Technical solution

Technical practical and stakeholder specific considerations regarding a problem

Goal: Find over encompassing themes within SDG 9/11 that relate to **multiple** technologies (or methods) and to a chosen DTAS

Must showcase innovative and comprehensive approach to meet challenges

The technical solution must:

Meet requirements of challenges and have strong real-world applicability
(Be scalable, Link to real cases, Represent clear advancement)

Has a solution to (a) clearly defined challenge(s)

Ways to go about finding technical solution:

Apply Outside-in thinking

Contents

TECHNICAL SOLUTION CASES BASED ON ASSIGNMENT 2

“How can digital twinning be applied to autonomous systems in order to address the <challenge(s)> of <stakeholder(s)>?”

Applied Autonomy (Norwegian Startup)

A Norwegian startup developing autonomous systems for urban mobility and logistics.

Potential stakeholders the startup itself, city planners, public transport authorities, logistics companies, and citizens.

Challenge: Efficiently managing on-demand trips using autonomous vehicles, optimizing routes, managing energy consumption, assessing environmental impacts, and potentially mitigating urban disaster risks.

This aligns with SDG 11 (Sustainable Cities and Communities) by improving urban transport and resilience, and SDG 9 (Industry, Innovation, and Infrastructure) by fostering innovative infrastructure solutions.

- Digital Twin Role: Creates a high-fidelity virtual replica of the urban environment, including road networks, traffic conditions, energy infrastructure, and potentially environmental factors (e.g., flood plains if relevant). This DT allows for:
  - Simulating different trip management strategies.
  - Assessing the impact of autonomous vehicle deployment on traffic flow and energy grids.
  - Optimizing routes based on real-time and predicted conditions.
  - Testing geofencing parameters virtually.
  - Adjusting geofencing parameters in cases of urban disasters
- Autonomous System Role: The autonomous vehicles themselves, plus the central management system. These systems use AI/ML to:
  - Navigate complex urban environments safely and efficiently.
  - Make real-time decisions based on sensor data and inputs from the DT (e.g., rerouting based on predicted congestion or hazard warnings).
  - Manage vehicle energy consumption autonomously across multiple autonomous vehicles operation in the same area (e.g. an natural diaster that needs to get to a certain ground zero and traffic should halt for this).
  - Respond to on-demand trip requests and dynamically allocate vehicles.

DTAS Synergy: The DT provides the comprehensive virtual environment and predictive insights, while the AS (vehicles and management system) executes actions in the physical world based on these insights and real-time sensor data, creating a continuous feedback loop for optimization and risk mitigation.

Digital Twins & Autonomous Systems (DTAS)

The 2030 Agenda for Sustainable Development, adopted by the United Nations in 2015, provides a global blueprint for peace and prosperity for people and the planet. Among the 17 Sustainable Development Goals (SDGs) are SDG 9, which focuses on building resilient infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation, and SDG 11, which aims to make cities and human settlements inclusive, safe, resilient, and sustainable. Achieving these goals requires transformative solutions that can address the complex challenges arising from industrial activities, rapid urbanization, and disparities in access to resources and opportunities. Digitally twinned autonomous systems represent a promising frontier in this endeavor, offering innovative approaches to optimize resource utilization, enhance efficiency, improve safety, and foster sustainability across various sectors.

Digital twins are virtual representations of physical assets, processes, or systems that mirror their real-world counterparts with high fidelity.[1] These dynamic models are continuously updated with real-time data from sensors and other sources, enabling comprehensive monitoring, simulation, and analysis of performance.[1] By creating a virtual sandbox of their physical assets, organizations can gain valuable insights, predict potential issues, and optimize operations without disrupting real-world processes.[1] Autonomous systems, on the other hand, are self-operating technologies equipped with the capacity to make decisions and take actions without direct human intervention.[4] Leveraging advanced technologies such as artificial intelligence (AI) and machine learning (ML), these systems can analyze complex data, perceive their environment, and execute tasks with precision and speed.[4]

