SUDEM FORESIGHT

Contents

1. Introduction

The SUDEM foresight analysis is developed as part of Work Package 2 and serves as a strategic foundation for the project’s curriculum and knowledge-transfer activities. Its purpose is to provide an in-depth qualitative understanding of current challenges, emerging trends, future needs, and possible development directions in the field of digitally enabled disaster management.

The foresight does not aim to function as a standard quantitative analysis. Instead, it applies a qualitative strategic planning approach based on identified trends, partner expertise, emerging technologies, operational needs, and future-oriented scenarios. Its role is to help the SUDEM consortium better understand how disaster-management systems, digital technologies, educational requirements, and professional competence needs are expected to evolve.

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The analysis focuses on the digitalisation of disaster-management processes, including IoT and sensing, big data handling, artificial intelligence, remote observation, disaster awareness, remote teaching and learning, and special hazards. Particular attention is also given to Higher Education and Lifelong Learning, since SUDEM aims to develop an interdisciplinary educational framework that responds to both academic and professional needs.

The foresight approach additionally incorporates horizon-scanning methodologies focused on identifying emerging technologies, weak signals, future risks, evolving operational trends and long-term societal transformations that may influence future disaster-management ecosystems. The foresight methodology applied within SUDEM combines analysis of past developments, current operational conditions and future-oriented scenarios in order to identify emerging trends, future risks, technological transformations and long-term educational requirements. This approach supports anticipatory planning and adaptive educational development for future disaster-management ecosystems. Horizon scanning methodologies are particularly important for identifying weak signals, disruptive technologies, persistent vulnerabilities and emerging operational challenges before they become fully visible within mainstream disaster-management practices.

The foresight provides the conceptual basis for the initial SUDEM curricular framework by identifying the challenges, solutions, trends, and future picture that should guide the design of the project courses and their interrelations. In this way, the foresight links strategic future planning with the educational architecture of SUDEM and supports the development of a coherent, interdisciplinary, and future-oriented curriculum.

2. Status Quo

2.1. Operational Landscape

The current disaster-management environment is characterised by increasing complexity, uncertainty, and interconnectivity between natural, technological, industrial, and societal systems. Climate change, urbanisation, critical infrastructure dependencies, industrial development, and digital transformation are contributing to more frequent and complex disaster scenarios that often involve cascading effects across multiple sectors and operational domains.

Current disaster-management systems are increasingly expected to support the full cycle of prevention, early detection, response and recovery. This requires resilient monitoring and

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emergency-management systems capable of reducing loss of life, limiting infrastructure damage and supporting coordinated response under complex natural and man-made disaster conditions [26] [27] .

