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Review

Harnessing the Metaverse for Livestock Welfare: Unleashing Sensor Data and Navigating Ethical Frontiers

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Abstract: The metaverse, a virtual world comprising a collective virtual shared space where users interact with one another through avatars and computer-generated objects, aims to closely mimic our real world by integrating elements of Artificial Intelligence (AI), immersive reality, advanced connectivity, and Web3. As metaverse technologies gain momentum across multiple sectors, including animal farming, their potential for addressing complex challenges such as climate change and sustainability in precision food production systems becomes increasingly apparent. However, it is crucial to consider the ethical implications and the role of sensor data and livestock behavior analysis in developing metaverse technologies for modern animal farming, given the sensitive and controversial nature of animal welfare. Failure to address these ethical considerations and harness the power of sensor data and behavior analysis could lead to a lack of credibility and insensitivity towards adopting metaverse technologies in the animal farming sector. It is essential to ensure that the development of metaverse technologies does not prioritize technology over animal welfare, ethics, socio-economic implications, and the potential for data-driven insights. Addressing diversity and equity in the context of animal farming and the metaverse is crucial to avoid perpetuating existing inequalities during the implementation of metaverse technologies. This groundbreaking paper ventures into unexplored territory, shedding light on the untapped potential of the metaverse for modern animal farming. While research on this topic is still in its infancy, we embark on a journey of visionary speculation, presenting a compelling technology forecast that envisions the extraordinary possibilities awaiting us in the future. By delving into the metaverse's transformative capabilities, we provide a glimpse into a world where animal farming transcends its traditional limitations and embraces a new era of efficiency, sustainability, and ethical practices.

Keywords: Animal welfare; Virtual environments; Metaverse; Augmented reality; Precision Livestock Farming; Ethical farming; Sustainability; Livestock; Environmental impact; Digital agriculture

1. Modern Animal Farming and Metaverse

Animal farming has been an integral part of human society for thousands of years, providing essential resources such as food and clothing. The domestication of animals dates back approximately 10,000 years, with dogs being the first domesticated species, followed by cattle, chickens, pigs, and sheep (Collarini et al., 2022; Van der Horst & Maree, 2022). As animal farming practices have evolved, technology has played an increasingly significant role in enhancing efficiency and productivity.

Modern animal farming is characterized by the use of advanced technologies such as Artificial Intelligence (AI), robotics, and automation, which have improved the industry's efficiency (Liu et al., 2020). Precision livestock farming technologies have demonstrated their effectiveness in improving animal welfare in various aspects of livestock management. Examples such as robotic milking, crowd gates, and manure pushers have shown positive outcomes in terms of efficiency and reduced labor, while also minimizing stress and enhancing animal welfare.

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The deployment of automated bird fetchers in the poultry industry has contributed to a notable reduction in keel fractures and pre-slaughter stress. This technology has proven to be beneficial in ensuring the well-being of birds during handling and transportation processes. Additionally, robotic calf feeders offer advantages over traditional individual housing, as they allow for socialization while providing a biologically appropriate level of milk. This method has been associated with better cognitive development and reduced social isolation in calves, promoting their overall welfare. These examples demonstrate how precision technologies can effectively address specific challenges in livestock management, leading to improved animal welfare outcomes.

However, a few technological advancements have raised ethical concerns regarding animal welfare. Key concerns include overcrowding, limited access to food and water, and the use of hormones to promote growth (Kirchhelle, 2018). Furthermore, the spread of disease in animal farming can have detrimental consequences for ecosystems and human health.

Environmental implications of animal farming are also significant, as it requires substantial amounts of land, water, and other resources. Animal waste contributes to pollution and other environmental issues, while carbon emissions from animal farming contribute to climate change (Rojas-Downing et al., 2017).

In recent years, virtual environments have emerged as a potential solution to address some of the ethical and environmental concerns associated with animal farming. Virtual environments offer numerous benefits, such as improved animal welfare, reduced costs, and increased efficiency. Many experts believe that these technologies can help mitigate some of the challenges (Neethirajan, 2023) inherent in modern farming practices.

However, the implementation of virtual environments in animal farming raises crucial ethical considerations that require meticulous examination. To ensure the responsible development and application of virtual environments in animal farming, it is essential to assess their impact on animal welfare, environmental sustainability, and human-animal interactions. By addressing these ethical concerns and leveraging the potential of emerging technologies, the future of animal farming in the metaverse can contribute to the development of more humane, environmentally responsible, and efficient practices.

2. Definition of the metaverse, virtual reality and augmented reality

The metaverse is a collective, immersive, hyper spatio-temporal virtual shared space that exists online, enabling users to interact using avatars and computer-generated objects (Wang et al., 2022). It aims to create a virtual world that closely mimics reality by integrating cutting-edge trends such as AI, immersive reality, advanced connectivity, and Web3.

Virtual reality (VR) is a technology that generates a simulated environment, either resembling or diverging from the real world (Liagkou et al., 2019). VR employs computer-generated imagery, sound, and other sensory experiences to create an immersive environment, typically necessitating the use of a headset or similar device to fully engage users in the virtual setting.

In contrast, augmented reality (AR) overlays digital information onto the real world, enhancing user experiences primarily through mobile applications (Farshid et al., 2018). Unlike VR, which generates a fully simulated environment, AR enriches real-world experiences with digital content.

Virtual environments in animal farming are computer-based systems that emulate real-world settings. These systems leverage sensors, cameras, and other technologies to oversee and manage various aspects of animal farming. In recent years, the application of virtual environments in animal farming has gained traction as a method for improving animal welfare, reducing costs, and increasing efficiency (Jukan et al., 2017).

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By integrating the metaverse, virtual reality, and augmented reality in animal farming, researchers and industry professionals can potentially revolutionize current practices. The combination of these technologies can create immersive and interactive experiences, providing novel insights and opportunities for optimizing animal welfare and farm management. As the metaverse continues to expand, exploring its applications in animal farming will be essential for driving innovation, enhancing sustainability, and addressing ethical concerns in the industry.

Digital twin technology involves creating a virtual replica or representation of a physical object such as farm feeding stations or a biological farm animal, a system, or process [15]. This virtual replica, known as a digital twin, is designed to mimic the physical or biological counterpart in real-time, capturing data and interactions to provide insights and enable analysis.

A virtual environment, on the other hand, refers to a simulated or virtual space that replicates real-world elements or scenarios. It can be created using technologies like virtual reality (VR) or augmented reality (AR). The data collected from digital twins of animals, which are replicas of the real livestock, can be integrated into virtual environments. This integration enables farmers or researchers to interact with and manipulate the digital twins within the virtual environment, allowing for simulations, analysis, and experimentation in a controlled and immersive settings.

The integration of digital twins into virtual environments enables optimization and predictive modeling. By leveraging the data collected from the digital twins, farmers can analyze and optimize resource usage, minimize waste generation, and predict potential issues or challenges. These capabilities allow for proactive decision-making to enhance sustainability and overall farm efficiency.

Digital twins provide the data and representation of the physical animals, while virtual environments serve as the simulated space where these digital twins can be visualized, interacted with, and analyzed. This integration facilitates the exploration of sustainable farming practices, offering a safe and controlled environment to experiment, optimize, and improve animal welfare and environmental impact.

2.1. Evolution of Animal Farming and Ethics

Throughout thousands of years, human-animal interactions have significantly influenced the evolution of animal farming practices. However, the modern industrialization of animal farming has raised ethical concerns surrounding animal welfare. Critics argue that contemporary farming systems are cruel, inhumane, and unsustainable, fueling a rising interest in alternative animal farming methods that prioritize animal welfare and ethical treatment (Hampton et al., 2021).

2.1.1. The Evolution of Animal Farming and its Impact on Animal Welfare

Animal welfare legislation has evolved over time in response to concerns about inhumane treatment of animals within farming industries. The British Cruelty to Animals Act of 1822, for example, prohibited mistreatment of domestic animals like horses and dogs, while the United States enacted a law in 1828 prohibiting cruel treatment of animals during transportation by ship (DeMello, 2021). The 1866 ASPCA Act was the first U.S. law specifically addressing animal welfare, with other countries, including the European Union, subsequently implementing similar laws. These laws mandate provision of adequate food, water, and living space for animals, and prohibit certain practices, such as gestation crates for pregnant pigs (Carey et al., 2020).

Recently, demand for stricter animal welfare laws has grown due to high-profile animal cruelty cases raising public awareness. Despite debates surrounding their necessity and effectiveness, many countries have implemented laws governing animal treatment, reflecting increasing concern for animal welfare.

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2.1.2. Future of Animal Farming in the Metaverse

The realm of modern animal farming stands on the precipice of a paradigm shift, propelled by the uncharted possibilities offered by the metaverse. While research on metaverse applications in this domain is scarce, this paper serves as a guiding beacon, illuminating the path toward a futuristic landscape where virtual realities revolutionize the way we care for and interact with animals. As a technology forecast, we dare to envision the metaverse as a catalyst for groundbreaking advancements, ushering in a new era of enlightened practices.

Unveiling the Metaverse's Potential:

In this visionary exploration, we envision a metaverse-driven future that harmonizes animal welfare, sustainability, and technological innovation. By harnessing the metaverse's immersive capabilities, animal farming transcends physical constraints and opens doors to limitless possibilities. Let us delve into the enticing domains that lie ahead:

The transformative potential of virtual environments in redefining animal farming by mitigating cruelty and enhancing welfare is garnering substantial interest. By replicating natural habitats, these environments can effectively alleviate stress and anxiety in animals, stemming from confinement and isolation, ultimately contributing to improved health and welfare. Virtual and augmented reality technologies present novel opportunities for farmers and consumers to engage with animals, such as simulating farming experiences and disseminating welfare-related information. Additionally, immersive virtual experiences play a crucial role in educating consumers about contemporary animal farming practices, fostering ethical approaches.

Beyond promoting animal welfare, virtual environments offer valuable advantages to farmers and the food industry. They equip farmers with precise, real-time data on animal health and behavior, facilitating informed decision-making and heightened efficiency. Moreover, virtual environments have the potential to reduce costs associated with traditional farming practices while also mitigating environmental impacts.