The integration of digital twins and autonomous systems holds immense potential for tackling the intricate challenges outlined in SDGs 9 and 11. Digital twins provide the virtual replica and the continuous stream of data reflecting the real-time status of physical entities, while autonomous systems offer the intelligence to analyze this information, identify patterns, predict outcomes, and implement optimal actions.[2] This synergy creates a powerful feedback loop where insights from the virtual world can drive tangible improvements in the physical world, leading to enhanced sustainability and efficiency across industrial and urban landscapes. This report will delve into specific challenges within SDG 9 related to industrial sustainability and growth in underserved areas, as well as challenges within SDG 11 concerning urban infrastructure and safety in rapidly urbanizing environments. For each challenge, the potential role of digitally twinned autonomous systems will be explored, and a comprehensive list of relevant academic journals, technical articles, and search engines will be provided to facilitate further research.

Addressing Challenges within SDG 9: Industry, Innovation, and Infrastructure

- Real-time Monitoring and Optimization of Resource Consumption and Emissions in Manufacturing Processes

  A significant challenge within SDG 9 is the imperative to reduce the environmental impact of industries through real-time monitoring and optimization of resource consumption and emissions in manufacturing processes. Traditional methods of monitoring resource use and emissions often fall short due to their reliance on manual data collection, which is prone to inaccuracies and delays, and infrequent analysis that limits the ability to respond promptly to inefficiencies or deviations.8 As an integral part of production management, real-time monitoring provides actionable data insights to help manufacturers identify bottlenecks and optimize resource utilization.8 However, manual, paper-based monitoring presents the risk of delayed responses and data inaccuracies, which can significantly impact operations.8 Traditional data collection approaches are considerably time- and effort-consuming because of the structural complexity of industrial processes, often leading to human errors and lacking real-time, dynamic, and precise data.9

  Digitally twinned autonomous systems offer a transformative approach to overcome these limitations. By leveraging the extensive network of sensors within the Industrial Internet of Things (IIoT), continuous data on crucial parameters such as energy consumption, raw material input, water usage, and waste generation can be collected from manufacturing equipment and processes.[8] These sensors, including vibration, temperature, proximity, and gas sensors, provide invaluable insights into the performance and health of industrial assets.[14] Simultaneously, digital twins, as virtual replicas of the entire manufacturing environment, serve as platforms for visualizing and analyzing this influx of real-time data.[1] These software-based representations mirror the physical assets, systems, or processes, enabling a comprehensive understanding of their current state and potential future behavior.[1] Autonomous systems, powered by AI and machine learning algorithms, can then analyze this rich dataset, identify patterns indicative of inefficiencies, predict potential equipment failures or emission exceedances, and automatically adjust process parameters to achieve optimal performance and minimize environmental impact.[4]

  This integrated approach directly addresses the need to **reduce the environmental impact of industries**. Real-time monitoring of emissions, including carbon dioxide, sulfur oxides, nitrogen oxides, volatile organic compounds (VOCs), and fine particulate matter, becomes feasible through the deployment of specialized sensors and their integration into digital twins.[28] Advanced environmental monitoring of atmospheric emissions in real-time can lead to significant reductions in these pollutants.[38] Autonomous systems can be programmed to trigger alerts when emissions approach regulatory limits and even implement corrective actions, such as adjusting process parameters or activating pollution control systems, to ensure compliance.[38] Furthermore, Predictive Emission Monitoring Systems (PEMS), which utilize empirical models to forecast emissions based on real-time process data, offer a cost-effective alternative or supplement to traditional Continuous Emission Monitoring Systems (CEMS).[52]