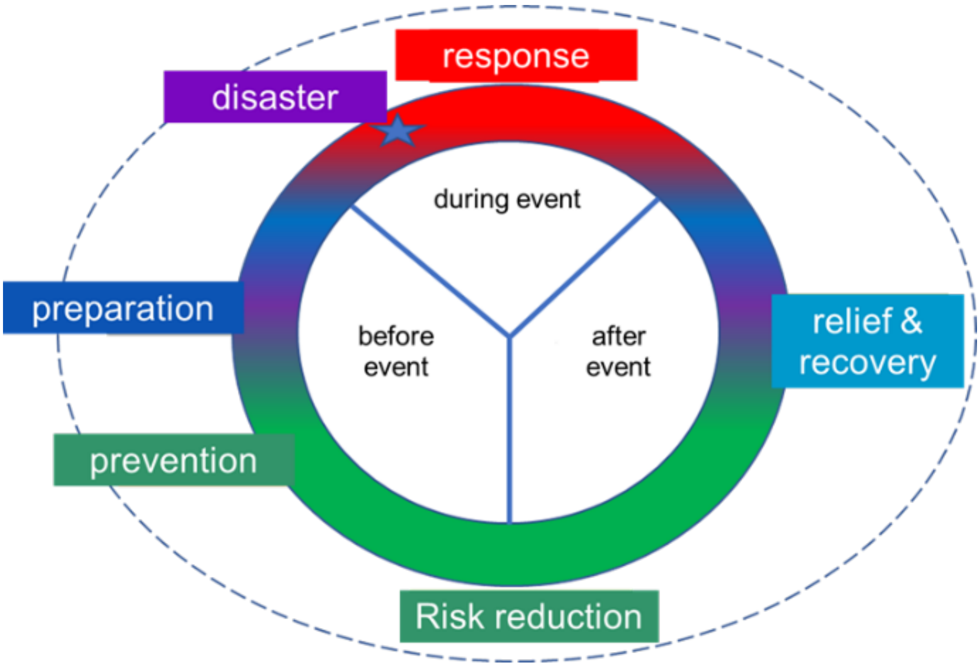

Figure 1. Lifecycle model of disaster management activities

Recent European disaster events demonstrate how environmental hazards, infrastructure dependencies and institutional coordination challenges increasingly overlap. The 2021 Ahr Valley flood in Germany showed that the problem was not only the availability of monitoring data, but also the difficulty of translating warnings and hydrological information into timely operational action. This illustrates the need for disaster-management systems that combine monitoring, communication, coordination and decision-making within one integrated operational workflow [2] [3] . Bulgaria faces a broad spectrum of natural and man-made disaster risks including floods, earthquakes, wildfires, industrial accidents, transportation incidents and extreme weather events. Climate change, urbanisation and infrastructure interdependencies further intensify these risks and increase pressure on disaster-management systems and emergency-response capacities. Similar disaster patterns are also observed across Germany, the Netherlands and Ukraine, where floods, industrial accidents, extreme weather events and infrastructure-related crises increasingly affect societal resilience, economic stability and public safety.

Rapid urbanisation and infrastructure expansion are further increasing the complexity of disaster-management ecosystems. Future metropolitan environments are expected to concentrate increasingly large volumes of critical infrastructure, transportation systems,

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communication networks, and societal dependencies within densely populated urban regions. This development may significantly amplify systemic vulnerability, cascading infrastructure failures, and the operational consequences of extreme environmental events. It is expected that by 2050 two-thirds of the world's population will live in metropolitan areas. Currently, 20-40 million inhabitants reside in each mega city, like the ones in India and China. This creates an immense need for private and public infrastructure, especially for mobility. Each citizen worldwide is responsible for 115 tons of building mass but in the EU the figures are higher – in Germany for example its 490 tons. Each citizen is burdened with thousands of € in living, working and transport infrastructure costs. With the growth of the world's population at 2.6 people a second and the majority living in cities goes hand in hand with the increase of building mass – 1.3t per second. This leads to numerous consequences, including climate change – 6-8 ^{o}C rise in global temperatures is expected by 2050, along with an immense increase in air humidity and related extreme weather events and disasters. Recovery expenses following unexpected natural extreme events in EU amount to hundreds of billions of EUR. Emergency preparedness costs 2-4 thousand EUR per capita. In addition to its operational dimension, infrastructure also has a societal value to be preserved.
Climate change, infrastructure interdependencies, and urban density are therefore expected to place growing pressure on disaster-management preparedness, resilience planning, and adaptive operational coordination [1].

Modern disasters increasingly combine physical and digital dimensions. Natural hazards, industrial accidents, infrastructure failures, cyber-physical disruptions, and communication breakdowns can simultaneously affect operational coordination, emergency response capabilities, and societal resilience. As a result, disaster-management systems are becoming more dependent on digital infrastructures, communication networks, sensing technologies, and real-time information exchange.

At the same time, disaster-management organisations face growing operational pressure related to situational awareness, interoperability, adaptive decision-making, and coordination between multiple stakeholders. Emergency responders, public authorities, infrastructure operators, and technical experts must increasingly cooperate within interconnected and rapidly evolving operational environments.

Digital technologies are already playing an increasingly important role within disaster-management ecosystems. AI-supported analytics, IoT systems, UAVs, remote sensing, edge computing, distributed coordination systems, and data-driven operational platforms are becoming important components of preparedness, monitoring, operational response, and resilience-building activities.

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Contemporary disaster-management ecosystems increasingly operate through emergency control centres coordinating information flows between monitoring systems, operational responders, public authorities, medical teams, rescue units and infrastructure operators. During disaster situations, information may originate from multiple heterogeneous sources including emergency calls, sensors, UAVs, satellite systems, field operators and public reporting channels, creating highly dynamic and information-intensive operational environments [12] [13] [14] .

Contemporary disaster-management environments increasingly include high-impact technological and radiological risk scenarios related to nuclear facilities, radioactive materials, critical infrastructure and hybrid warfare conditions. The war in Ukraine has demonstrated how military conflicts may significantly increase risks associated with nuclear infrastructure security, radiological contamination and protection of civilian populations near critical energy facilities.

However, the current disaster-management environment also remains highly fragmented in many areas. Technological systems, operational procedures, educational structures, and institutional coordination mechanisms are often developed separately, limiting interoperability and reducing the effectiveness of integrated disaster-management processes.

These developments create growing demand for interdisciplinary approaches capable of integrating technological innovation, operational coordination, resilience methodologies, and adaptive educational models within one coherent disaster-management ecosystem.

2.2. Technological Landscape

The technological landscape of modern disaster management is evolving rapidly through the increasing integration of digital systems, intelligent infrastructures, and real-time operational technologies. AI, IoT systems, sensing platforms, UAVs, edge computing, cloud infrastructures, communication networks, and distributed coordination systems are becoming increasingly important components of disaster-management ecosystems.