Efficient Resource Utilization: Virtual environments enable precise monitoring and control of resources such as water, feed, and energy. By optimizing resource allocation and reducing wastage through data-driven decision-making, farmers can minimize costs associated with overuse or inefficient utilization of resources.

Reduced Infrastructure Expenses: Virtual environments offer the possibility of reducing or eliminating certain infrastructure requirements in physical farming. For example, the need for expansive physical spaces and equipment can be minimized in virtual environments, leading to reduced capital expenditures and maintenance costs.

Enhanced Production Efficiency: Virtual environments provide a controlled and customizable setting for animal farming. By optimizing factors such as lighting, temperature, and ventilation, farmers can create ideal conditions that maximize animal growth, health, and productivity. This enhanced efficiency can lead to increased production output and subsequently lower per-unit costs.

Mitigation of Environmental Impact: By utilizing virtual environments, farmers can minimize the need for expanding agricultural land and mitigate the environmental consequences associated with deforestation or habitat destruction. Preserving land and natural resources contributes to long-term sustainability and reduces costs associated with ecosystem degradation.

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While the exact extent of cost reduction may vary depending on the specific implementation and context, the concept suggests that virtual environments have the potential to optimize resource utilization, streamline production processes, and minimize the negative environmental footprint, thereby contributing to cost savings in the long run.

Nevertheless, it is imperative to thoroughly examine the limitations and ethical implications of these technologies.

2.1.3. Virtual and Augmented Reality in Animal Farming

Virtual and augmented reality (VR/AR) technologies are emerging as pivotal tools in animal farming, with the capacity to enhance animal welfare, boost efficiency, and mitigate the environmental impact of farming practices. These innovative technologies find application in diverse areas, such as training, education, simulating farming scenarios, monitoring animal health, alleviating stress, and promoting sustainable agricultural practices (Radianti et al., 2020; Kim et al., 2019; Neethirajan and Kemp, 2021; Phupattanasilp et al., 2019; Fejzic et al., 2019; Ronaghi et al., 2021). These advancements substantially affect both farmers and animals, shaping the future of animal farming.

2.1.4. Overall Benefits of Virtual Environments on Animal Welfare

The exploration of potential benefits associated with virtual environments on animal welfare in commercial farming represents an evolving perspective that acknowledges the developmental stage of research in this field. It is crucial to recognize that conducting comprehensive, full-scale studies on commercial farms to ascertain the viability of virtual environments as a substitute for traditional livestock practices is an ongoing process.

At present, the research landscape surrounding virtual environments in animal farming is characterized by an amalgamation of opinions and theoretical propositions. While promising, the discussions pertaining to the potential benefits of virtual environments should be approached with prudence due to the following considerations:

Limited Empirical Evidence on Commercial Farms:

To date, there is a scarcity of empirical research conducted on a full-scale within commercial farming settings. The lack of comprehensive studies exploring the practical implications and outcomes of implementing virtual environments limits our ability to draw concrete conclusions regarding their efficacy in substituting traditional livestock practices.

Ongoing Development and Refinement:

The field of virtual environments in animal farming remains in a state of ongoing development, necessitating continuous refinement of methodologies, technologies, and implementation strategies. As researchers strive to bridge the gap between theory and practical application, it becomes imperative to embrace the evolving nature of this area of study.

Holistic Evaluation of Animal Well-being:

The assessment of animal welfare within virtual environments encompasses multifaceted aspects, including physical health, mental stimulation, social interactions, and overall behavioral patterns. Capturing the complexity of these factors in virtual settings is a challenging task, requiring extensive investigation to ensure a comprehensive understanding of the impact on animal well-being.

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Charting the Path Forward:

Given the nascent stage of research on virtual environments in animal farming, it is vital to emphasize the need for further exploration, validation, and collaboration across scientific disciplines. Full-scale studies conducted within commercial farms are essential to address existing knowledge gaps and provide tangible insights into the potential benefits and limitations of virtual environments as a substitute for traditional livestock practices.

More Enhanced space and freedom: Virtual environments can simulate outdoor grazing areas or natural habitats, allowing animals to move around and engage in natural behaviors. For example, an indoor farm with limited space can utilize augmented reality to create the illusion of a larger, more natural environment for the animals. This approach encourages the expression of species-specific behaviors, such as grazing, foraging, and social interactions, which contribute to an animal's overall psychological and physical health.

In a study by Klaas et al. (2021), it was demonstrated that providing virtual environments for poultry significantly reduced stress levels and increased the occurrence of natural behaviors, such as scratching and dust-bathing. These findings suggest that implementing virtual environments in livestock farming can offer animals an enhanced sense of space and freedom, contributing to better welfare and quality of life.

Reduced stress and anxiety: Virtual environments have been found to reduce stress and anxiety in animals, leading to significant improvements in their welfare. By simulating comfortable and natural settings, these environments help alleviate the negative effects of confinement and isolation often experienced by animals in conventional farming systems.

A study by Norouzi et al. (2022) investigated the impact of virtual environments on the stress and anxiety levels of animals in indoor farming settings. The researchers found that animals exposed to virtual environments, which replicated their natural habitats, exhibited lower levels of stress and anxiety compared to those housed in traditional confinement conditions. This reduction in stress and anxiety was attributed to the animals' ability to engage in species-specific behaviors, experience a more stimulating environment, and avoid the stressors commonly associated with confinement.

Improved health and nutrition: Virtual environments, incorporating the concept of digital twins, have the potential to offer a range of tools and capabilities for monitoring and optimizing animal health and nutrition. By leveraging advanced technology, these environments create digital replicas of individual animals, providing valuable insights into various aspects of their health, such as feed intake, disease detection, and targeted treatments.

Digital twins in virtual environments can be equipped with sensors and monitoring devices to track individual animals' feed intake, ensuring that each animal receives the appropriate nutrition according to their needs. This information can be crucial in detecting undernourishment, overfeeding, or nutrient imbalances, allowing farmers to adjust their feeding strategies accordingly. In scenarios where feed and nutrient intake can be closely monitored through virtual environments, farmers can optimize the animals' diets as a tailored nutrition possibility to support their immune systems, further reducing their dependence on antibiotics.

Early detection of diseases is another critical aspect of animal health that can be supported by virtual environments using digital twins. Technologies such as thermal imaging cameras, wearable sensors, and acoustic monitoring systems can be employed to identify early signs of illness, stress, or discomfort in animals. By recognizing these issues at an early

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stage, farmers can implement targeted interventions and treatments to prevent further health complications and ensure optimal welfare.

Decreased use of antibiotics: Virtual environments can facilitate a reduction in antibiotic usage in animal farming by improving animal welfare and reducing disease prevalence. The benefits of this approach can be observed in various circumstances and scenarios:

Stress reduction: In farming environments where animals are kept in confined or crowded conditions, stress can compromise their immune systems, making them more susceptible to diseases. By using virtual environments to simulate more comfortable and natural surroundings, stress levels can be reduced, enhancing the animals' immune response and decreasing their reliance on antibiotics (Fejzic et al., 2019).

Early disease detection: Virtual environments, equipped with various monitoring technologies, can assist in the early detection of diseases or health issues. By identifying signs of illness or stress at an early stage, farmers can implement targeted interventions to prevent further health complications and reduce the need for antibiotics.

Improved biosecurity: Virtual environments can enable remote monitoring of animal health and welfare, reducing the need for physical contact between humans and animals. This can help maintain biosecurity, minimize the risk of pathogen transmission, and ultimately decrease the reliance on antibiotics.

Example: In a dairy farm setting, virtual environments can be integrated with wearable sensors on cows, such as collars or ear tags, which continuously monitor their health parameters, such as body temperature, heart rate, and rumination patterns. The collected data can be analyzed in real-time and visualized within the virtual environment, enabling farmers and veterinarians to remotely monitor the health and welfare of the animals without the need for physical contact.

In cases where the sensor data indicates signs of illness or distress, such as fever or reduced rumination, farmers and veterinarians can respond promptly by examining the affected animals and initiating appropriate interventions. This early detection and targeted intervention can help minimize the spread of diseases, maintaining overall herd health without resorting to blanket antibiotic treatments.

By reducing the need for physical contact, virtual environments and remote monitoring technologies can also help maintain biosecurity and minimize the risk of pathogen transmission, further decreasing the reliance on antibiotics in animal farming.

Enhanced research and development: Virtual environments provide a valuable platform for simulating various animal farming practices and evaluating their impact on animal welfare. By using these environments, researchers and farmers can test different scenarios and approaches, making it easier to develop more efficient and humane farming practices. This ultimately leads to improved animal welfare and reduced animal suffering.

A specific example of using virtual environments to evaluate the impact of animal farming practices on animal welfare is the simulation of various environmental enrichments and their effects on the behavior and well-being of pigs. In a virtual environment, researchers can create different simulated settings with varying levels of enrichment, such as different types of bedding, play objects, or social structures. By monitoring the virtual pigs' behaviors and stress levels in response to these enrichments, researchers can gain valuable insights into which enrichment strategies are most effective in promoting animal welfare. In this case, the virtual environment allows researchers to efficiently test a wide range of

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enrichment options without causing any harm or distress to real animals. By identifying the most beneficial and humane practices through these simulations, farmers can adopt these strategies on their farms, ultimately leading to improved animal welfare and reduced suffering.

Diminished animal cruelty: By simulating animal farming processes, virtual environments offer a more humane and ethical alternative to traditional methods. They enable researchers and farmers to study the effects of different practices on animal health without causing harm to real animals. Additionally, these environments can help identify and promote less invasive alternatives to painful physical interventions such as castration, tail docking, and dehorning. The potential for diminishing animal cruelty through metaverse reality in farming awaits further scientific validation.

A specific example of how virtual environments can help diminish animal cruelty is by simulating the impact of alternative methods to painful physical interventions like castration in pigs.

In a virtual environment, researchers can model the effects of different alternatives to surgical castration, such as immunocastration or the use of pain relief during the procedure. By comparing the simulated animals' stress levels, health, and behavioral responses to these alternatives, researchers can identify the most humane and effective methods to minimize the pain and distress associated with such interventions.