The integration of digitally twinned autonomous systems also leads to **increased resource efficiency**. By providing a comprehensive view of resource consumption patterns, these systems enable the optimization of energy, raw materials, and water usage.[10] Real-time access to production line metrics and energy consumption data allows for faster and more informed decisions that minimize waste and maximize the utilization of resources.[10] Optimizing production processes to use fewer materials and less energy is crucial for achieving sustainability in industry.[62] Digital twins can identify areas where resources are being underutilized or wasted, enabling manufacturers to implement targeted improvements in efficiency.[48] Notable case studies, such as IKEA's reduction of HVAC energy use by 30% and Foxconn's over 30% annual energy consumption reduction through the implementation of digital twins, demonstrate the tangible benefits of this approach.[43]

Finally, digitally twinned autonomous systems contribute to **sustainable infrastructure** by aiding in the design and management of more environmentally responsible manufacturing facilities.[28] A sustainable factory operates in an ecologically friendly and resource-efficient manner.[65] Digital twins enable the optimization of assembly and production line layouts, as well as the simulation and optimization of energy use and material flows even before physical construction begins.[45] This proactive approach to design and management ensures that sustainability is embedded throughout the lifecycle of the manufacturing infrastructure.

- Remote Skills Training and Access to Information through Digital Platforms in Areas with Lower Education and Income and Limited Internet Access

  Digital twins hold significant potential for enhancing remote skills training by creating immersive and interactive virtual learning environments that simulate real-world scenarios.[122] These virtual replicas of industrial equipment, manufacturing processes, or other technical domains allow learners to gain practical experience and build confidence in a safe and controlled environment, regardless of their physical location.[122] This is particularly valuable for providing skills training in specialized fields where access to physical equipment might be limited in underserved areas.

  Finally, fostering digital literacy is essential for empowering individuals in these regions to effectively utilize digital platforms and access information online.[142]

Addressing Challenges within SDG 11: Sustainable Cities and Communities

- Efficient Management and Maintenance of Urban Infrastructure (Water, Energy, Transportation Networks) Arising from Rapid Urbanization

  Rapid urbanization presents significant challenges to the efficient management and maintenance of urban infrastructure, including water, energy, and transportation networks. The increasing influx of population into cities puts immense pressure on existing systems, leading to congestion, overcrowding, and strain on essential services. Infrastructure planners often struggle to keep pace with this growth, and capacities are frequently reached or exceeded before necessary expansions can be implemented. Moreover, many cities grapple with aging infrastructure systems that are in dire need of repair, maintenance, and modernization to ensure safety, reliability, and efficiency. Compounding these issues is the impact of climate change, which exacerbates existing challenges by increasing the risks of extreme weather events such as floods, storms, and heatwaves, further straining urban infrastructure.

  Digitally twinned autonomous systems offer a powerful suite of tools for addressing these challenges. Creating digital twins of urban infrastructure networks, encompassing water distribution systems, energy grids, and transportation networks, provides city managers with real-time visibility into the condition and performance of these critical assets.[1] These virtual replicas integrate data from various sources, including sensors, IoT devices, and existing management systems, to offer a holistic and up-to-date view of the infrastructure's status.[179] Autonomous robots and drones can be deployed for the inspection and monitoring of infrastructure, including areas that are difficult or dangerous for humans to access, such as underground pipes, bridges, and power lines.[191]

Within these digital twins, AI-powered analytics can be employed to analyze the vast amounts of data collected, enabling the prediction of maintenance needs, optimization of resource allocation (such as water and energy distribution), and improvement of the efficiency of transportation networks.[75] For instance, AI can analyze traffic patterns in real-time to optimize traffic signal timings and reduce congestion, or predict potential energy consumption spikes to better manage the power grid.[203] Furthermore, autonomous systems can be utilized for the maintenance and repair of infrastructure, with robots capable of performing tasks such as pothole patching, pipe sealing, and even self-repairing machinery, reducing downtime and improving the lifespan of critical infrastructure.[191]

Remote Monitoring for Safety and Security and Optimized Resource Allocation for Basic Services in Unsafe Areas and Slums

Addressing the challenges arising from rapid urbanization also necessitates a focus on unsafe areas and slums, which often suffer from extreme poverty, inadequate infrastructure, and a lack of basic services such as transportation, water, and sanitation. Ensuring the safety and security of residents in these areas, as well as optimizing the allocation of scarce resources for essential services, presents a complex challenge for urban authorities.

