government. However, in countries like Türkiye where private and public hospitals operate within the healthcare system together, obtaining such services through outsourcing via private hospitals in mobile application areas can lead to many problems or compensation issues for the institution.

Public institutions generally have established processes governed by laws and regulations, making it difficult to actively respond to current technologies. In this regard, especially for systems where public hospitals have a significant share in the healthcare system like Türkiye, it is considered highly beneficial to issue project calls through supporting institutions similar to TÜBİTAK for scientific research activities. Alongside this, creating special funds for project calls involving universities, healthcare institutions, and the private sector by healthcare policy makers and regulators is also considered highly beneficial for the rapid development of information technologies in healthcare.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interest.

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Android Ransomware Detection System using Feature Selection with Bootstrap Aggregating MARS

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***Abstract*— Android ransomware has become one of the most dangerous types of attack that have occurred recently due to the increasing use of the Android operating system. Generally, ransomware is based on the idea of encrypting the files in the victim's device and then demanding money to provide the decryption password. Machine learning techniques are increasingly used for Android ransomware detection and analysis. In this study, Android ransomware is detected using Bootstrap Aggregating based Multivariate Adaptive Regression Splines (Bagging MARS) for the first time in feature selection. A feature matrix with 134 permissions and API calls in total was reduced to 34 features via the proposed Bagging MARS feature selection technique. Multi-Layer Perceptron (MLP), one of the classification techniques, produced the best accuracy with 90.268%. Additionally, the proposed feature selection method yielded more successful results compared to the filter, wrapper, and embedded methods used. Thus, this method, which was used for the first time to detect the common features of Android Ransomware, will enable the next Android Ransomware detection systems to work faster and with a higher success rate.**

Keywords*— *Bagging, feature selection, machine learning, MARS, ransomware, static analysis

I. INTRODUCTION

Ransomware may infect a victim's computer when the victim opens an e-mail attachment sent to him/her, visits a website, downloads an unsecure file, or installs unapproved software. After infecting the victim's computer, the malicious software begins the first encryption phase by deleting the unencrypted original files, thereby preventing the victim from access ing their files. The attacker does not allow access to the original files until he/she is paid a ransom via a payment method such as virtual money.

If the ransom is not paid in the time specified by the attacker, he/she destroys the encryption key and permanently deletes the data [1]. In the beginning, the majority of ransomware victims were Windows desktop users. After a while, ransomware emerged on different platforms including Android, iOS and other mobile operating systems. In recent years, types of attack shifted towards ransomware of a particular type [2]. Ransomware attacks continued at the beginning of 2020 with a range of rapidly spreading ransomware including Maze, Sodinokibi, DoppelPaymer, Nemty, Nefilim, CLOP and Sekhmet. According to the cybersecurity firm Emsisoft, attackers published the stolen data on their own websites in case a payment was not made.

Emsisoft announced that the aim of ransomware groups is, in general, selling the stolen data to rivals, using the stolen data to attack business partners of the victim and publishing the victim's private information on their webpages for everyone to see.Some attackers have exploited COVID-19 with reventive measures to prevent future incidents [3].