IoT and sensing technologies are enabling continuous environmental monitoring, infrastructure observation, early-warning systems, and real-time situational awareness. Distributed sensors, remote sensing platforms, and UAV-supported observation systems are increasingly used to collect operational data during disaster preparedness and response activities.

Artificial intelligence and data-driven analytical systems are also gaining importance within disaster-management operations. AI-supported analytics, predictive modelling, automation,

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and intelligent decision-support systems are being explored to improve operational coordination, risk evaluation, resource allocation, and adaptive response capabilities under uncertain conditions.

Existing disaster-management systems already use advanced digital components such as IoT-enabled water-level sensors, radar and ultrasound monitoring, coastal observation systems, satellite data, weather forecasting platforms, digital risk maps and public warning systems. In Germany, examples include the DWD SINFONY forecasting system, digital flood and heavy-rain hazard maps, and the BBK Modular Warning System (MoWaS), which distributes alerts through multiple channels including warning apps, sirens, radio, television and digital information systems [4] [5] [6] [7] [8]. These systems increasingly rely on digital monitoring infrastructures, early-warning systems, geospatial analysis, remote sensing technologies, UAV-supported observation and integrated operational coordination platforms. Bulgaria has established national disaster-management structures involving early-warning systems, search-and-rescue coordination and public-awareness infrastructures supporting preparedness and operational response.

Resilient monitoring systems increasingly combine diverse sensors and detectors, including seismic, hydrological, meteorological and environmental sensors, together with UAVs, satellite observation and other remote-sensing technologies. These systems expand monitoring capabilities across large areas and provide data for early detection, forecasting and coordinated response [27] [28] [29] .

Modern disaster-management systems increasingly integrate computer-aided infrastructures including IoT networks, communication systems, big-data platforms, decision-support systems, logistics systems and distributed sensing technologies in order to improve operational efficiency and effectiveness. The growing digitalisation of emergency management is transforming disaster-response ecosystems into interconnected cyber-physical operational environments. Existing research additionally emphasises the importance of workflow-oriented emergency-management architectures capable of monitoring disaster-management activities from event occurrence to operational completion. Such architectures support operational traceability, process monitoring and performance evaluation across the full disaster-management lifecycle [15] [16] [12] .

The increasing diversity of sensing infrastructures used within disaster-management ecosystems can be illustrated through earthquake-monitoring architectures integrating geographically distributed, object-mounted, and mobile sensing systems. In the Following figure, for example, a set data sources are depicted that can be used for detecting the effects of earthquakes. The domain of data sources is divided into three categories. The first category includes data sources which can be deployed to geographical areas. The second category includes data sources which can be mounted on physical objects. The third category refers to data sources which can be brought to the locations where disasters have been effective.