Digitally twinned autonomous systems can offer innovative solutions for enhancing safety and improving resource allocation in these contexts. AI-powered surveillance systems, including CCTV cameras and drones, can be integrated with digital twins of urban environments to provide remote monitoring for safety and security.[180] These systems can be equipped with features like object detection, anomaly recognition, and even predictive capabilities to identify potential threats and enable faster responses from law enforcement or emergency services.[227] AI can also be employed for crime prediction and proactive policing in urban areas, allowing for more efficient allocation of security resources to high-risk locations.[234] ~~However, it is crucial to acknowledge and carefully consider the ethical implications of AI-powered surveillance, particularly regarding data privacy, potential biases, and the risk of misuse.~~ (this is not an ethics course)

Digital twins can also provide a valuable platform for optimizing the allocation of basic services in slums and underserved areas.[182] By creating virtual models of these communities, integrating data on population density, infrastructure availability, and resource consumption, city authorities can gain a better understanding of the needs and demands of residents.[182] Smart city solutions, leveraging sensors and IoT devices, can monitor resource usage in real-time, enabling more responsive and efficient urban governance in slums.[248] Additionally, autonomous delivery systems, such as drones and robots, offer the potential to overcome transportation challenges and improve access to essential goods and services like medical supplies and food in these often-inaccessible urban environments.[249](they did this with heart transplants in Rwanda)

Miscellaneous

Initial ideas for CBL

Robot that can

- determine air quality in a certain space. The objective is to use this robot in a city to find locations for creating green spaces. If this is too simple, we can also think of pathfinding in the city etc.
- determine the quality of water bodies. This can help authorities efficiently choose which water bodies need to be cleaned.
- plan routes in a city for disabled people. Not everyone can directly follow routes suggested by regular apps like google maps.

- patrol the pavement or other road and check for quality; this allows for efficient maintenance. (Pavement surveillance robots)
- water plants in a city to keep greenspaces alive. This is especially for places with hot and dry weather.
- Traverse through a building and tests Wi-Fi strength. This can help optimize router placement in large office spaces and best utilize limited resources.
- that can distinguish and fetch basic tools from a shared storage space and makes the storage space more organized, so the worker does not have to waste time searching for a particular tool. (Workshop robot)

Traffic Data for Geofencing & On-Demand Trip Management

- Stakeholder/Context: Similarly to Applied Autonomy, stakeholders include city transport authorities, mobility service providers, and citizens. The focus here is more specifically on leveraging *traffic data*.
- Challenge: Improving urban accessibility, reducing transport costs, and enhancing infrastructure resilience by integrating real-time traffic data deeply into the management of autonomous mobility systems. This directly addresses SDG 11 (Sustainable Cities and Communities) and supports SDG 9 (Industry, Innovation, and Infrastructure).
- Digital Twin Role: Acts as the integration platform for diverse, real-time data streams, especially traffic data (from sensors, cameras, connected vehicles, etc.). The DT models traffic flow, predicts congestion, and simulates the effects of geofencing policies or dynamic routing strategies based on live traffic conditions.
- Autonomous System Role: The autonomous vehicles and their management system make decisions heavily influenced by the traffic insights provided by the DT. They autonomously adjust routes, speeds, and operational zones (geofencing) to optimize for travel time, energy efficiency, and safety based on current and predicted traffic patterns.
- DTAS Synergy: The DT processes complex, real-time traffic data to provide actionable intelligence. The AS uses this intelligence for dynamic operational adjustments (geofencing, routing, scheduling) that would be too complex or slow for manual intervention, leading to more resilient and efficient urban transport.