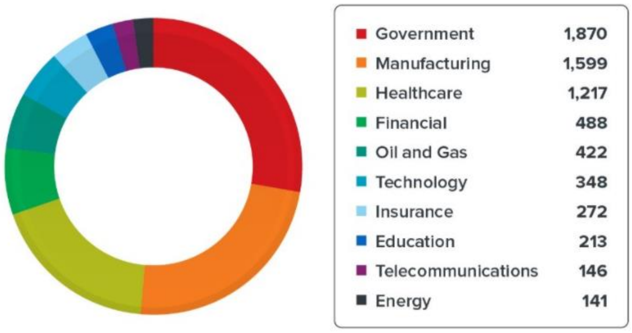

Figure 1. Industries Affected by Ransomware

As seen in Figure 1, ransomware victims range across a broad spectrum including industries such as production, health and education to municipal management [4]. Mobile operating systems used around the globe are 74.25% Android, 25.15% iOS, 0.23% Samsung and 0.37% other operating systems [5]. According to Chebyshev (2020) [6], there were 60.176 mobile ransomware attacks in 2018 worldwide, while this number rose to 68.362 in 2019. Victims of the largest 11 ransomware attacks in 2020 have spent 144,2 million dollars up to now on various costs ranging from investigating the attack, reinstating networks and restoring backups, paying computer hackers and applying according to these numbers, there is a 13.6% increase in mobile ransomware attacks, annually. The distribution of recent ransomware attacks across countries is given in Figure 2 [7]. Ransomware hides in uncertified source downloads, Google Play applications and exploitation kits using security vulnerabilities that are yet unpublicized, and spread from there. There are two ransomware types, crypto-ransomware and screen locker ransomware. Crypto-ransomware encrypts the user's data and files. The key used in the encryption process is required to decrypt them.

Screen locker ransomware is activated by the user downloading a fake application from Google Play store or a

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third-party market, and the mobile device then being rendered inoperable by locking the user screen. In general, a ransomware attack has three main stages: Earning the execution privilege, preventing access, and finally notifying the victim with the ransom message [8].

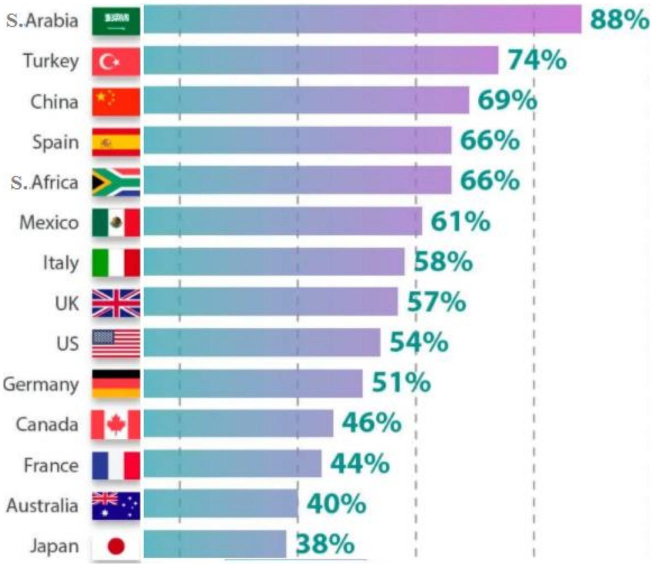

Figure 2. Distribution of Ransomware Attacks across Countries

Ransomware is a one of the type of malware. However, it has its own characteristics. Since they encrypt and store the files on the infected system, cleaning them from the system does not save the victim's information. Ransomware's work differently than other malware requires the use of different operating features specific to ransomware in their detection. Some of these features are given below. In recent years, ransomware attackers have found many methods to avoid detection by antivirus software and security utilities. However, ransomware does have some common properties that can allow the detection tools to reveal them. In the Android environment, ransomware has been found to have some common behavior and features, as follows [9-10].

Obtaining administrator privileges

- Detecting and disabling working anti-viruses
- Encrypting user files on the device
- Stealing contact information
- Starting device camera and taking photos
- Locking or unlocking the device
- Turning ring and notification tones off
- Showing threatening short messages

As a result, the use of unique features in the detection of Ransomware will increase the detection speed and accuracy. For this reason, it has become necessary to work specifically for Ransomware. Although there have been various studies to detect malicious ransomware, there are not many studies on Android ransomware detection. Automated malicious software analysis can be performed via two traditional methods, static and dynamic. Static analysis is basically the investigation of resources obtained via re-compilation before executing the code. Static analysis is a investigation simple and fast method. Dynamic analysis, on the other hand, is a method that investigates behavior emerging from the execution of the software on either a real machine or a virtual environment. In this study, static analysis is used for ransomware investigation. In this study, a dataset of 2990 samples in total was used for feature selection. As a result, Bagging-MARS was more efficient than the other feature selection methods it was compared with. The proposed method considerably exceeded Random Forest, one of the most commonly used and best-known embedded methods in the literature.