By utilizing virtual environments to study the impact of these alternatives on animal welfare, researchers can avoid causing unnecessary harm or distress to real animals. Once the most humane and effective alternatives are identified, farmers can adopt these practices on their farms, ultimately reducing animal suffering and promoting better welfare standards across the industry.

Increased public awareness and understanding: Virtual environments play a crucial role in fostering greater public awareness and understanding of animal welfare and ethical treatment in animal farming. These environments can offer immersive and realistic experiences of animal farming practices, allowing people to better understand the challenges and ethical considerations involved in livestock production. As a result, virtual environments can facilitate more informed and ethical decision-making among consumers, policymakers, and other stakeholders. One specific example of how virtual environments can foster greater public awareness and understanding of animal welfare and ethical treatment in animal farming is through the development of virtual reality (VR) farm tours.

For instance, a virtual reality farm tour could be designed to showcase the daily life of animals on a farm, highlighting different farming practices, living conditions, and the handling of animals. Users could wear VR headsets and experience a first-person perspective of the animal's environment, from housing and feeding to veterinary care and other welfare considerations. This immersive experience would allow users to better understand the complexities and challenges involved in livestock production and the importance of ethical farming practices.

By offering a realistic and engaging experience, virtual farm tours can help to bridge the gap between consumers and the agriculture industry, promoting greater transparency and understanding of how food is produced. This increased awareness can encourage consumers to make more informed and ethical choices regarding the products they purchase and can also inspire policymakers and other stakeholders to advocate for more humane and sustainable farming practices.

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2.1.5. Limitations and Drawbacks of the use of Virtual Environments for Animal Welfare

While the potential benefits of virtual environments for animal welfare and human-animal interactions are significant, it is crucial to carefully consider the limitations and ethical implications of these technologies.

Long-term Effects: Concerns exist regarding the potential long-term impacts of virtual environments on animal behavior and stress levels. Initial studies indicate that virtual environments can reduce stress levels and improve animal behavior, but the sustainability of these effects remains uncertain. There is a risk that prolonged exposure to virtual environments could lead to desensitization or habituation, ultimately harming animal welfare (Naik et al., 2019).

Scenario 1 - Virtual environments for poultry: In a poultry farm, a virtual environment is used to simulate natural surroundings such as variable daylight patterns and visual landscapes. Although the initial results show reduced stress and improved behavior, over time, the birds might become habituated to the virtual environment, diminishing the positive effects on their welfare. The long-term implications could include reduced adaptability to real-world stimuli, making the birds more susceptible to stress when faced with real-life challenges.

Scenario 2 - Enrichment for animals: In a farm animal husbandary, virtual environments are implemented to provide the animals with an enhanced and varied habitat that mimics their natural or outdoor environment. However, after prolonged exposure, the animals may become desensitized to the virtual stimuli, reducing the intended enrichment effect. This could lead to boredom, stress, and other behavioral issues, ultimately compromising the animals' welfare.

Scenario 3 - Training animals using virtual environments: In a livestock training program, virtual environments may be used to teach animals to perform certain tasks or behaviors. Initially, the animals respond positively and learn the desired behaviors. However, over an extended period, they may become desensitized or habituated to the virtual stimuli, rendering the training less effective. This could potentially lead to behavioral issues or difficulty in adapting to real-life situations, negatively impacting animal welfare.

Ethical Concerns: Ethical issues arise from the use of virtual environments in animal farming, particularly if employed to replace or reduce the need for physical environments. While virtual environments can enhance living conditions for animals, they may also justify the continued use of animals for human consumption without addressing underlying ethical concerns.

Scenario - Lab-grown meat production: Virtual environments are used to simulate animal behavior and physiology to optimize lab-grown meat production. While this could reduce the need for large-scale animal farming, it could also perpetuate the reliance on animals for human consumption without addressing the ethical concerns surrounding animal rights and exploitation.

Limited Impact: The metaverse's impact on animal welfare in the physical world may be limited if virtual environments are not combined with changes to farming practices. Although virtual environments can improve animal welfare, they may not address the root causes of animal suffering, which could be related to the broader animal farming system (Stowers et al., 2017).

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Scenario - Virtual environments for improved housing conditions: A virtual environment is used to simulate more natural surroundings in an industrial livestock farm, enhancing animal welfare on the surface. However, the animals are still subjected to the underlying issues of confinement, intensive production systems, and other stressors associated with industrial farming practices.

Scenario - Simulated free-range environments: Virtual environments are used to provide animals with the illusion of a free-range environment while they remain confined indoors. Although their immediate surroundings may seem more appealing, their physical freedom is still limited, and they may still suffer from stress or health issues related to confinement.

Cost and Accessibility: Implementing virtual environments in animal farming can be expensive and may not be accessible to all farmers, particularly smaller ones. Virtual environments necessitate significant technological infrastructure and may require specialized skills and resources (Bower et al., 2020).

Scenario - Small-scale farmers: A small-scale farmer struggles to implement virtual environments for their livestock due to the high costs associated with setting up and maintaining the necessary technological infrastructure. This could lead to a disparity in animal welfare improvements, where only large-scale farms with more resources can benefit from such technologies.

Scenario - Developing countries: Farmers in developing countries may lack access to advanced technology, reliable internet connections, or the necessary training to implement virtual environments effectively. This may result in limited adoption of virtual environments in these regions, leaving the potential benefits of improved animal welfare unattainable for many farmers and their animals.

Potential for Misrepresentation: Virtual environments can misrepresent animal behavior or their environment, leading to inadequate decision-making by farmers. While virtual environments can simulate natural habitats for animals, they may not accurately replicate real-life environments' complexity and subtleties (Neo et al., 2021).

Scenario - Inaccurate simulation of animal social interactions: A virtual environment simulates a social structure for a group of pigs, but it fails to accurately represent the subtle complexities of their real-life social interactions. This leads farmers to make misguided decisions on group dynamics and housing arrangements, inadvertently causing increased stress and aggression among the animals.

Scenario - Misrepresentation of environmental conditions: A virtual environment is used to monitor temperature and humidity levels in a poultry farm. However, due to technical limitations, the simulation does not accurately represent the microclimates within the farm, leading the farmer to make suboptimal adjustments to ventilation or heating systems. This results in adverse impacts on the welfare of the animals due to inadequate environmental conditions.

Lack of Physical Stimulation: Virtual environments may not offer the same level of physical stimulation as real-life environments, potentially negatively affecting animal welfare. Animals in virtual environments may become bored or frustrated due to a lack of natural stimuli such as sunlight, wind, or natural substrates. This may impact their physical health, including musculoskeletal development or immune function, as they may be unable to engage in natural behaviors such as running, climbing, or grazing (Sagehorn et al., 2023).

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Scenario - Insufficient opportunities for exercise: A group of dairy cows is kept in a virtual environment that simulates grazing but does not provide enough physical space for the animals to move around and exercise. Over time, the lack of physical activity affects their musculoskeletal health, leading to issues such as lameness and joint problems.

Scenario - Absence of natural stimuli: Birds kept in a virtual environment designed to mimic a forest habitat lack exposure to natural elements such as wind, sunlight, and branches to perch on. This absence of natural stimuli impacts their immune function and psychological well-being, leading to increased stress and susceptibility to diseases.

3. Sensor Data and Livestock Behavior

The integration of sensor data and livestock behavior analysis in animal farming has the potential to revolutionize the industry by providing real-time information on animal health and welfare, optimizing productivity, and promoting sustainable practices (Neethirajan, 2020; Neethirajan and Kemp, 2021).

3.1. Types of sensors used in animal farming

Advancements in sensor technology have led to the development of various types of sensors, which can be categorized into the following groups:

a) Wearable sensors: These sensors are attached to the animal's body (e.g., collars, ear tags, leg bands) and can monitor vital signs, behavior, and location. Examples include accelerometers (Neethirajan, 2020), heart rate monitors (Neethirajan, 2023), and GPS trackers (Millward et al., 2020).

b) Non-wearable sensors: Installed in the farm environment, these sensors capture data on ambient conditions, such as temperature, humidity, and air quality. Examples include environmental sensors such as carbon dioxide, humidity sensors, temperature sensors (Kayad et al., 2020), thermal cameras (Colaco et al., 2023), and gas detectors (Niloofar et al., 2021).

c) Imaging sensors: These sensors capture visual information, such as animal posture and movement patterns. Examples include cameras, Kinect camera (Ruchay et al., 2020), 3D cameras (O'Mahony et al., 2019), LiDAR (Tamás et al., 2019), and computer vision algorithms (Neethirajan, 2022).

d) Acoustic sensors: These sensors monitor sounds produced by animals or their environment to detect stress (Ginovart-Panisello et al., 2020), vocalizations (Heuvel et al., 2022), or changes in ambient noise. Examples include microphones and ultrasonic sensors (Lee et al., 2019).

3.2. Monitoring animal behavior and health

Sensor technology can greatly enhance the ability to monitor animal behavior and health, contributing to improved welfare and productivity (Llonch et al., 2022).

a) Movement and activity: Accelerometers and GPS trackers can provide data on an animal's movement patterns, activity levels, and location. This information can help identify changes in behavior that may indicate health issues, stress, or welfare concerns.

b) Physiological parameters: Wearable sensors can monitor vital signs, such as heart rate, respiration rate, and body temperature. These data can provide early warning signs of illness, heat stress, or other health issues.

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c) Social behavior: Imaging and acoustic sensors can help observe social interactions among animals, which can be crucial for understanding group dynamics, preventing aggressive behaviors, and ensuring appropriate socialization (Neethirajan and Kemp, 2021b).

d) Feeding and drinking behavior: Sensors monitoring feed and water intake (Alameer et al., 2020) can provide insights into an animal's nutritional status and health. Changes in consumption patterns may indicate health problems, stress, or suboptimal environmental conditions.

e) Reproductive behavior: Sensors can help monitor reproductive behaviors, such as mounting or estrus detection, leading to improved breeding efficiency and success (Neethirajan and Kemp, 2021C).

f) Detection of health issues: Sensor data can be combined with machine learning algorithms to predict or detect health issues, such as lameness (Fioranelli et al., 2019), mastitis (Silva et al., 2021), or respiratory diseases (Poulopoulou et al., 2019), allowing for early intervention and treatment.