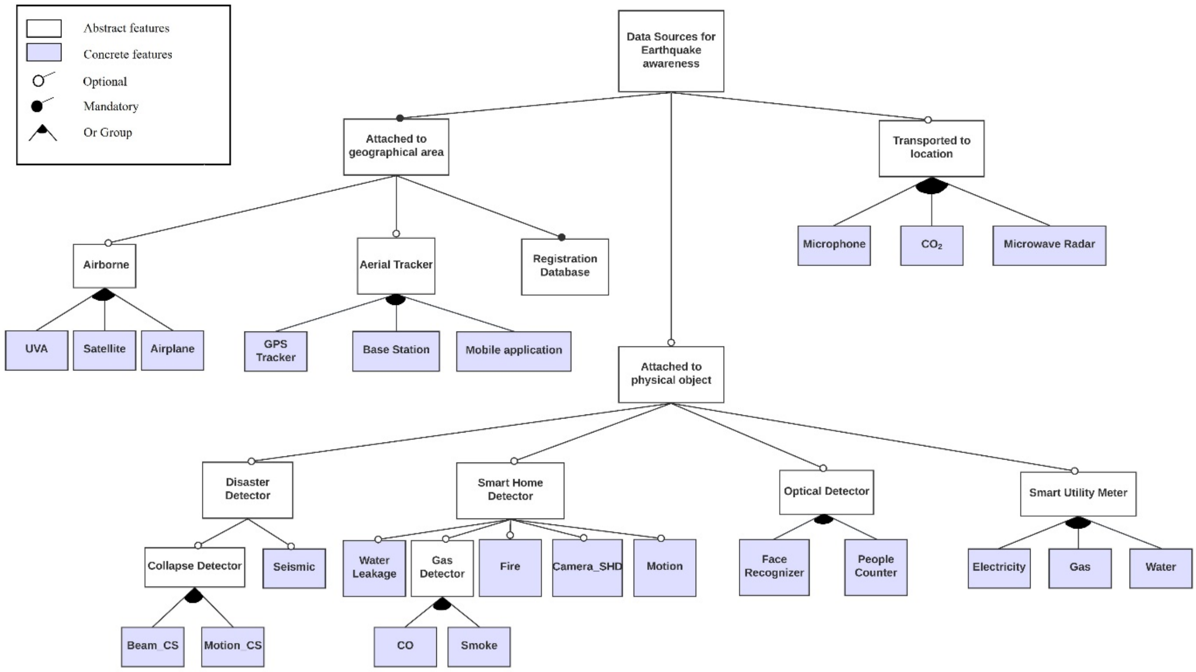

Figure 2. A feature model depicting the kinds of data sources that can be adopted for detecting the effects of earthquakes [17]

Disaster-management ecosystems increasingly require specialised monitoring, detection and assessment capabilities for radiological, chemical and biological threats. Modern risk-management systems therefore integrate environmental monitoring, radiation detection, risk-analysis methodologies and critical-infrastructure protection mechanisms within broader disaster-management architectures.

Edge computing and distributed digital infrastructures further support real-time operational responsiveness by enabling localised data processing and reducing dependency on centralised communication systems. These technologies are particularly important in disaster scenarios where communication reliability and operational continuity are critical.

At the same time, the technological landscape remains fragmented and unevenly implemented across different organisations, sectors, and countries. Interoperability limitations, lack of integrated operational standards, cybersecurity concerns, and insufficient interdisciplinary expertise continue to restrict the full operational potential of digitally enabled disaster-management ecosystems.

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These developments demonstrate both the opportunities and challenges associated with the digital transformation of disaster management and highlight the growing need for interdisciplinary educational frameworks capable of connecting technological innovation with operational preparedness and resilience-oriented coordination.

2.3. Educational Landscape

The current educational landscape related to disaster management remains fragmented across many academic and professional domains. Traditional educational programmes often focus on isolated disciplines such as emergency response, engineering, information technologies, civil protection, environmental studies, or risk management without sufficiently integrating these areas into one interdisciplinary operational framework.

The increasing complexity of digitally enabled disaster-management ecosystems creates growing need for interdisciplinary educational approaches combining systems engineering, operational coordination, data analysis, AI-supported decision-making, IoT infrastructures, digital resilience and workflow-oriented disaster-management methodologies [16] [17] .

The growing complexity of radiological, chemical and hybrid-threat environments additionally creates increasing demand for specialised educational programmes focused on radiation protection, risk assessment, emergency preparedness and critical-infrastructure resilience. Current geopolitical developments demonstrate the importance of interdisciplinary preparedness education capable of supporting effective response to CBRN-related emergencies.

As digital transformation increasingly affects disaster-management ecosystems, there is growing need for educational approaches capable of combining technological competencies with operational understanding. However, many existing programmes still provide limited integration of AI, IoT systems, sensing technologies, data-driven decision-making, resilience engineering, and workflow-oriented disaster-management methodologies.

Another challenge is the gap between theoretical education and practical operational requirements. Many educational models provide limited exposure to collaborative problem-solving, interdisciplinary coordination, real-life disaster scenarios, and adaptive operational decision-making under uncertain conditions. As a result, learners may develop strong disciplinary expertise while lacking broader systems thinking and operational interoperability competencies.

Existing educational and preparedness activities increasingly include higher-education programmes, professional-development workshops, simulation exercises, community-based training and public-awareness campaigns focused on resilience, crisis communication and operational coordination. However, stronger integration between digital technologies, operational workflows and interdisciplinary disaster-management competencies remains necessary.

The current educational situation also reflects growing demand for flexible and continuously evolving learning environments. Rapid technological development creates increasing need for lifelong learning, professional upskilling, and adaptive educational models capable of supporting both Higher Education (HED) and Lifelong Learning (LLL) contexts.

Digital learning environments and remote educational platforms are becoming increasingly important, particularly for interdisciplinary collaboration, accessibility, scalability, and international knowledge exchange. Nevertheless, many educational ecosystems still lack integrated digital infrastructures capable of supporting workflow-oriented and collaborative disaster-management education.

Technological progress alone is insufficient if human factors, training and communication practices are not addressed. Regular disaster exercises, practical training for responders, improved crisis communication and public awareness are necessary to ensure that digital tools are effectively used during real emergencies [2] [3] [8].

These limitations demonstrate the need for future-oriented interdisciplinary educational frameworks capable of integrating technological innovation, operational workflows, collaborative methodologies, and adaptive learning within one coherent disaster-management educational ecosystem.

3. Challenges Identified

3.1. Operational Challenges

Modern disaster-management operations face increasing complexity due to the growing interdependencies between technological systems, critical infrastructures, communication networks, public institutions, and societal processes. Disaster scenarios are becoming more dynamic, multi-dimensional, and difficult to manage through traditional operational approaches.