Also, the accuracy rate of Bagging-MARS surpasses Random Forest in all machine learning techniques used. In Section 2 of this study, a literature review is performed on related work. Section 3 covers some basic concepts related to the theoretical substructure of the proposed technique. In Section 4, information about the dataset and the evaluation metrics used are given, and the experimental results of the proposed technique are presented. In Section 5, the application results from the Bagging-MARS technique are discussed and interpreted in the conclusions.

II. Related Work

Recent research on Android ransomware detection has developed various approaches to make detection and prevention of such malware more effective. In this article, studies by Kirubavathi and Anne (2024) [11], Rahima et al. (2024) [12], and Li et al. (2024) [13] have contributed to significant developments in this field by highlighting different techniques and methods. Kirubavathi and Anne used behavioral analysis and machine learning techniques in the detection of Android ransomware in their study. This study focuses on identifying specific behavioral patterns of ransomware, thus enabling the detection of malware. The proposed model optimizes the detection process by monitoring the behaviors of ransomware on Android devices. With this approach, early warning systems are being developed to prevent the spread of ransomware. Rahima and his colleagues presented an approach based on hamming distance, a new feature selection method, for the detection of Android ransomware. This study aimed to increase the accuracy of the detection model by using this new method in the feature selection phase. Rahima and his team managed to make the detection of ransomware more sensitive and faster with this method, and especially emphasized the benefits of hamming distance. Li and his colleagues developed an Android ransomware detection framework called ARdetector. This framework detects ransomware using both static and dynamic analysis methods. The study aims to provide a multi-layered defense mechanism against ransomware attacks, preventing attacks from being hidden in various ways. ARdetector has been presented as a powerful tool in the analysis of Android applications and has achieved high accuracy rates in ransomware detection.

Also, the feature selection stage is a critical step in obtaining an efficient classifier model because, along with the effect of input data on designing a strong classifier, it is directly affected by long execution times and classifier accuracy.

Feature selection and population classification has caught the attention of many researchers in statistics, machine learning, neural networks and data mining for years. Fast Correlation-Based Filtering (FCBF) was proposed by Deisy et al. (2007) [14] to remove both irrelevant and unnecessary features using symmetric similarity. When the recent studies on feature selection were investigated, Yıldız and Doğru (2019) [15] proposed a method to detect malicious Android software via feature selection with the Genetic Algorithm (GA). Three different classification techniques consisting of separate feature subsets chosen by GA were applied to detect and comparatively analyze malicious Android software.

Chakravarty, (2020) [16] investigated the most effective permission recognition using feature reduction. They used Gain Ratio and J48 to evaluate the features selected and features used for feature reduction in Random Forest, Multi-Layer Perceptron, Sequential Minimal Optimization (SMO) and Randomizable Filtered classifiers. Experimental results showed that five permissions may provide almost complete feature accuracy and therefore optimize the malicious detection software system.

Varma et al. (2020) [17] contributed to finding the minimal feature set for malicious software detection using a series of importance values of dependent features along with Ant Colony Optimization (ACO) as a heuristic search technique. The malicious software dataset called claMP, which has both integrated and raw features, was accepted as the comparison dataset for this study. Analytical results proved that claMP can achieve 97.15% and 92.8% data storage optimization with minimum loss of accuracy for integrated and raw datasets, respectively.

In published literature, there are few studies proposing static and/or dynamic approaches to detect Android ransomware. Some studies using static analysis – Andronio et al. (2015) [4]– investigated the common properties and analysis results for existing mobile ransomware families. They proposed HellDroid, which is a fast, effective and fully automated approach that recognizes harmless software, known and unknown malicious software and examples of them.

The working principle of Helldroid is generally based on detecting the building blocks necessary for mobile ransomware to work. It detects if an application is trying to lock or encrypt the device without user permission and if ransom requests are shown on screen. HellDroid shows almost zero false positives in a large dataset consisting of hundreds of apk files, including harmless/malicious software and ransomware.

Zheng et al. (2016) [18] proposed GreatEatlon, which is a next generation mobile ransomware detector. As a preventive countermeasure, they envisioned the deployment of GreatEatlon in the application store. In essence, GreatEatlon uses static program analysis techniques to extract the correct information dataflow necessary to resolve reflection-based, anti-analysis attempts and detect malicious usage of the device management API and cryptographic APIs.