3.3. Assessing environmental conditions and their impact on livestock

Environmental sensors play a critical role in assessing and managing the conditions in which animals are housed. These sensors can help monitor and control various factors that impact animal welfare and productivity.

a) Temperature and humidity: Sensors can measure ambient temperature and humidity, ensuring that animals are kept within their thermal comfort zone. This information can be used to adjust heating, ventilation, and air conditioning (HVAC) systems, preventing heat stress or cold stress and promoting optimal growth and health.

b) Air quality: Gas detectors and particulate matter sensors can monitor air quality by measuring levels of gases (e.g., ammonia, carbon dioxide) and airborne particles (e.g., dust). Poor air quality can cause respiratory issues and stress in animals, leading to reduced productivity and increased susceptibility to disease.

c) Lighting: Light sensors can help optimize lighting conditions, which can impact animal behavior, circadian rhythms, and reproductive success. For instance, adjusting light intensity and duration can influence the laying patterns in poultry or promote rest and relaxation in dairy cows.

d) Noise levels: Acoustic sensors can measure ambient noise levels in the farm environment. Excessive noise can cause stress and negatively affect animal behavior, health, and productivity. By identifying sources of noise pollution, farmers can implement mitigation strategies to minimize its impact on livestock.

e) Space utilization: Imaging sensors and spatial computing technology can provide insights into how animals utilize their environment. This information can help identify overcrowding or underutilized areas and inform decisions on optimizing pen design, stocking density, and enrichment strategies.

f) Weather and outdoor conditions: Sensors monitoring weather conditions (e.g., rainfall, wind speed, solar radiation) can help inform decisions on animal management in outdoor systems, such as grazing or shelter provision.

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Metaverse can be used to create virtual training programs for farmers and veterinarians to learn how to identify and treat livestock illnesses in a realistic, simulated environment. This would not only improve the efficiency of disease diagnosis and treatment but also minimize the need for invasive procedures on live animals during the training process.

Another practical scenario could involve using the metaverse to simulate different environmental conditions, allowing farmers to assess the potential impact of various climate changes or farming practices on animal welfare and productivity without causing any harm to real animals. This could help farmers make more informed decisions about their management strategies, taking into account potential risks and benefits.

3.4. Sensor Fusion and Multimodal Integration

Here, I highlight the potential of combining various technologies and data sources to enhance the overall experience of animal farming within the metaverse. These technologies are currently in various stages of development and implementation, with some being more widely accessible to the livestock industry than others. In this section, we discuss specific technologies, such as predictive analytics, computer vision algorithms, and deep learning-based sound processing, which are used to improve virtual farming experiences. Additionally, we explore the role of personalization tools, spatial computing technology, and geolocation data in creating immersive, interconnected virtual farming worlds.

The integration of real-time predictive analytics, simulation modeling tools, and computer vision algorithms enabled by the sensor data has the potential to shape immersive experiences throughout the animal farming journey. By deploying farm animal behavior analytics, social network capabilities, and deep learning-based ambient sound processing in immersive 3D virtual environments, virtual content optimization can be achieved for metaverse events related to animal farming.

Movement and behavior tracking tools, spatial computing technology, and geolocation data are pivotal in animal farming digital engagement across virtual animal husbandry environments. Personalization tools articulate multi-sensory farmer and farm animal experiences, and provide insights into animal nutrition, behavior, reproduction, and habits in virtual farms and immersive virtual interconnected farming worlds.

The use of analytics in immersive hyper-connected virtual spaces enables seamless user engagement processes in immersive virtual environments. Deep learning-based ambient sound processing and real-time sensor data integration can further enhance immersive farming activity and farm management experiences in extended reality settings.

Data-driven artificial intelligence, virtual navigation tools, computer vision algorithms, and playful behavior enrichment or enhancement technologies play a crucial role in creating immersive and responsive environments that promote animal welfare, productivity, and sustainability. These technologies, when combined with ethical considerations, can revolutionize animal farming within the metaverse.

3.4.1. Practical Materialization of the Concept “virtual environment”

The practical materialization of a virtual environment involves the implementation of technologies and systems that create immersive and interactive virtual spaces. Here are some practical elements that contribute to the materialization of a virtual environment:

Virtual Reality (VR) Hardware: VR headsets, such as Oculus Rift, HTC Vive, or PlayStation VR, provide users with an immersive visual and auditory experience

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(Elmqaddem, 2019) by blocking out the physical world and replacing it with a simulated environment. These headsets typically consist of high-resolution displays, motion tracking sensors, and audio systems.

Virtual Reality Software: Software platforms and applications specifically designed for virtual reality enable the creation and rendering of virtual environments. These platforms allow developers (Du et al., 2020) to design and build interactive spaces, incorporate realistic graphics, and implement user interactions within the virtual environment.

Simulated Spaces and Objects: Virtual environments are designed to replicate physical spaces or create entirely new digital worlds. These spaces can range from realistic representations of existing locations to fantastical realms (Bolter et al., 2021). Simulated objects within the virtual environment can include landscapes, buildings, animals, and other elements that provide a sense of presence and interactivity.

User Interactions: To enhance the sense of immersion, virtual environments enable users to interact with the simulated world (Monteiro et al., 2021). This can include gestures, hand controllers, voice commands, or even full-body tracking systems. Users can navigate within the virtual space, manipulate objects, communicate with other users, and perform various actions based on the capabilities of the virtual environment.

Real-Time Rendering and Physics Simulations: To create a seamless and realistic experience, virtual environments employ real-time rendering techniques to display high-quality graphics and animations (Friston et al., 2021). Physics simulations are utilized to simulate object interactions, movements, and environmental effects such as gravity, wind, and lighting.

Networking and Multiplayer Support: Virtual environments can be shared among multiple users, enabling collaborative experiences and social interactions. Networking technologies allow users to connect (Li et al., 2023), communicate, and interact with each other within the virtual environment, fostering a sense of presence and shared experiences.

Content Creation and Development Tools: Tools and software frameworks are used to create and develop virtual environments. These tools facilitate the creation of 3D models, textures (Farooq et al., 2022), animations, scripting, and logic systems required to build interactive and engaging virtual spaces.

By combining these practical elements, virtual environments can be materialized, providing users with immersive, interactive, and visually appealing experiences in simulated digital worlds. The implementation of virtual reality hardware, software, simulated spaces, user interactions, real-time rendering, networking (Wu et al., 2023), and content creation tools all contribute to the practical materialization of virtual environments.

4. Ethical Implications of Metaverse in Modern Animal Farming

Ethical Concerns: The metaverse's use in animal farming can lead to the potential commodification and objectification of animals in the virtual world. This disconnect may result in a lack of empathy and understanding of animal needs, normalizing unethical practices such as genetic modification or invasive procedures without proper justification (Rollin, 2011). However, it is essential to recognize that virtual and augmented reality technologies are not inherently unethical. These transformative technologies have the remarkable potential to awaken our empathy and foster a profound understanding of animals in extraordinary ways. By immersing ourselves in simulated environments that mirror the wild, we can embark on an enlightening journey to unravel the intricate behaviors

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and unspoken needs of these remarkable creatures (Bertrand et al., 2018). Through this experiential lens, we open the door to a deeper connection and a renewed sense of reverence for the natural world and its magnificent inhabitants.

Accountability and Responsibility: As the lines between virtual and physical worlds blur, questions arise about accountability and responsibility in modern animal farming. It may become more challenging to hold individuals and corporations accountable for their actions, such as cruel or unethical treatment of animals in the metaverse. Determining responsibility and accountability for such behavior can be problematic. The metaverse discussed so far is built upon information from actual animals rather than purely fictional or non-player characters (NPCs) in a video game. The mention of blurred lines between the virtual and physical worlds refers to the potential challenges that may arise in determining responsibility and accountability when it comes to the ethical treatment of animals. For example, if an individual mistreats a virtual representation of a real animal in the metaverse, questions might emerge about the ethical implications and the extent to which this behavior can be punished or regulated. It is crucial to establish appropriate guidelines and regulations for such scenarios in the metaverse to ensure that ethical considerations are upheld, and animal welfare remains a priority.

The Potential for Positive Impact: The metaverse's use in modern animal farming is not inherently unethical. Virtual reality and augmented reality technologies can provide new ways of interacting with animals and promoting empathy and understanding. Simulating the experiences of animals in the wild can allow people to gain a deeper understanding of their behaviors and needs. It is crucial to ensure that these technologies follow ethical principles that prioritize animal well-being and dignity and that they do not perpetuate a culture that normalizes animal exploitation and neglect.

4.1. Socio-Economic Implications of Metaverse in Modern Animal Farming

The Cost Reduction and Efficiency: While the initial investment in implementing virtual environments may be costly, they have the potential to reduce long-term costs associated with traditional farming practices (Klerkx et al., 2019). Virtual environments can optimize resource utilization, such as feed, water, and energy, leading to reduced expenses. By accurately tracking and adjusting the dietary needs of individual animals, virtual environments can minimize waste and improve feed efficiency, ultimately lowering the cost of feed. Additionally, virtual environments can enable proactive health monitoring, early disease detection, and targeted treatments, reducing veterinary expenses and improving overall animal health and productivity.

Increased Productivity and Profitability: Virtual environments have the capacity to enhance productivity and profitability in animal farming. By providing real-time data and analytics, virtual environments enable farmers to make informed decisions regarding herd management, breeding programs, and optimal resource allocation. This improves operational efficiency, reduces losses, and enhances overall productivity (Javaid et al., 2022). Virtual environments can also facilitate precision farming techniques, allowing farmers to maximize yields while minimizing input costs. These factors contribute to improved profitability in animal farming.

Shift in Traditional Farming Practices: The adoption of virtual environments may bring about changes in traditional farming practices (Castiblanco Jimenez et al., 2020), potentially affecting the job market for farmers. While it is true that there could be some job losses in certain sectors, the emergence of the metaverse also creates new opportunities in the tech and virtual farming industries. Farmers and industry professionals can adapt

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their skills to work in areas such as data analysis, virtual environment management (Steffen et al., 2019), and technology support, opening up new avenues for employment.