Climate change, infrastructure vulnerability, urbanisation and increasingly interconnected societal systems continue to intensify disaster-management complexity. Existing operational structures must increasingly address cascading disaster effects involving infrastructure disruption, environmental impacts, population displacement and public-health risks.

Large-scale disasters increasingly expose coordination difficulties between local, regional and national disaster-management structures. The 2021 Ahr Valley floods demonstrated that delays in information transmission, fragmented operational responsibilities and insufficient coordination between administrative levels can significantly reduce the effectiveness of emergency response activities. Another growing operational challenge is the increasing

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dependency on interconnected critical infrastructure systems. Energy networks, transport systems, communication infrastructures and healthcare systems are becoming increasingly interdependent, meaning that disruptions in one sector may rapidly create cascading operational consequences across wider disaster-management ecosystems [2] [3].
Large-scale disaster scenarios generate highly dynamic operational conditions in which manual coordination and resource allocation become increasingly difficult. The complexity of simultaneously managing rescue teams, medical support, logistics, infrastructure repair and public safety operations may exceed the cognitive and operational capacities of human-cantered coordination models [18] .
One of the primary operational challenges is maintaining effective situational awareness under rapidly evolving and uncertain conditions. Disaster-management organisations must process large volumes of information from multiple sources while simultaneously coordinating response activities across different operational actors and institutions.
Another major challenge is interoperability between systems and organisations. Communication infrastructures, monitoring platforms, operational procedures, and digital tools are often developed independently, limiting coordinated response capabilities and reducing operational efficiency during complex disaster scenarios.
Operational coordination across multiple stakeholders also remains difficult, particularly in situations involving cascading failures, infrastructure disruptions, or simultaneous natural and technological hazards. Effective coordination increasingly requires integration of real-time communication, distributed decision-making, adaptive workflows, and resilient digital infrastructures.
Military conflicts and hybrid-threat environments create additional operational challenges related to protection of nuclear facilities, evacuation planning, contamination monitoring, civilian protection and continuity of critical infrastructure operations. Such scenarios require highly coordinated multi-agency response capabilities under conditions of uncertainty and elevated societal risk.
Resource allocation and adaptive decision-making under uncertainty represent additional operational challenges. Disaster-management professionals must increasingly operate within environments characterised by incomplete information, rapidly changing conditions, and pressure for immediate response.
The growing integration of digital technologies further introduces operational challenges related to cybersecurity, data reliability, system resilience, and dependence on interconnected digital infrastructures. As disaster-management ecosystems become more technologically advanced, operational actors require stronger interdisciplinary competencies combining technological understanding with practical coordination capabilities.
These operational challenges highlight the need for integrated and workflow-oriented educational approaches capable of preparing future professionals for complex digitally enabled disaster-management environments.

3.2. Technological Challenges

The rapid digital transformation of disaster-management ecosystems introduces significant technological challenges related to integration, interoperability, scalability, reliability, and operational implementation of emerging technologies. While AI, IoT systems, sensing infrastructures, edge computing, UAVs, and distributed communication platforms offer

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substantial opportunities, their effective integration within real operational environments remains complex.
Existing disaster-management systems still suffer from significant technological limitations including lack of end-to-end workflow traceability, limited process automation, insufficient performance monitoring capabilities and weak integration between operational subsystems. Many current systems remain fragmented and rely heavily on manual decision-making processes. Another important challenge is the absence of scalable digital ecosystem platforms capable of supporting distributed operational optimisation and third-party service integration within disaster-management environments. Existing optimisation efforts are often performed off-line rather than through adaptive real-time operational platforms. The integration of heterogeneous sensing infrastructures, UAV systems, GIS platforms, IoT devices and distributed communication architectures additionally creates major challenges related to data fusion, interoperability, synchronisation and operational consistency [15] [16] [17] . Existing disaster-management systems still face challenges related to digital infrastructure resilience, interoperability between monitoring platforms, geospatial-data integration, real-time situational awareness and adaptive decision-support capabilities. Fragmented digital ecosystems may reduce operational efficiency during rapidly evolving disaster scenarios. UAV technologies, remote sensing systems and IoT-enabled monitoring infrastructures additionally create new cybersecurity, regulatory and operational coordination challenges requiring integrated governance frameworks and resilient operational architectures.
One of the primary technological challenges is interoperability between heterogeneous systems and infrastructures. Disaster-management organisations often operate using different communication protocols, monitoring systems, operational platforms, and data structures, limiting efficient information exchange and coordinated operational response.
Another major challenge is real-time data handling and operational scalability. Modern disaster-management environments generate large volumes of data from sensors, monitoring systems, UAVs, and communication networks. Processing, analysing, and operationalising these data in real time requires resilient and scalable digital infrastructures capable of functioning under uncertain and resource-constrained conditions.
Cybersecurity and digital resilience also represent growing concerns. Increasing dependence on interconnected digital systems creates vulnerabilities related to cyberattacks, communication disruptions, infrastructure failures, and operational instability during crisis situations.
One of the major technological challenges is the integration of heterogeneous data sources originating from satellite systems, UAVs, IoT sensor networks, emergency-response platforms and public communication channels. Existing disaster-management ecosystems often lack unified digital architectures capable of efficiently combining and interpreting real-time operational data across multiple organisational and geographical environments. The growing use of IoT technologies additionally introduces challenges related to distributed sensing, secure connectivity, scalable data transmission and decentralised data processing. Advanced sensing systems require reliable and energy-efficient communication infrastructures capable of supporting large volumes of continuously generated operational information. Another significant challenge is interoperability between regional and national systems. Differences in data formats, operational standards and communication protocols