Mercaldo et al. (2016) [19] proposed a method that can identify the characteristic properties of a ransomware program inside malicious software and detect the ransomware. According to experimental results, they claimed that the proposed method can be the correct way to develop commercial solutions that successfully detect ransomware and prevent their effects.

Maiorca et al. (2017) [10] utilized the information extracted from API packets that enabled characterizing applications without any special information regarding user-defined content such as the application language. Results obtained from the data showed that it is possible to detect Android ransomware and distinguish them from malicious software in general with a very high accuracy. Moreover, they correctly distinguished true ransomware from the false positives using R-PackDroid to identify applications detected as ransomware with a very low confidence by the Virustotal service.

Cimitille et al. (2017) [20] proposed a technique based on formal methods to detect malicious ransomware in Android devices. They made the method usable by implementing it in a tool called Talos. Results obtained showed that Talos was quite effective in recognizing ransomware even if it was hidden, and detected them with a 99% accuracy.

In some studies using dynamic analysis, Song et al. (2016) [21] proposed an effective method to prevent mutated ransomware attacks exploiting vulnerabilities in existing systems against novel ransomware patterns on Android platforms. The proposed technique was based on investigating these processes by processor usage, memory usage and input/output ratio based statistical methods to detect those processes exhibiting abnormal behavior. If a suspicious ransomware-executing process was detected, the proposed method stopped the process and the user was requested to delete the programs related to that process. The high detection speed was thanks to the method being applicable to Android source code instead of the mobile application.

Chen et al. (2018) [22] gathered 2,721 ransomware samples covering most of the existing Android ransomware families and proposed a method characterized systematically by various aspects including time diagrams and malicious intent features. Moreover, since the detection results of existing anti-virus tools are quite unsuccessful, they proposed a new real-time detection system called RansomProber to detect ransomware extorting users by encrypting data. RansomProber can deduce if file encryption services have been started manually or not by analyzing the user interface widgets of related activities and the user's finger movement coordinates. Experimental results showed that RansomProber could effectively detect encrypting ransomware with high accuracy and acceptable execution time performance.

On the other hand, there are studies that perform both dynamic and static analyses. When some of these studies were investigated, Ferrante et al. (2017) [23] proposed a hybrid method that could actively withstand ransomware. The proposed method consisted of a dynamic approach that first observed the execution time behavior of applications that were going to be used on a device before installation with a static approach, and then determined if the system was under attack or not. While they used the frequency of process codes in their static ransomware detection, the dynamic detection takes the CPU, memory and network usages and system call statistics into account. They evaluated the performance of their hybrid detection technique in a dataset with both ransomware and legal applications. Results showed that although both the static and dynamic detection methods provided good performance in ransomware detection, the hybrid method showed the best performance, detecting ransomware with 100% sensitivity and having a false positive rate below 4%.

Gharib et al. (2017) [24] proposed the DNA-Droid which has a two-layer detection framework. They used a dynamic analysis layer on top of a static analysis layer as a complementary layer. In DNA-Droid, they used new features and a deep neural network to obtain a series of features with a powerful capacity to distinguish ransomware and harmless samples. Furthermore, sequence ordering techniques were used to profile ransomware families. A web system was developed to extract dynamic features for researchers. DNA-Droid has been tested against thousands of samples. Example results showed that it has a high precision and recall even in detecting unknown ransomware samples while keeping the false negative rate below 1.5%.

III. THEORETICAL BACKROUND

A. *Android Ransomware Permissions and Application Programming Interface Calls*

A permission for an Android application developer is a constraint that limits access to documents, a part of the code, or data in the device. It is applied to protect critical data that can be limited, and protect the code. Every permission is defined with a unique label. In general, the label indicates the limited action.

Today, every Android application developed has a related AndroidManifest.xml file. The manifest file contains all the necessary details needed for the Android platform to execute the application since its compilation. Moreover, it gives information about application components such as services and activities.