Digital Divide and Accessibility: The metaverse's widespread use in animal farming may exacerbate the digital divide between large and small-scale farmers (Gillpatrick et al., 2022). Small-scale farmers may lack the necessary resources to access and utilize virtual environments, putting them at a disadvantage compared to larger farms with the means to invest in such technologies. Consequently, this disparity could widen the gap between small and large-scale farms and further strain the livelihoods of small-scale farmers.

Public Perception and Trust: The integration of the metaverse into animal farming can influence public perception and trust in the industry. While virtual environments have the potential to improve transparency and awareness of animal welfare issues, they could also lead to skepticism regarding the authenticity of the information presented. Ensuring that virtual environments accurately represent farming practices and animal welfare will be crucial in maintaining public trust and promoting ethical consumption.

Regulatory and Legal Considerations: The metaverse's implementation in animal farming will require the development of new regulatory frameworks and legal structures to govern its use and address potential ethical concerns. Policymakers and stakeholders will need to collaborate to establish guidelines and regulations that ensure the responsible application of virtual environments in animal farming while safeguarding animal welfare, farmer livelihoods, and consumer interests.

Education and Training: The adoption of the metaverse in modern animal farming necessitates new educational and training programs to equip farmers and industry professionals with the skills and knowledge required to navigate and utilize virtual environments effectively. The development of specialized courses, workshops, and resources can help facilitate the transition to virtual farming practices and ensure that farmers can maximize the benefits of these technologies for animal welfare and farm productivity.

Ethical Consumerism: The metaverse's use in animal farming can contribute to the rise of ethical consumerism by providing consumers with immersive experiences that raise awareness of animal welfare issues and sustainable farming practices. These experiences can influence consumer behavior and promote the demand for ethically produced animal products, driving the industry towards more humane and environmentally friendly practices. However, it is essential to balance the promotion of ethical consumerism with the need to maintain an accurate representation of animal farming practices and avoid potential misrepresentation or greenwashing.

4.2. Economic Impact of Virtual Environments on Animal Farming

The use of virtual environments in animal farming can have a significant economic impact on the industry. Virtual environments can help to reduce costs associated with traditional farming practices, while also increasing efficiency, productivity, and profitability. It is important to note that the initial high costs expenses can be offset over time through the efficiency and cost-reduction capabilities of virtual farming environments.

cost

In addition to reducing the cost of inputs, virtual environments can also help to reduce the need for expensive medication and other treatments. By creating more sustainable and healthy farming systems, virtual environments can help to reduce the incidence of disease and other health problems in animals, which can be a significant expense for

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farmers. This can help to reduce the cost of animal healthcare and increase the profitability of animal farming. However, there are also economic costs associated with the adoption of virtual environments in animal farming. The adoption of new technologies, such as virtual environments, can require significant investment in terms of equipment, software, and training. This can be a significant barrier for some farmers, particularly small-scale farmers who may struggle with the costs of adopting new technologies.

Moreover, the adoption of virtual environments may also have implications for the labor force in animal farming. While virtual environments may reduce the need for labor in some aspects of animal farming, such as feeding and monitoring, they may also require new types of labor, such as software engineers and virtual environment designers. This can lead to a shift in the types of jobs available in animal farming and may require farmers and other stakeholders to adapt to new forms of labor and technology.

The economic benefits (Table 1) can help farmers to increase profitability and make animal farming more accessible and affordable for small-scale farmers. By adopting virtual environments, farmers can drive sustainable value and create a more ethical and sustainable animal farming system.

Table 1: Economic Impact of Virtual Environments on Animal Farming

Impact	Description	Potential Benefits
Cost Reduction	Reduction in the cost of feed and other inputs by creating more efficient and sustainable farming systems. Optimization of the use of feed by tracking the dietary needs of individual animals and adjusting their feed accordingly, which can reduce 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. This can increase productivity, efficiency and profitability, and make animal farming more accessible and affordable for small-scale farmers.	Increased productivity and profitability, more accessible and affordable animal farming.
Sustainability	Can promote sustainability by reducing the environmental impact of traditional farming practices. By creating more sustainable and environmentally-friendly farming systems, virtual environments can reduce the negative impact of animal farming on the environment, while also promoting more ethical and sustainable farming practices.	Reduced environmental impact, promotion of more ethical and sustainable farming practices.
Animal Welfare	Virtual environments can help farmers monitor their animals' behavior and health, enabling early intervention and reducing stress. By improving animal welfare, farmers can create value and gain a competitive advantage in the market.	Improved animal welfare, creation of value and competitive advantage.

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Impact	Description	Potential Benefits
Data Analysis	Virtual environments 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, leading to increased productivity and profitability.	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 virtual environments. By providing farmers with the necessary resources, they can maximize the benefits of virtual environments and drive sustainable value.	Increased skills and knowledge, maximized benefits of virtual environments, 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. By working together, stakeholders can develop innovative solutions to improve animal welfare, increase productivity, and promote sustainable agriculture.	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 to maintain their credibility and access to markets.	Maintained credibility, access to markets.
Technological Advancements	By adopting new technologies, such as artificial intelligence and machine learning, farmers can optimize their production processes, reduce costs, and increase efficiency.	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 about their farming practices, farmers can build trust and loyalty, leading to increased demand for their products.	Increased demand for products, trust and loyalty from customers.

4.3. Strategies For Creating Economic Opportunities and Sustainable Value in Virtual Farming:

The use of virtual environments, advanced sensor technologies, and livestock behavior analysis within the metaverse has the potential to revolutionize livestock management

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and monitoring (Figure 1). By leveraging these tools, data-driven decision-making can optimize animal health, productivity, and environmental impact, promoting ethical and sustainable practices in the animal farming sector.

Improve Animal Welfare: Virtual environments enable farmers to monitor and intervene early in their animals' behavior and health, reducing stress and creating value. Enhancing animal welfare not only benefits the animals but also provides a competitive advantage in the market.

Increase Productivity with Data: Virtual environments generate extensive data that farmers can analyze to optimize production processes, reduce waste, and increase efficiency. By identifying areas for improvement through data analysis, farmers can enhance productivity and profitability.

Invest in Training and Education: Providing farmers with training and education in utilizing virtual environments is crucial. By equipping them with the necessary skills and knowledge, farmers can maximize the benefits of virtual environments and drive sustainable value creation.

Collaborate with Stakeholders: Collaboration with stakeholders such as animal welfare advocates, food safety experts, and technology providers is key. By leveraging their expertise, farmers can develop innovative solutions to improve animal welfare, increase productivity, and promote sustainable agriculture.

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Ensure Regulatory Compliance: Regulatory compliance is essential for the long-term sustainability of virtual livestock farming. Adhering to regulations governing animal welfare, food safety, and data privacy maintains credibility and market access.

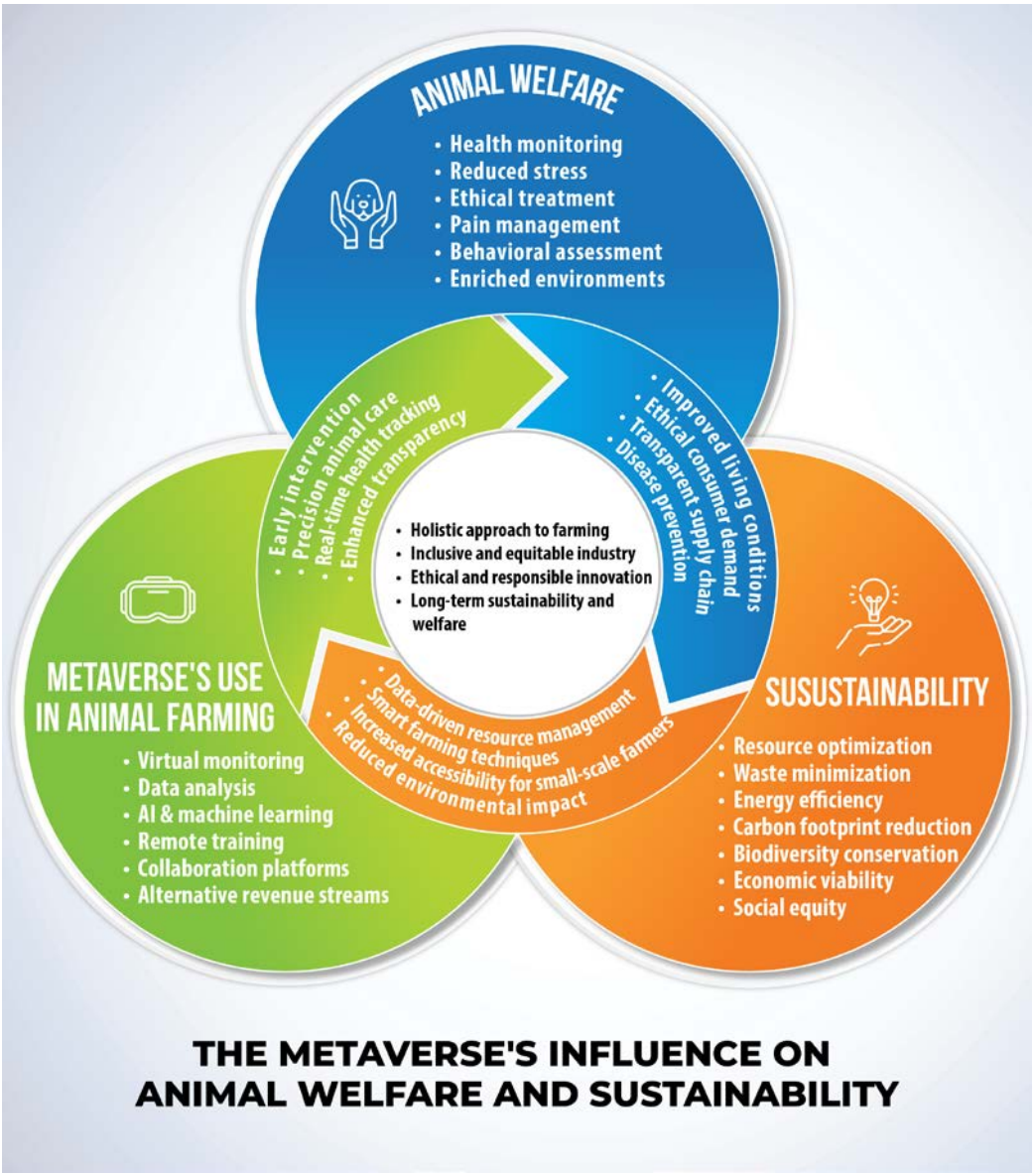

Figure 1. The Metaverse's influence on animal welfare and sustainability.