BMW’s iFactory

- Stakeholder/Context: BMW, specifically its manufacturing division aiming for highly efficient and flexible production ("iFactory"). Stakeholders include production managers, process engineers, maintenance teams, and supply chain managers.
- Challenge: Optimizing complex automotive production workflows, minimizing errors and downtime, improving order sequencing flexibility, and reducing resource consumption (especially energy) in the manufacturing process. This aligns with SDG 9 (promoting inclusive and sustainable industrialization) and contributes to SDG 12 (Responsible Consumption and Production) through resource efficiency.
- Digital Twin Role: Creates a detailed virtual replica of the entire production line or specific segments. This DT integrates real-time data from sensors on machinery (IIoT) and tracks materials/products. It enables:
    - Simulation of different production schedules and workflows *before* implementation.

        - Identification of potential bottlenecks or error points.
        - Virtual testing of layout changes or new equipment integration.
        - Detailed tracking and analysis of energy consumption patterns linked to specific processes or machines.
    - Autonomous System Role: Includes AI-powered analytics platforms and potentially autonomous robotic systems within the factory. These systems:
        - Analyse data within the DT to predict equipment failures (predictive maintenance).
        - Identify optimal process parameters or order sequences based on simulations.
        - Automatically adjust machine settings or material flows to optimize efficiency or avoid predicted problems.
        - Trigger alerts or autonomous corrective actions based on real-time monitoring data compared against the DT baseline.
    - DTAS Synergy: The DT provides the virtual testing ground and real-time mirror of production. The AS analyses this comprehensive data view to make intelligent decisions and autonomously implement optimizations or corrective actions on the physical factory floor, enhancing efficiency and sustainability.

IKEA

- Stakeholder/Context: IKEA, focusing on its manufacturing and logistics/waste management operations. Stakeholders include factory managers, logistics coordinators, sustainability officers, and waste management teams.
- Challenge: Optimizing production orders based on real-time factors and reducing waste (both material waste in production and inefficiencies in waste collection/management). This links to SDG 9 (sustainable industrialization) and SDG 12 (Responsible Consumption and Production).
- Digital Twin Role: Represents IKEA's production facilities and potentially its waste management logistics. It integrates live data from sensor networks (tracking material flow, machine status, energy use, waste bin levels, etc.). The DT allows for:
    - Visualizing and analyzing resource consumption and waste generation in real-time.
    - Simulating different production schedules to minimize waste.
    - Modeling and optimizing waste collection routes based on real-time fill levels and predicted waste generation.
    - Monitoring energy use (e.g., HVAC) for optimization opportunities.
- Autonomous System Role: AI algorithms analyze data within the DT to identify optimization opportunities. This could involve:
    - Autonomous adjustment of production parameters to reduce material scrap.
    - Autonomous scheduling and routing of waste collection vehicles or internal transport systems.
    - Automated control of building systems (like HVAC) based on real-time conditions and predictive models derived from the DT.
- DTAS Synergy: Sensors feed real-time data into the DT, creating an accurate virtual picture. The AS leverages this picture to make autonomous decisions – adjusting production, optimizing logistics (like waste routes), or controlling facility systems – thereby improving efficiency and reducing waste, as demonstrated by their documented energy savings.