Android applications are compressed files with an ".apk" extension. Android is developed via an Application Programming Interface (API) and consists of four types of components: activities, services, broadcast receivers and content providers. Android software interacts with applications using these components. In application packages, instead of multiple class files, all classes are packaged into a single file with a ".dex" extension. Android application packages are jar files that contain the application byte code, local code libraries, application resources and the AndroidManifest. The AndroidManifest is an XML file that contains information like the application package name and the application permissions. It is written in a human-readable XML format and transformed into binary XML during compilation [25].

Feature selection is a method used to select the most appropriate features that can be more easily classified into a specific class (malicious or harmless). In this study, the permissions and the API Calls parameters are used as features that can be helpful in determining if the Android software is malicious or not. To find these features, the Apktool reverse engineering tool is used. The AndroidManifest.xml and the smali files are investigated for permission requests and API Calls, respectively. These features were obtained by writing a bash script in the Ubuntu operating system. As a result, the feature matrix with a total of 134 permissions and API Calls was transformed into a feature matrix with the best 34 features.

B. *The Proposed Method*

Feature selection techniques identify and remove irrelevant and redundant information, enhancing the effectiveness of data mining algorithms [26]. As computer and information technologies have advanced, the analysis of multi-dimensional databases has become inevitable. The curse of dimensionality decreases classifier performance on high-dimensional datasets due to increased complexity, training requirements, and computation times. Reducing the number of features is essential to address this issue. Dimensionality reduction can be achieved through feature extraction or feature selection. Feature extraction compresses or transforms original features but lacks interpretability, while feature selection removes irrelevant and redundant features to choose the best subsets. Three feature selection algorithms are: Filter technique: Features are ranked and selected based on this ranking for model evaluation.Wrapper method: Features are tested with a machine learning algorithm to select the subset that improves model performance using heuristic methods like forward and backward selection.Embedded method: Combines filter and wrapper techniques to rank and select the highest-ranking features, enhancing classifier performance [27].In this study, the Bagging-MARS method is proposed for Android ransomware detection. This method achieved higher accuracy with 34 features compared to other techniques, as shown in Figure 3.

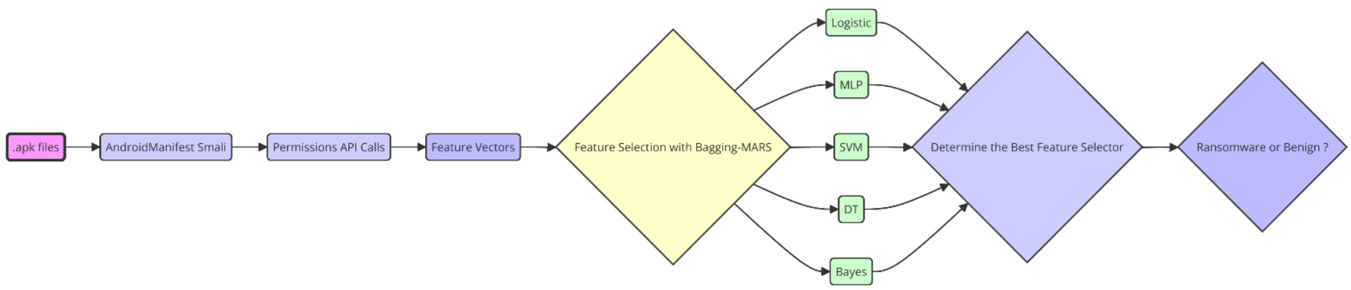

Figure 3. Architecture of the Proposed Technique

C. Bootstrapping

Bootstrap algorithms are used to create and resample large datasets. The bootstrap method reevaluates the statistical inferences of some parameters. Numerous resampling iterations are performed to make this process more reliable. Variance estimates are successfully obtained using the bootstrap method, which is frequently used for variance estimation. Additionally, the bootstrap method is superior when the sample distribution is not normal or when variance analysis is conducted on very small datasets. Bootstrapping is a method that is quite easy to understand and can be used with limited assumptions, without the need for intensive mathematical formulas [28].