Embrace Technological Advancements: To stay competitive, farmers must embrace technological advancements such as artificial intelligence and machine learning. Adopting these technologies optimizes production processes, reduces costs, and increases efficiency.

Build Customer Relationships: Fostering relationships with customers is vital for sustainable value creation. By engaging with customers and providing transparent information about farming practices, farmers can build trust, loyalty, and increase demand for their products.

Consider Alternative Revenue Streams: Virtual livestock farming opens up new revenue streams, such as selling access to data or providing consulting services. Diversifying

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revenue streams reduces reliance on traditional farming practices and creates more sustainable business models.

Promote Environmental Sustainability: Virtual livestock farming contributes to environmental sustainability by reducing the carbon footprint of the agricultural industry. Optimizing production processes and minimizing waste helps create a more sustainable food system.

5. Social Implications of Virtual Environments for Animal Farming

The use of virtual environments in animal farming can also have significant social implications, affecting a range of stakeholders, including farmers, consumers, and animal welfare advocates.

The adoption of virtual environments can offer a range of mainly economic benefits, including increased efficiency and profitability, as well as reduced labor costs to the farmers, this has clear social implications and it can help to make animal farming more accessible and profitable for small-scale farmers, as well as larger commercial operations. Additionally, the use of virtual environments may allow farmers to meet the growing demand for sustainably produced and ethically sourced food, which is becoming increasingly important to consumers.

Consumers may also benefit from the use of virtual environments in animal farming, as it can provide greater transparency and traceability in the food supply chain. By tracking the dietary needs and health of individual animals, virtual environments can help to ensure that food products are produced in a safe, ethical, and sustainable manner. This can also help to increase consumer confidence in the food supply chain, which is becoming increasingly important in the wake of food safety scandals and concerns about animal welfare.

Higher efficiency and productivity of animal farming operations, also, influence food industry and security, both locally and globally. By allowing for greater control over animal nutrition, health, and living conditions, virtual environments can help to reduce the risk of disease outbreaks and other issues that can negatively impact animal welfare and productivity. This can help to increase the overall supply of food products, which is particularly important in regions where food security is a concern.

5.1. Role of Virtual Environments in Creating New Forms of Value Distribution And Accessibility

The adoption of virtual environments in animal farming has the potential to create new forms of value distribution and accessibility. This can enable greater access to food and promote a more equitable distribution of value across the industry stakeholders.

One way in which virtual environments can facilitate value distribution is by increasing the efficiency of distribution systems. By creating more accurate and real-time data on production, farmers can better manage their resources, optimize their operations, and speed up processes. This can lead to increased yields, improved quality, and lower costs of production, which can be passed on to consumers in the form of more affordable food and better distribution.

Moreover, the use of virtual environments can promote a more equitable distribution of value across the supply chain. By providing farmers with greater transparency and data

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on the price of their products, they can negotiate fairer prices with distributors and retailers, reducing the concentration of power in the hands of large agribusinesses.

5.2. Inclusion, Equity, and Governance in the Metaverse

The discussion on inclusion, equity, and diversity in the metaverse and animal farming highlights the importance of considering the socio-economic impact of virtual environments and the need to ensure that these technologies are developed and used in ways that are socially responsible and sustainable.

By involving a wide range of stakeholders in the development and use of virtual environments, including farmers, animal welfare experts, technology experts, policymakers, and members of the public, it is possible to identify potential biases or unintended consequences of virtual environments and to develop solutions that address them. This can help to ensure that the benefits of virtual environments are shared equitably and that vulnerable groups are not left behind.

Moreover, the cost and accessibility, as previously discussed, of virtual environments in animal farming can have significant socio-economic implications. Ensuring that virtual environments are designed and used in ways that are inclusive and equitable can help to address these concerns and to ensure that virtual environments do not exacerbate existing socio-economic inequalities.

5.3. Potential for Virtual Environments to Promote Inclusion, Equity, And Diversity

In traditional animal farming, there are often barriers to entry for small-scale farmers, particularly those from marginalized communities, due to the high costs of equipment, land, and other resources. In contrast, virtual environments have lower barriers to entry, as they can be accessed from anywhere with an internet connection and a computer. This could enable more diverse groups of people to enter the animal farming industry and increase equity.

However, there are also risks of perpetuating existing inequalities in animal farming through virtual environments. For example, if only those who have access to technology and the resources to invest in virtual animal farming can participate, then the digital divide could be further exacerbated. It is important to ensure that virtual animal farming is accessible to all, regardless of their socio-economic background.

In addition, it is important to consider the ethical implications of creating digital representations of farm animals. If virtual animals are designed to appeal only to certain demographics or perpetuate harmful stereotypes, this could have negative consequences for inclusion and diversity in animal farming.

Virtual environments have the potential to promote inclusion, equity, and diversity in animal farming by providing a platform for collaboration and knowledge sharing among stakeholders. These platforms can provide opportunities for small and marginalized farmers to participate in the industry and access new markets. Additionally, virtual environments can help break down language barriers by providing translation services, making it easier for farmers from different countries and backgrounds to communicate and share knowledge.

Virtual environments can also help to promote social equality and animal welfare by providing access to education and training. For example, virtual reality simulations can provide farmers with a safe and controlled environment to learn new techniques for

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handling and caring for animals. Additionally, virtual environments can help to increase public awareness and education around animal welfare issues, leading to more informed and responsible consumer behavior.

Moreover, farmers with mobility impairments may find it challenging to engage in traditional animal husbandry, such as physically herding livestock or cleaning animal enclosures. Virtual environments can provide a platform for these farmers to engage in animal farming in a way that accommodates their physical limitations. This can lead to greater inclusion of farmers with disabilities and promote greater equality in the industry.

The potential of virtual environments to promote inclusion, equity, and diversity in animal farming and to improve animal welfare is significant. It is important to consider the perspectives of various stakeholders, including farmers, consumers, and animal welfare advocates, in developing and implementing virtual environments in animal farming. By doing so, we can ensure that these technologies are used to promote the common good and contribute to a more sustainable and equitable agricultural industry.

6. Governance of Metaverse in Modern Animal Farming

Technology governance plays a significant role in ensuring that digital tools are deployed equitably and effectively (Matheny et al., 2019). Without proper governance, there is a risk that only large-scale, well-funded operations will be able to benefit from the advantages of virtual environments, exacerbating existing social and economic disparities. By promoting equity and inclusivity, technology governance can help ensure that the benefits of digital technologies are shared by all farmers, regardless of their resources or location.

Technology governance plays a crucial role in the socio-economic impact of virtual environments in livestock farming. It encompasses the policies, procedures, and regulations that guide the development and deployment of digital technologies, ensuring equitable access and promoting inclusivity.

In the context of virtual environments in animal farming, technology governance can ensure that all farmers have access to the necessary tools to improve animal welfare, increase productivity, and ensure food safety. This involves developing digital tools with input from all stakeholders, providing training and support for farmers, and establishing clear guidelines and regulations around the use of virtual environments.

Moreover, technology governance can ensure that the deployment of digital technologies does not exacerbate existing social and economic disparities. Governments can promote equity and inclusivity in the agricultural industry by providing subsidies or grants to farmers who lack the resources to purchase and implement virtual environments.

Animal welfare refers to the physical and psychological well-being of animals, encompassing their health, behavior, and quality of life. However, the perception and understanding of animal welfare can vary among different stakeholders, including producers, consumers, legislative bodies, and social structures worldwide. A comprehensive exploration of animal welfare involves examining contrasting viewpoints, evolving societal expectations, and incorporating the latest research, insights from industry experts, and emerging frameworks.

Contrasting Views on Animal Welfare:

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Animal welfare also encompasses a range of perspectives influenced by cultural, ethical, and economic factors. Contrasting viewpoints on animal welfare include:

Utilitarian Approach: Some stakeholders prioritize animal welfare based on the minimization of suffering and the promotion of overall well-being. They advocate for practices that reduce pain, provide adequate nutrition, and ensure appropriate housing conditions.

Rights-Based Approach: Another perspective advocates for recognizing animals as sentient beings with inherent rights. This viewpoint asserts that animals should be free from exploitation and harm, leading to a focus on ending practices such as intensive farming and animal entertainment.

Industry Considerations: Producers often face challenges in balancing animal welfare with economic viability. Economic factors, consumer demands, and productivity requirements can influence the implementation of animal welfare practices within the industry.

Evolving Societal Expectations:

Societal expectations regarding animal welfare have evolved over time. Key factors contributing to changing expectations include:

Ethical Considerations: Growing public awareness and ethical concerns have led to increased demands for more compassionate and responsible treatment of animals in various sectors, including farming, research, and entertainment.

Consumer Demand: Consumers are increasingly seeking products derived from animals raised in humane conditions. Animal welfare labels, organic farming, and free-range practices have gained popularity, reflecting changing consumer expectations.

Scientific Advances: Advances in scientific understanding of animal cognition, emotions, and behavioral needs have influenced societal expectations. Research has highlighted the importance of providing animals with opportunities for natural behaviors, minimizing stress, and ensuring social interaction.

Latest Research and Insights:

To gain a comprehensive understanding of animal welfare, researchers and industry experts have contributed valuable insights. Recent research and expert perspectives include:

Assessing Animal Sentience: Studies on animal cognition, neuroscience, and behavior provide evidence of animals' capacity to experience emotions, pain, and suffering. These findings inform the need for policies and practices that prioritize animal well-being.