Pretoria Flood Risk Mitigation

- Stakeholder/Context: City authorities, disaster management agencies, infrastructure planners, and residents in Pretoria (or a similar urban area facing flood risks).
- Challenge: Understanding, predicting, and mitigating the risks associated with flooding in an urban environment to protect citizens and infrastructure, thereby enhancing urban resilience. This directly addresses SDG 11 (making cities resilient and safe).
- Digital Twin Role: Creates a dynamic virtual model of the city, incorporating topography, infrastructure (drainage systems, roads, buildings), river systems, and potentially real-time weather data (rainfall sensors, forecasts). This DT allows for:
    - Simulating various flood scenarios based on different rainfall intensities or infrastructure failure points.
    - Visualizing the potential impact of floods on different areas and critical infrastructure.
    - Testing the effectiveness of different mitigation strategies (e.g., new barriers, improved drainage, early warning systems) virtually.
    - Providing a common platform for stakeholder decision-making based on shared data and simulations.
- Autonomous System Role: Could involve AI-powered prediction systems and potentially autonomous infrastructure controls. These systems:
    - Analyse real-time sensor data (e.g., river levels, rainfall) and data from the DT simulations to predict flood events with greater accuracy and lead time.
    - Generate automated alerts and warnings for relevant authorities and the public.
    - Potentially trigger autonomous actions, such as closing flood gates, activating pumps, or dynamically rerouting traffic away from affected areas based on predictions and real-time conditions mirrored in the DT.
- DTAS Synergy: The DT provides the detailed environmental model and simulation capabilities. The AS uses real-time data and the DT's predictive outputs to autonomously generate warnings or initiate control actions, enabling faster and more effective responses to flood threats, ultimately supporting better stakeholder decision-making and enhancing urban resilience.

Not in Assignment two ↓

Schneider Electric Le Vaudreuil Site (Manufacturing - Sustainability Focus)

- **Stakeholder/Context:** Schneider Electric's management, plant operators, maintenance teams, and sustainability officers at their Le Vaudreuil manufacturing site in France. The wider community benefits indirectly from reduced environmental impact.
- **Challenge:** Significant operational costs and environmental impact stemming from high energy consumption, material waste during production, and associated CO_2 emissions. The challenge is to optimize operations for greater sustainability and efficiency simultaneously. This directly addresses **SDG 9** (Industry, Innovation, and Infrastructure – specifically sustainable industrialization), **SDG 12** (Responsible Consumption and Production), and contributes to **SDG 13** (Climate Action) through emissions reduction.
- **Digital Twin Role:** The site employs digital twins representing its physical plant installations – machinery, production lines, energy distribution systems, and potentially building management systems

(like HVAC). These twins integrate real-time data from numerous sensors across the factory floor and building infrastructure. The DT serves as:

  - A virtual mirror for real-time monitoring of energy usage, material flow, and process parameters.
  - A simulation platform to test the impact of potential changes (e.g., process adjustments, new equipment) on energy, waste, and emissions *before* physical implementation.
  - An analytical tool to identify root causes of inefficiency or waste hotspots.

- **Autonomous System Role:** AI-powered analytical systems work in conjunction with the digital twin. These autonomous systems:
  - Continuously analyze the real-time data and simulation results from the DT to pinpoint opportunities for optimization.
  - Predict potential inefficiencies or deviations from optimal performance.
  - Can implement automated adjustments to process parameters, machine settings, or energy controls (e.g., optimizing heating/cooling based on occupancy and predicted needs) to achieve efficiency targets.
  - Provide optimized recommendations and alerts to human operators for actions requiring manual intervention.
- **DTAS Synergy:** The digital twin provides the comprehensive, data-rich virtual representation of the plant. The autonomous system leverages this detailed view and predictive capability to make intelligent decisions and execute autonomous control actions or provide precise recommendations. This synergy directly translates into measurable improvements: **25% reduction in energy consumption, 17% reduction in material waste, and 25% reduction in CO2 emissions**, demonstrating a powerful feedback loop where virtual insights drive tangible physical efficiencies and sustainability gains.

Frisco, Texas Public Safety Coordination (Urban Planning - Real-time Coordination/Safety Focus)

- **Stakeholder/Context:** Public safety agencies in Frisco, Texas (Police Department, Fire Department, Transportation Department), their respective personnel (officers, firefighters, dispatchers), city management, and ultimately, the citizens whose safety and emergency response times are improved.
- **Challenge:** Lack of real-time, unified situational awareness across different public safety departments during incidents, leading to potential delays in response, inefficient resource allocation, and difficulties in inter-agency coordination. This challenge impacts the city's ability to ensure safety and resilience, aligning with **SDG 11** (Sustainable Cities and Communities – specifically making cities safe and resilient).
- **Digital Twin Role:** This system functions as a dynamic **Information Twin** or a Common Operational Picture, rather than a physics-based simulation twin. It creates a live, geographically referenced virtual representation (a map-based interface) that integrates real-time data streams from multiple sources. Key functions include:
  - Displaying locations of ongoing public safety incidents.
  - Tracking the real-time locations of personnel and vehicles from police, fire, and potentially transportation departments.
  - Integrating relevant contextual data (e.g., traffic conditions, building layouts, hydrant locations).
  - Providing a single, shared, and continuously updated view of the operational environment for all collaborating agencies.