A small number of samples with a high-dimensional feature space causes a decline in classifier performance in machine learning, statistics, and data mining systems. The results of feature selection methods significantly impact the success of data mining processes, especially when datasets are large. To obtain the best results from feature selection methods, it is necessary to conduct a comprehensive search in the search space and ensure accuracy in classification by checking each subset of features. It is not necessary to check each subset of features to achieve the same performance; it demonstrates that only a very small combination subset needs to be checked to achieve the same performance with a comprehensive approach.

The success of data mining algorithms stems from different factors. For instance, the quality of the input data is one of these factors. If the data contains irrelevant or redundant information or noise, the learning process across the search space will be more difficult. Feature selection techniques allow for the identification and removal of some irrelevant and redundant information. Such a process depends on the selection of a subset of optimal features that maximizes the efficiency of the data mining algorithm on the initial data. In the context of classification, bootstrapping repeats the entire classification experiment many times to obtain estimation accuracy from repeated experiments. Therefore, many bootstrap resamples are generated by (randomly) replicating each original sample to estimate the error rate in a few samples [29]. A sample of size m is taken from the original sample through resampling. Sampling with replacement means that some data points may be skipped [30].

D. Multivariate Adaptive Regression Splines (MARS)

MARS is a non-parametric regression method developed in the early 1990s by Jerome H. Friedman [31]. Designed for both binary and continuous outcome variables, MARS is known for its flexibility, accuracy, and speed. Unlike linear methods, MARS considers subsets of variables by dividing the predictor variable space into overlapping regions to form spline functions called basis functions [32, 33]. This method effectively handles non-monotonic relationships between predictor variables, making it superior in interpreting complex relationships in high-dimensional data compared to other linear and parametric methods [34, 35].

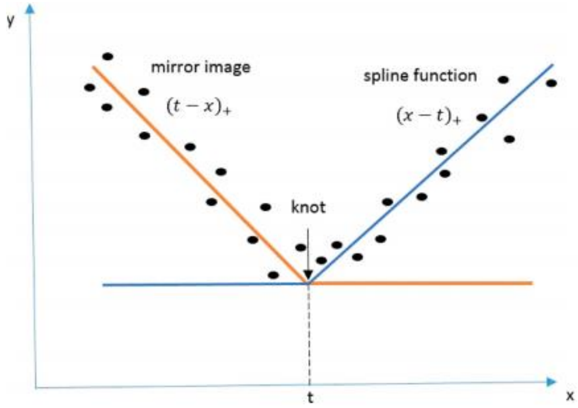

Figure 4. Inflection Point of the Spline Function

Friedman (1991) [36] recommended including the main region while determining sibling subregions, as this makes future splits more effective (Lewis and Stevens, 1991) [37]. MARS is used for prediction when the output variable is continuous and for classification when the output variable is categorical, demonstrating its wide applicability as a highly flexible, accurate, and fast technique [38]. Figure 4 shows the inflection point of a spline function [39].

In constructing the MARS model, the initial maximum model is refined using a backtracking algorithm that eliminates the least effective variables one by one. submodels generated during this process are compared using the Generalized Cross-Validation (GCV) criterion to determine the best-approximating submodel.

$$GCV = \frac{\sum_{i=1}^{N}\left(y_i-\hat{f}_\lambda(x_i)\right)^2}{(1-M(\lambda)/N)^2} \quad (1)$$

Here, $M(\lambda)$ and N show the effective parameter count and the number of observations, respectively. In this expression, $M(\lambda)$ is found by $M(\lambda) = r + cK$ where r and K denote the number of independent basis functions and the number of nodes selected in the incremental part, respectively. Bagging-MARS Pseudo Code is as follows.