Animal Welfare Assessment: Researchers worldwide have developed a series of assessment frameworks to evaluate animal welfare objectively. These frameworks consider indicators such as health, behavior, environmental conditions, and the animals' ability to express natural behaviors.

Impact of Housing and Management: Investigations into housing and management systems have shown that providing animals with appropriate space, enrichment, and social opportunities can enhance their welfare. Alternative systems, such as free-range and pasture-based farming, offer potential improvements.

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Emerging Frameworks and Future Directions:

Positive Welfare: The concept of positive welfare focuses not only on minimizing negative experiences but also on promoting positive experiences for animals. It emphasizes providing environments that enable animals to engage in natural behaviors, experience positive emotions, and have a good quality of life.

Technology Integration: Emerging technologies, such as precision farming, advanced sensors, and artificial intelligence, can aid in monitoring and enhancing animal welfare. These tools enable real-time data collection, behavioral analysis, and targeted interventions.

International Collaboration: Global organizations, such as the World Organisation for Animal Health (OIE), aim to develop and enforce animal welfare standards internationally. Collaboration across nations helps drive consistent improvements in animal welfare practices worldwide.

One of the key roles of governance in promoting animal welfare in the metaverse is to establish clear guidelines and regulations around the use of virtual environments in animal farming. These guidelines can help ensure that virtual environments are used responsibly and ethically and that the welfare of animals is prioritized. Governance can also promote transparency in animal farming by requiring the public disclosure of information related to animal welfare outcomes, building trust and confidence in the use of virtual environments in animal farming among all stakeholders.

6.1. Human-Animal Interactions in Virtual Farming

The interaction between animals and humans in virtual environments offers a fascinating avenue for research, delving into the realms of emotion bonding and empathy. While this field is still developing, scientific studies are shedding light on the mechanisms by which virtual environments can facilitate these connections, and how monitoring tools can contribute to the bonding between farmers and animals.

Virtual environments have the potential to create rich and immersive experiences that bridge the gap between animals and humans. Through visual representations, interactive behaviors, and even haptic feedback, virtual environments can simulate realistic encounters, fostering a sense of interaction and connection. These virtual interactions provide opportunities for farmers to observe and engage with animals (Neethirajan, 2021), allowing for direct observation of behaviors, needs, and emotional responses.

Scientific studies have explored the concept of emotion bonding and empathy in the context of animal interactions within virtual environments. Virtual interactions between humans and animals have the potential to evoke positive emotional responses (Barbot et al., 2020) and enhance empathy. By simulating realistic scenarios and behaviors, virtual environments can evoke emotional connections, leading to a deeper understanding of animal needs and emotions.

Monitoring tools play a crucial role in strengthening the bonding between farmers and animals within virtual environments. Advanced sensor technologies, such as accelerometers, heart rate monitors, and vocalization detectors, enable real-time monitoring of animal behavior, physiological states, and vocal cues. By analyzing these data, farmers can gain insights into the well-being of their animals, track changes in emotions and stress levels, and make informed decisions to optimize animal welfare.

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These monitoring tools not only provide valuable information about animal well-being but also facilitate bonding between farmers and animals. By having access to real-time data and insights, farmers can develop a deeper understanding of their animals' needs, recognize patterns, and establish a more empathetic connection. This knowledge enables farmers to respond promptly and appropriately to their animals' requirements, promoting a sense of care, trust, and well-being within the virtual environment.

However, it is important to acknowledge that virtual environments cannot fully replicate the depth and complexity of real-life interactions. The tactile and sensory experiences of physical interactions cannot be completely replicated virtually. Hence, the integration of virtual environments should be viewed as a supplement to real-world interactions, rather than a complete replacement.

Through immersive experiences, realistic simulations, and advanced monitoring tools, virtual environments provide unique opportunities to explore the emotional connection between farmers and animals. As this field continues to evolve, interdisciplinary research and collaboration are key to further understanding the intricacies of these interactions and harnessing the full potential of virtual environments in promoting animal welfare and optimizing the farmer-animal bond.

6.2. Role of empathy and emotional intelligence in virtual interactions with animals

The role of empathy and emotional intelligence is increasingly being recognized in virtual interactions with animals. As the world continues to move towards virtual and remote interactions, especially with the ongoing COVID-19 pandemic, people are increasingly turning to technology to interact with animals in a variety of contexts, such as virtual zoos, aquariums, and even pet therapy sessions.

Empathy is the ability to understand and share the feelings of others, and it is crucial in virtual interactions with animals because it allows us to connect with them emotionally. When we empathize with animals, we can see things from their perspective and understand their needs and wants (Fox, 2021). This can help us provide them with better care and improve our interactions with them.

Emotional intelligence is also important in virtual interactions with animals. Emotional intelligence is the ability to recognize and manage one's own emotions, as well as the emotions of others. In virtual interactions with animals, emotional intelligence allows us to regulate our own emotions, which can be helpful in situations where animals may be unpredictable or in cases where we may encounter an animal in distress.

In virtual interactions with animals, technology can provide a unique opportunity to connect with animals in a way that may not be possible in person. For example, virtual reality can allow us to experience what it is like to be in an animal's habitat, which can help us better understand their behavior and needs. Additionally, virtual interactions with animals can be a powerful tool for education and conservation efforts, as it allows people to connect with animals that may be endangered or difficult to see in person.

However, it is important to note that virtual interactions with animals should not replace in-person interactions or be the sole means of connecting with animals. In-person interactions provide important sensory information (Vigors and Lawrence, 2019) that is difficult to replicate virtually, such as the smells and sounds of an animal's environment. Additionally, in-person interactions allow for more meaningful connections and can provide a deeper understanding of an animal's behavior and needs.

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6.3. Trust and bonding between farmers and their animals in virtual environments

The importance of building trust and bonding between farmers and their animals in virtual environments cannot be overstated. With the rise of digital technologies, virtual interactions have become increasingly common in the agricultural industry, and farmers are turning to technology to connect with their animals remotely.

In the absence of physical proximity, farmers must rely on virtual tools to create a bond with their animals. This can be achieved through virtual tours, video calls, and live streaming of the animals. It is essential to establish a consistent routine for these interactions to ensure that the animals are comfortable and receptive to the virtual environment.

Building trust is a critical component of the bonding process. Farmers must be patient and take the time to understand their animals' behavior and body language, even in a virtual setting. This understanding can help farmers anticipate their animals' needs and respond appropriately, further strengthening the bond between them.

Moreover, farmers must create an environment that is conducive to their animals' well-being. This includes providing a comfortable space for them to rest, ensuring that they have access to water and food, and creating a safe and secure environment.

The ultimate goal of building trust and bonding between farmers and their animals is to improve animal welfare and productivity (Rault et al., 2020). A strong bond can help reduce stress, which can impact the animals' health and productivity. By creating a virtual environment that fosters trust and bonding, farmers can enhance their animals' welfare and ultimately improve their bottom line.

7. Designing Ethical Metaverse for Animal Farming

Virtual environments hold the potential to transform animal farming practices for both farmers and animals. However, it is important to recognize that the introduction of new technologies does not automatically address all concerns and challenges. Therefore, the development of an ethical metaverse must incorporate certain principles that have been established through prior discussions.

First, it is important to consider the both the physical and psychological well-being of the animals themselves. The virtual environment should be designed to meet the animals' basic needs, such as access to food and water, as well as space for movement and socialization. The virtual environment should also be free from stressors and potential harm to the animals.

Second, the ethical considerations for designing virtual environments for livestock farming include ensuring that the virtual environment is accessible to all animals, regardless of their age, size, or breed. This is particularly important in situations where certain animals are considered more valuable or desirable than others.

Third, virtual environments should be designed to promote animal welfare and reduce the overall suffering of animals in livestock farming. This can be achieved by designing virtual environments that provide animals with a sense of safety and security, as well as opportunities for natural behavior and enrichment.

Fourth, it is important to consider the ethical implications of virtual environments on human labor and employment. Virtual environments may have the potential to automate some tasks traditionally done by farm workers, which could lead to job displacement or

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changes in employment structures. It is important to consider the social and economic impact of these changes and to work towards creating equitable and just working conditions.

Fifth, virtual environments may have the potential to change the nature of human-animal interactions in livestock farming. As such, it is important to consider how the virtual environment might impact the relationship between humans and animals and to design the environment in a way that promotes positive interactions and relationships.

Table 2 summarizes the principles for designing an ethical metaverse for animal farming. It provides an overview of the key ethical considerations and principles that must be taken into account when developing and implementing virtual environments in animal farming. The table can be used as a quick reference guide for farmers, animal scientists, bioengineers, veterinarians, policymakers, consumers, and business-to-business clients who are interested in adopting virtual environments in animal farming, to ensure that ethical considerations are met, and the technology is used responsibly.

Table 2. *Principles for Designing an Ethical Metaverse for Animal Farming*

Principle	Description
Animal well-being	Virtual environments should meet the basic needs of animals such as access to food, water, space for movement, and socialization. The virtual environment should be free from stressors and potential harm to the animals.
Accessibility	The virtual environment should be designed to be accessible to all animals, regardless of their age, size, or breed.
Animal welfare	Virtual environments should be 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 virtual environments on human labor and employment should be considered, with a focus on creating equitable and just working conditions.
Human-animal interactions	Virtual environments should be designed to promote positive interactions and relationships between humans and animals.
Transparency and accountability	The virtual environment should 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.

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Principle	Description
Monitoring and evaluation	Regular monitoring and evaluation should be carried out to assess the impact of virtual environments on animal welfare.
Sustainability and environmental responsibility	Designers of virtual environments should consider the environmental impact of the system and take measures to minimize its footprint.
Accessibility	Virtual environments should 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	Virtual environments should 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	Virtual environments can provide farmers with a 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 in a way that reflects the needs and values of all stakeholders.

8. Best Practices for Virtual Environments that Promote Animal Welfare and More Efficient Farming

The urgency of exploring best practices for designing and implementing virtual environments that promote animal welfare, enhance agricultural efficiency, and contribute to a more sustainable and eco-friendly future cannot be overstated. As the world faces mounting challenges related to climate change, resource scarcity, and a growing global population, it is imperative that innovative solutions are developed to address these pressing concerns.