Autonomous System Role: While full autonomy might be limited, AS components enhance the system's effectiveness:

- AI/ML algorithms can analyze incoming data streams to predict incident severity or required resources.
- Automated alerting systems instantly notify relevant personnel and agencies based on incident type and location.
- Route optimization algorithms can suggest the fastest paths for responding units based on real-time traffic data integrated into the information twin.
- The system facilitates significantly faster and more informed *human* decision-making, acting as an intelligent assistant that automates information fusion and highlights critical coordination needs, bordering on semi-autonomous coordination support.

- **DTAS Synergy:** The Information Twin provides the crucial unified, real-time view by integrating disparate data sources. The Autonomous System components process this fused information, provide predictive insights (e.g., optimal routing), automate alerts, and streamline the coordination process across agencies. This synergy breaks down communication silos and leverages real-time data to enable faster, more coordinated, and effective emergency responses.

Viamo AI Voice Tutoring (Education - Accessibility/AI Tutoring Focus)

- **Stakeholder/Context:** Students in underserved regions (example: Sub-Saharan Africa) lacking reliable internet or smartphones, educational content providers, NGOs focused on education access (like partner Team Taleem), and Viamo as the technology provider.
- **Challenge:** Providing scalable, personalized, and effective educational support (like tutoring) to learners who face significant technological barriers (limited internet, basic mobile phones only) and potentially geographical isolation. This directly addresses **SDG 4** (Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all) and contributes to **SDG 10** (Reduce inequality within and among countries) by bridging the digital divide in education.
- **Digital Twin Role:** While not a traditional physical asset twin, a **Learner Digital Twin** concept applies. This is an adaptive digital profile created and continuously updated for each student based on their interactions with the AI tutor. This profile models the learner's:
    - Current knowledge level and skill mastery.
    - Learning pace and style (inferred from interaction patterns).
    - Areas of difficulty and strength.
    - Progress over time. This dynamic profile serves as the virtual representation of the learner's state.
- **Autonomous System Role:** The core of the solution is the AI-powered tutor delivered via voice calls on basic mobile phones. This AS performs several key functions autonomously:
    - Uses *voice recognition* and *natural language processing* to interact with the student through voice.
    - Leverages *adaptive learning algorithms* to analyze the student's responses and interaction patterns, constantly updating the Learner Digital Twin.
    - *Personalizes the learning experience* in real-time by adjusting question difficulty, providing tailored feedback, selecting appropriate content, and modifying the teaching strategy based on the insights from the Learner Digital Twin. It acts as a stand-alone, automated tutor.
- **DTAS Synergy:** The Learner Digital Twin provides the evolving model of the student's knowledge and needs. The Autonomous AI Tutor interacts with the student, gathers data to update the twin, and then uses the twin's insights to autonomously tailor the educational interaction. This synergy allows for highly

personalized and adaptive learning support to be delivered at scale through simple, accessible voice technology, overcoming major infrastructure limitations.

Concept map goals

- Data Analysis/Scenario Planning: The descriptions highlight the types of data used and the potential for simulation/scenario analysis within the DT.
- SDG Linkage: Clearly articulate *how* your specific technical solution for the chosen case addresses the targets within those SDGs.
- DTAS Characteristics: We must ensure our technical solution clearly leverages core characteristics of a DTAS to solve the identified challenge.

Core concepts

DT (virtual representation, data integration, simulation) and AS (AI/ML, decision-making, autonomous action)