Input: Dataset D (n samples, m features)
Output: Final Bagging-MARS Model
1. Determine hyperparameters:
  - B: Number of bootstrap samples
  - M: Maximum number of iterations for MARS model
  - P: Penalty parameter
  - Nk: Maximum number of nodes
2. Create an empty model list: Model_List = []
3. For b = 1 to B:
  a. Create bootstrap sample: D_b = Bootstrap sample(D)
  b. Train MARS model:
  Model_b = MARS (D_b, Max_Iteration=M, Penalty=P, Nk=Nk)
  c. Add model to model list: Model_List.append(Model_b)
End For
4. Make predictions for final model:
  a. Make predictions on test data X:
  Predictions = []
  For each Model in Model_List:
    Prediction = Model.predict(X)
    Predictions.append(Prediction)
  End For
  b. Calculate the final prediction (average or majority vote):
  Final_Prediction = Aggregate (Predictions)
5. Evaluate the final model:
  a. Final_Accuracy = Evaluate (Final_Prediction, Actual Values)
  b. Final_F_Measure = Calculate_F_Measure(Final_Prediction, Actual Values)
6. Return the final model and performance metrics as output.

IV. Experiment and Discussion

To evaluate the performance of machine learning methods for classifying Android ransomware, several metrics are used as follows:

$$ACC = \frac{(TP+TN)}{(TP+TN+FP+FN)} \quad (2)$$

$$TPR = \frac{TP}{(TP+FN)} \quad (3)$$

$$TNR = \frac{TN}{(TN+FP)} \quad (4)$$

$$P = \frac{TP}{(TP+FP)} \quad (5)$$

$$F-M = \frac{(2 \times P \times TPR)}{(P+TPR)} \quad (6)$$

In this study, 990 benign data points from the Google Play Store [40] and 2000 malicious data points from Virustotal [41], Andrototal, and Ransommobi [42] were collected as detailed in Table 1.

TABLE I. Android Datasets

Dataset	Source	Number of Samples	Features
Benign (Non-Malicious)	Google Play Store	990	Application permissions, API calls
Malicious	Virustotal, Andrototal, Ransommobi	2000	Application permissions, API calls

The study utilized thirteen feature selection methods, encompassing Bagging-MARS, Random Forest, AdaBoost, Naive Bayes, J48, Logistic Regression, Information Gain, Gain Ratio, Chi-Square, Correlation, OneR, and RRelief. For the classification task, five machine learning techniques were employed: Logistic Regression, Multi-Layer Perceptron (MLP), Support Vector Machines (SVM), Decision Trees (DT), and Bayesian methods.

TABLE II. Performance Evaluation Results (Precision)

	Machine Learning Tecniques				
Feature Selection Techniques	**Logistic**	**MLP**	**SVM**	**DT**	**Bayes**
Logistic Regression	0.670	0.681	0.660	0.665	0.663
Information Gain	0.660	0.604	0.660	0.660	0.783
Gain Ratio	0.660	0.604	0.660	0.660	0.660
Chi-Square	0.739	0.608	0.723	0.718	0.747
Correlation	0.842	0.849	0.842	0.852	0.856
One R	0.736	0.727	0.744	0.749	0.747
RRelief	0.760	0.754	0.760	0.760	0.760
J48	0.848	0.828	0.859	0.845	0.816
Naive Bayes	0.848	0.828	0.859	0.845	0.816
SVM	0.848	0.858	0.856	0.857	0.793
Random Forest	0.875	0.877	0.876	0.875	0.841
AdaBoost	0.591	0.616	0.587	0.586	0.649
Prop. Bagging-MARS	0.904	0.905	0.897	0.898	0.887

The precision performance results, as illustrated in Table 2, indicate that the Bagging-MARS method achieved the highest precision, with a value of 0.905. This was followed by Random Forest with a precision of 0.877, SVM with 0.858, and J48 with 0.828. In contrast, Information Gain and Gain Ratio exhibited the lowest precision, both scoring 0.604. Overall, it was observed that filter methods generally underperformed during the feature selection process for ransomware detection.