By leveraging cutting-edge technologies and adopting best practices in virtual environments, we can create a paradigm shift in the livestock farming industry. These practices will not only ensure the ethical treatment of animals but also optimize resource utilization, reduce environmental impacts, and improve overall agricultural efficiency. By investing

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in research and development, promoting innovation, and supporting the adoption of best practices in virtual environments, we can pave the way for a more sustainable and eco-friendly future in livestock farming. This will not only improve the well-being of animals but also contribute to global food security and economic growth, ensuring a better quality of life for all.

By creating virtual environments that simulate the natural conditions and behaviors of animals, farmers can provide them with better living conditions that align with their natural instincts and needs. In these virtual environments, animals can have access to spaces and features that mimic their natural habitats, such as appropriate space for movement, opportunities for social interactions, and access to natural lighting and environmental stimuli. By simulating these natural habitats, virtual environments can contribute to improving the overall well-being and welfare of the animals, ensuring that their physical and psychological needs are met.

Below provides a list of comprehensive guides to best practices for designing virtual environments that prioritize animal welfare and promote efficient farming.

Access to Food, Water, and Adequate Living Conditions

Animals in virtual environments must have access to an adequate supply of food and water that meets their nutritional needs. The virtual environment should simulate the animal's natural habitat, incorporating ample space, temperature control, ventilation, and lighting that mimic natural conditions. A diverse array of food sources should be provided, reflecting the unique dietary requirements of each animal species.

Space and Freedom of Movement

Ensuring animals have enough space to move around freely, stretch their limbs, and exhibit natural behaviors is crucial for their well-being in virtual environments. By providing adequate room for animals to move, interact, and socialize with one another, virtual environments can help reduce stress and improve overall animal welfare.

Health and Medical Care

Adequate health care must be provided to animals in virtual environments, mirroring the standards found in real-life farming. This includes regular check-ups and prompt medical attention for any health issues that may arise.

Reduction of Stress and Pain

Virtual environments must be designed to meet the physical and emotional needs of animals, minimizing stress and pain. By allowing animals to move freely, socialize, and interact positively with humans, virtual environments can provide a more humane and ethical living experience.

Catering to Animal-Specific Needs

Different animal species have unique needs and behaviors that should be considered in the design of virtual environments. For example, laying hens require nesting areas, while pigs need space to root and forage. Designing environments that cater to animal-specific needs can enhance animal welfare and promote ethical treatment.

Transparency and Accountability

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Virtual environments should adopt an open and transparent approach to their design, operation, and management. By being accountable to stakeholders, including farmers, consumers, and animal welfare advocates, virtual environments can help ensure ethical treatment and animal welfare.

Monitoring and Evaluation

Implementing Monitoring Systems: Virtual environments can utilize advanced sensor technologies to monitor animal behavior, health parameters, and environmental conditions. This allows for real-time monitoring and early detection of any issues that may affect animal welfare.

Regulatory Guidelines: Establishing clear guidelines and regulations specific to virtual farming ensures that animal welfare standards are enforced consistently. These guidelines can be developed in collaboration with animal welfare experts, industry stakeholders, and legislative bodies.

Promoting Sustainability and Environmental Responsibility

Designers of virtual environments must consider the environmental impact of the system and take measures to minimize its footprint. This includes reducing energy consumption, minimizing water usage, and managing waste production. Ultimately, virtual environments can play a significant role in promoting sustainability and environmental responsibility in animal farming, contributing to a more sustainable and eco-friendly future.

Increasing Accessibility

Virtual environments should 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. Virtual livestock farming could provide these individuals with an opportunity to participate in agriculture, promoting economic growth and improving food security.

Fostering Innovation

Virtual environments should create opportunities for innovation in the livestock farming industry. For example, the use of virtual environments could lead to the development of new technologies, such as sensors and artificial intelligence, which could improve the efficiency and effectiveness of livestock farming.

Enhancing Productivity

Virtual environments can provide farmers with a more efficient way of managing their livestock, enabling them to monitor their animals remotely and detect issues before they become significant problems. This approach can lead to increased productivity and efficiency, as farmers can make decisions based on real-time data, rather than relying on traditional methods.

Fostering Human Expertise

While emerging technologies can improve the efficiency of livestock farming, it is important to maintain a strong focus on human expertise and skills. This 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.

Encouraging Collaboration

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To ensure that the future of livestock farming in the metaverse remains focused on human needs, it is important to foster collaboration between farmers, scientists, and other stakeholders. This can help to ensure that new technologies and strategies are developed in a way that reflects the needs and values of all stakeholders.

Enforcing animal welfare in virtual environments requires a combination of monitoring, regulatory frameworks, thoughtful design, veterinary care, and measures to minimize stress and enhance positive experiences. By incorporating these measures, virtual environments can provide animals with a more humane and ethical living experience while maintaining their well-being.

Virtual environments have the potential to revolutionize the livestock farming industry by promoting animal welfare, enhancing agricultural efficiency, and contributing to a more sustainable and eco-friendly future. By implementing best practices in the design and management of virtual environments, we can ensure that these systems prioritize animal welfare, while also fostering innovation, collaboration, and human expertise. As the metaverse continues to expand, it is crucial that we seize this opportunity to reshape the livestock farming industry in a way that benefits animals, farmers, and the environment alike.

9. The Future of Farming

The future of livestock farming in the metaverse is full of potential and promise. By embracing new technologies and practices, we can transform the industry for the better, improving efficiency, productivity, and sustainability, while also enhancing animal welfare and human well-being. Emerging technologies, such as artificial intelligence (AI) and robotics, have the potential to revolutionize the livestock farming industry (Neethirajan & Kemp, 2021). These technologies can be used to improve the efficiency, productivity, and sustainability of livestock farming, while also enhancing animal welfare. Here are some examples of how these technologies can be used in livestock farming:

Artificial intelligence (AI): AI can be used to monitor and analyze data from livestock farms, providing farmers with real-time insights into animal health, behavior, and productivity. This can help farmers make informed decisions about breeding, feeding, and other aspects of livestock management. For example, AI can be used to predict the onset of disease, enabling farmers to take early action to prevent an outbreak.

Robotics: Robotics can be used in various aspects of livestock farming, from feeding and cleaning to milking and shearing (Lovarelli et al., 2020). Robotic milkers, for example, can milk cows more efficiently and with less stress for the animals. Robotic feeders can provide animals with precise amounts of feed, reducing waste and improving efficiency.

Sensors: Sensors can be used to monitor various aspects of animal health and behavior, such as temperature, heart rate, and activity level (Neethirajan, 2020). This information can be used to identify potential health issues or stressors, enabling farmers to intervene early and improve animal welfare.

Smart farming systems: Smart farming systems combine various technologies, such as AI, robotics, and sensors, to create a comprehensive system for managing livestock farms (Neethirajan, 2023). These systems can provide farmers with real-time data and insights, enabling them to make informed decisions and improve efficiency.

Precision (or) Digital Livestock Farming: Precision agriculture uses technologies such as GPS and remote sensing to create precise maps of farms, enabling farmers to manage their

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land and resources more efficiently. This can lead to reduced inputs, such as water and fertilizer, while also improving productivity and reducing environmental impact.

One of the most promising areas of development in virtual livestock farming is the use of artificial intelligence and robotics. These technologies have the potential to revolutionize the industry, improving efficiency, productivity, and sustainability, while also enhancing animal welfare. For example, AI systems can be used to monitor and manage animal health and nutrition, while robotics can be used to automate tasks such as feeding and cleaning. However, it is important to ensure that these technologies are developed responsibly and sustainably, with a focus on human values and needs, as well as the welfare of animals, according to the aforementioned principles.

Navigating the ethical spectrum of metaverse implementation in animal farming requires balancing technological advancements with animal welfare, environmental sustainability, and societal values (Figure 2). As the metaverse transforms the agricultural landscape, it is crucial to prioritize ethical practices, maintain public trust, and ensure that the adoption of such technologies does not compromise the well-being of animals or the ecosystem. Engaging in open, multidisciplinary dialogue among stakeholders, from farmers to policymakers, will pave the way for responsible, conscientious integration of metaverse technologies in modern animal farming.

Figure 2. The ethical spectrum of metaverse in modern animal farming.

While the research landscape on metaverse applications in modern animal farming is still in its infancy, our technology forecast paves the way for a future where visionary possibilities become tangible realities. By embracing the metaverse's transformative capabilities, we unlock the potential for unprecedented advancements in animal welfare, sustainability, and technological innovation. As we embark on this journey, let us embrace the promise of a future where the metaverse and modern animal farming converge to create a harmonious and enlightened relationship, shaping a world where compassion, efficiency, and progress thrive hand in hand.

10. Conclusions

As we look to the future of animal farming, virtual environments enabled by sensor data provide exciting new possibilities for improving animal welfare, reducing stress and anxiety, and promoting sustainable and ethical practices. However, we must also consider

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the potential limitations and drawbacks of their use, including ethical concerns, long-term effects on animal behavior, cost and accessibility, and lack of physical stimulation.

It is essential that animal welfare remains at the forefront of the development of the metaverse in animal farming. By prioritizing ethical considerations and diversity and equity, we can ensure that virtual environments are implemented in a responsible and humane way. This requires a thoughtful and well-informed approach that takes into account the social and economic implications of this technology.

While the implementation of virtual environments in animal farming presents significant challenges, it also offers immense opportunities for improving the lives of animals and creating a more sustainable and equitable agricultural industry. By embracing this technology and addressing its limitations with a responsible and ethical approach, we can pave the way for a brighter future for animal farming.

The implementation of virtual environments in animal farming requires a careful balance of technological advancement, ethical considerations, and sustainability. By approaching this challenge with a responsible and ethical mindset, we can harness the potential benefits of the metaverse while ensuring that animal welfare and equity remain at the forefront of our efforts. Let us strive for a future where animal farming is both sustainable and humane, and where virtual environments serve as a tool to help us achieve this goal.

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