may create delays and reduce the effectiveness of coordinated disaster response activities [6] [7] [8] .
WUNU's input confirms that resilient disaster-monitoring systems still face major challenges related to incompatible standards and protocols, difficulties in integrating information from diverse sources, and the secure processing of large data volumes. These challenges affect the ability of disaster-management systems to generate accurate, timely and operationally useful information during crises [28] [29] [30] .
Radiological and CBRN-related disaster scenarios require advanced monitoring, detection and risk-assessment infrastructures capable of rapidly identifying contamination levels, affected areas and potential cascading consequences. Developing accurate and adaptive risk-assessment models remains a major technological challenge within high-risk disaster-management environments. Another important challenge involves integration of quantitative risk indicators, probability estimation models and generalised safety indices into operational decision-support systems capable of supporting regional preparedness planning and resource prioritisation.
The implementation of AI-supported systems introduces additional challenges related to transparency, reliability, operational trust, ethical considerations, and human-machine interaction within critical disaster-management processes. Ensuring that AI systems support rather than complicate operational decision-making remains an important issue.
Another challenge is the uneven technological maturity and digital readiness of institutions and operational stakeholders across different regions and sectors. Limited access to advanced digital infrastructures, technical expertise, and interdisciplinary competencies can restrict the operational effectiveness of emerging technologies.
These technological challenges demonstrate the need for interdisciplinary educational frameworks capable of connecting advanced digital technologies with operational understanding, resilience-oriented thinking, and adaptive disaster-management coordination.

3.3. Educational Challenges

The educational domain faces significant challenges in adapting to the increasing complexity and digital transformation of modern disaster-management ecosystems. Traditional educational models are often insufficient for preparing future professionals capable of operating within interdisciplinary, technology-driven, and rapidly evolving operational environments.
Existing educational approaches often remain insufficiently aligned with the interdisciplinary realities of modern disaster-management ecosystems. Practical workflow-oriented exercises, interoperability training, technology-supported simulations and cross-organisational disaster-management scenarios are still limited within many educational and professional training environments. Analysis additionally highlights communication deficits and insufficient preparedness exercises as important barriers to effective disaster response. Even technologically advanced systems may fail to achieve their full operational potential if users, responders and institutions are not adequately trained to interpret information and coordinate actions under dynamic crisis conditions [2] [3] . Existing educational systems often remain insufficiently adaptive to rapidly evolving technological and operational environments.
Emerging technologies such as AI, IoT, big-data analytics, UAV systems, quantum

technologies and digital resilience infrastructures require continuous curriculum modernisation and interdisciplinary educational integration.
They often do not sufficiently address process automation, operational optimisation, digital ecosystem architectures, performance measurement systems and interdisciplinary systems-engineering approaches required for future disaster-management environments [19] [20] .
One of the main educational challenges is the fragmentation between technological and operational learning domains. Programmes related to engineering, information technologies, emergency management, resilience, and public safety are frequently developed independently, limiting interdisciplinary understanding and reducing systems-oriented competence development.
Another challenge is the limited integration of emerging technologies within disaster-management education. AI, IoT systems, sensing infrastructures, edge computing, UAVs, and data-driven decision-support systems are increasingly important operational tools, yet many educational programmes still provide limited exposure to these technologies within practical disaster-management contexts.
The gap between theoretical learning and operational practice also remains a major issue. Many educational structures lack sufficient collaborative exercises, workflow-oriented learning, scenario-based methodologies, and real-life operational simulations capable of preparing learners for dynamic disaster environments characterised by uncertainty and multi-stakeholder coordination.
Educational scalability and adaptability represent additional challenges. Rapid technological development creates growing need for continuous professional upskilling, flexible learning pathways, and lifelong learning opportunities that can support both HED and professional training environments.
There is also increasing need for educational ecosystems capable of supporting interdisciplinary collaboration, knowledge co-creation, and adaptive curriculum evolution. Traditional static educational structures are often unable to respond quickly to emerging technological trends and changing operational requirements.
These educational challenges highlight the importance of developing interdisciplinary, workflow-oriented, and continuously evolving educational frameworks capable of integrating technological innovation, operational preparedness, and collaborative learning methodologies within modern disaster-management education.