TABLE III. Performance Evaluation Results (F-Measure)

	Machine Learning Techniques				
Feature Selection Techniques	**Logistic**	**MLP**	**SVM**	**DT**	**Bayes**
Logistic Regression	0.640	0.682	0.643	0.667	0.665
Information Gain	0.643	0.604	0.643	0.643	0.565
Gain Ratio	0.643	0.603	0.643	0.643	0.643
Chi-Square	0.568	0.608	0.567	0.567	0.558
Correlation	0.796	0.796	0.796	0.795	0.795
One R	0.705	0.707	0.710	0.712	0.557
RRelief	0.753	0.752	0.753	0.753	0.753
J48	0.825	0.857	0.828	0.860	0.744
Naive Bayes	0.816	0.827	0.811	0.818	0.750
SVM	0.794	0.802	0.797	0.803	0.777
Random Forest	0.875	0.876	0.842	0.874	0.778
AdaBoost	0.554	0.621	0.572	0.571	0.651
Prop. Bagging-MARS	0.901	0.903	0.897	0.898	0.868

The F-Measure values, as presented in Table 3, reveal that the Bagging-MARS technique outperformed all other feature selection methods, achieving the highest F-Measure of 0.903. This was followed by Random Forest with an F-Measure of 0.876, and SVM with an F-Measure of 0.802. In contrast, Information Gain and Gain Ratio recorded the lowest F-Measure values among the methods evaluated.

TABLE IV. Performance Evaluation Results (Accuracy)

	Machine Learning Tecniques				
Feature Selection Techniques	**Logistic**	**MLP**	**SVM**	**DT**	**Bayes**
Logistic Regression	69.264	68.327	66.889	69.495	66.655
Information Gain	66.889	65.050	66.889	66.889	57.525
Gain Ratio	66.889	65.016	66.889	66.889	66.889
Chi-Square	68.127	65.217	68.026	67.993	56.488
Correlation	81.638	81.806	81.638	81.739	81.839
One R	69.699	69.966	70.167	70.334	56.388
RRelief	76.689	76.220	76.689	76.689	76.689
J48	83.712	85.652	84.281	86.154	74.114
Naive Bayes	83.077	83.110	82.943	83.144	74.248
SVM	81.605	82.308	81.973	82.375	79.197
Random Forest	87.424	87.559	85.451	87.391	77.191
AdaBoost	66.488	64.816	66.890	66.923	65.284
Prop. Bagging-MARS	90.033	90.268	89.715	89.765	86.421

The accuracy performance results, as detailed in Table 4, demonstrate that the Bagging-MARS technique achieved the highest accuracy, with a value of 90.268%. This was followed by Random Forest, which attained an accuracy of 87.559%, and SVM, with an accuracy of 82.308%. In contrast, Information Gain and Gain Ratio produced the lowest accuracy values among the evaluated methods. Notably, the method introduced in this study for the first time outperformed the widely recognized Random Forest method, which is frequently cited in the literature. Additionally, AdaBoost, another well-known ensemble method, recorded an accuracy of 64.816%. The Bagging-MARS method clearly outperformed AdaBoost in this context.

V. CONCLUSIONS

In this study, a MARS method based on Bagging feature selection was proposed. It has been shown that this technique has advantages compared to other existing methods for improving classification. To conduct a comparative analysis for the detection of unknown Android ransomware, thirteen feature selection methods and five machine learning methods were investigated. To observe the effectiveness of feature selection, standard Android permissions and permissions selected by Bagging-MARS were used with classifiers. The models were built from static analysis based on the investigation of application permissions. Experimental results showed that the best performance was produced by MLP with 90.268% accuracy and an F-Measure of 0.903. Bagging-MARS is the most effective feature selection method for improving classification techniques in this comparison. The proposed method significantly outperformed Random Forest, one of the most commonly used and well-known embedded methods in the literature. The accuracy rate of Bagging-MARS surpasses Random Forest across all machine learning techniques used. Bagging-MARS achieved 90.268% accuracy, while Random Forest remained at 87.559% accuracy.

In conclusion, this study clearly demonstrates the high efficiency of the MARS method based on Bagging feature selection in detecting Android ransomware. The detailed analysis thoroughly examined the impact of various feature selection methods and machine learning techniques on correct classification performance. In this context, the Bagging-MARS method shows a significant advantage over other alternatives, proving to be an extremely valuable tool, especially in the context of Android ransomware detection.

The results may encourage future security-focused studies to consider such feature selection and machine learning approaches more in-depth for ransomware detection and prevention on the Android platform. The larger-scale application of such methods can help develop more effective protection mechanisms against rapidly evolving ransomware threats. This study paves the way for further advancements in research on Android ransomware detection.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest.

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