3.4. Coordination and Interoperability Challenges

Coordination and interoperability represent some of the most significant challenges within modern disaster-management ecosystems. Effective disaster response increasingly depends on the ability of multiple organisations, technological systems, operational actors, and communication infrastructures to function together within rapidly evolving and highly uncertain environments.
Germany's decentralised governance structure demonstrates how differences in regional standards, operational procedures and communication systems may complicate coordinated disaster-management activities during large-scale emergencies. Inconsistent protocols for data collection, information sharing and operational coordination may reduce interoperability between regional and national disaster-management systems. Another challenge involves the absence of unified digital ecosystems capable of supporting end-to-end operational

traceability and coordinated data fusion across multiple disaster-management actors. Fragmented data environments may slow down operational decision-making and reduce situational awareness during rapidly evolving crisis scenarios [2] [3] [8].

Many disaster-management systems continue to operate within fragmented organisational and technological structures. Public authorities, emergency responders, infrastructure operators, research institutions, and technical service providers often use different operational procedures, communication standards, digital platforms, and information-management systems. This fragmentation can reduce operational efficiency and complicate coordinated response activities during crisis situations.

Interoperability challenges are particularly important within digitally enabled disaster-management ecosystems. Monitoring systems, IoT infrastructures, sensing platforms, communication networks, AI-supported analytics, and operational coordination systems must increasingly exchange information in real time across organisational and geographical boundaries.

Another challenge is maintaining effective communication and coordinated decision-making during large-scale or cascading disaster events involving multiple operational stakeholders. Delays in information exchange, inconsistent situational awareness, and incompatible operational workflows can significantly affect response effectiveness and resilience capacities.

Another major interoperability challenge involves the coordination of distributed operational workflows across heterogeneous systems and organisations. Existing emergency-management environments frequently lack integrated digital architectures capable of supporting synchronised information exchange, workflow consistency and coordinated process management across multiple operational actors. Current GIS and event-driven systems additionally face limitations in maintaining consistency between distributed operational models, live field operations and digital representations of disaster-management activities [21] [22] .

Effective disaster management additionally requires strong alignment between national legislation, regional preparedness plans, early-warning infrastructures, critical-infrastructure protection systems and operational coordination mechanisms. Differences between institutional procedures and governance frameworks may complicate coordinated multi-level disaster response.

The growing complexity of digital infrastructures additionally creates challenges related to integration between technological systems and human operational processes. Disaster-management professionals increasingly require interdisciplinary competencies allowing them to understand both technological capabilities and operational coordination requirements.

These coordination and interoperability challenges highlight the need for interdisciplinary educational approaches focused on systems thinking, workflow-oriented learning, collaborative methodologies, and integrated operational understanding within modern disaster-management environments.

3.5. Resilience and Preparedness Challenges

Modern disaster-management ecosystems face growing challenges related to resilience, preparedness, and the ability to adapt to increasingly complex and interconnected disaster scenarios. Climate change, critical infrastructure dependencies, technological disruptions,

cyber-physical risks, and cascading failures create operational environments that require stronger adaptive capacities and long-term resilience-oriented planning.
As disaster-management systems become increasingly digitalised, system resilience and cybersecurity become critical preparedness concerns. IoT infrastructures, AI-supported systems, cloud platforms and interconnected communication architectures may introduce new vulnerabilities if sufficient redundancy, backup mechanisms and cybersecurity protections are not implemented. Cyberattacks targeting critical infrastructure, healthcare systems and operational communication platforms demonstrate the growing importance of resilient digital architectures capable of maintaining operational continuity during crisis situations. Future disaster-management systems must therefore combine technological innovation with robust cybersecurity and recovery capacities. Lack of redundancy is a major vulnerability within disaster-management ecosystems. Failure of a single critical subsystem may compromise data collection, communication and operational coordination across the wider response chain [9] [10] [11] .
One of the major challenges is maintaining continuity of operations during large-scale or prolonged disaster events. Critical infrastructures, communication systems, digital platforms, transportation networks, and emergency-response mechanisms are increasingly interconnected, meaning that disruptions in one domain can rapidly affect multiple operational systems and societal functions.
Current disaster-management systems additionally suffer from limited online monitoring and adaptive control capabilities. In many cases, operational deviations, delays and inefficiencies cannot be detected or corrected in real time, reducing the resilience and adaptability of disaster-response processes during rapidly evolving emergencies.
Preparedness also remains uneven across different institutions, regions, and operational sectors. Variations in technological readiness, operational coordination capabilities, training levels, and access to digital infrastructures can significantly influence disaster-response effectiveness and resilience capacities.
Another challenge is the growing dependence on digital systems within disaster-management operations. While digital technologies improve monitoring, coordination, and decision-making, they also introduce vulnerabilities related to cybersecurity, communication reliability, infrastructure failures, and operational dependence on interconnected systems.
Cyber-resilience is becoming a core requirement of disaster-management preparedness. As AI, IoT and cloud-based systems become more embedded in monitoring and emergency-management infrastructures, systems must be designed to withstand cyberattacks, recover functionality rapidly and minimise operational disruption during crisis conditions [28] [30] .
The increasing complexity of disaster scenarios additionally requires stronger interdisciplinary preparedness approaches integrating technological understanding, operational coordination, resilience engineering, and adaptive decision-making. Traditional preparedness models are often insufficient for addressing highly dynamic and multi-dimensional disaster environments.
The increasing possibility of radiological contamination, attacks on critical infrastructure and hybrid warfare scenarios further strengthens the importance of long-term societal resilience and preparedness planning. Disaster-management ecosystems must increasingly prepare for complex cascading emergencies involving environmental contamination, infrastructure disruption, public-health risks and large-scale population protection requirements.

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Educational preparedness also represents an important challenge. Future professionals require continuous upskilling, interdisciplinary competencies, workflow-oriented understanding, and practical operational training capable of supporting resilience-oriented disaster-management ecosystems.
These resilience and preparedness challenges demonstrate the need for adaptive educational frameworks capable of strengthening systems thinking, operational awareness, collaborative coordination, and digitally enabled resilience capacities within modern disaster-management environments.

4. Key Trends and Future Drivers

The disaster-management sector is undergoing rapid transformation driven by technological innovation, environmental pressures, digitalisation, and evolving societal expectations. These developments are reshaping operational workflows, resilience strategies, educational requirements, and the competencies needed by future disaster-management professionals.
One of the most important future drivers is the increasing integration of digital technologies within disaster-management ecosystems. AI-supported analytics, IoT systems, distributed sensing infrastructures, UAVs, edge computing, and real-time communication platforms are expected to become central components of preparedness, monitoring, operational coordination, and adaptive response activities.
Climate change and environmental instability are also expected to intensify the frequency, scale, and complexity of disaster events. Future disaster scenarios will likely involve stronger interdependencies between natural hazards, critical infrastructures, industrial systems, and societal vulnerabilities, creating growing need for resilience-oriented and interdisciplinary operational approaches.
Another important trend is the transition toward data-driven and workflow-oriented disaster management. Real-time situational awareness, predictive modelling, distributed coordination systems, and intelligent operational platforms are increasingly influencing how disaster-management decisions are made and implemented.
The educational landscape is also evolving in response to these changes. Future disaster-management education will require stronger integration between technological and operational domains, greater emphasis on systems thinking, collaborative learning, practical scenarios, and continuous professional upskilling across both HED and LLL.
Digital learning environments, remote collaboration platforms, and adaptive educational ecosystems are becoming increasingly important for ensuring accessibility, scalability, and international interdisciplinary cooperation within disaster-management education.
These trends and future drivers form the strategic context within which the SUDEM educational ecosystem and curricular framework are being developed.

4.1. AI-Driven Disaster Management

Artificial intelligence is expected to become one of the most transformative drivers of future disaster-management ecosystems. AI-supported analytics, predictive modelling, intelligent automation, and adaptive decision-support systems are increasingly influencing how disaster events are monitored, analysed, and managed across operational environments.

Future disaster-management systems will increasingly rely on AI to process large volumes of operational data generated by sensors, IoT infrastructures, UAVs, communication networks, and monitoring platforms. AI technologies are expected to improve situational awareness, risk assessment, early-warning capabilities, resource allocation, and operational coordination during rapidly evolving disaster scenarios. AI-supported forecasting, predictive modelling, weak-signal detection and adaptive operational analysis are expected to increasingly support anticipatory disaster-management processes and improve strategic preparedness capabilities.

Future disaster-management ecosystems are expected to increasingly adopt AI-supported process automation, adaptive scheduling systems, machine-learning-supported optimisation and automated demand-generation mechanisms capable of dynamically coordinating operational resources during large-scale emergencies. Simulation-oriented learning systems and machine-learning-supported operational models may additionally enable continuous improvement of disaster-response strategies based on accumulated operational data and simulated disaster scenarios [16] [18] .

Another important trend is the growing use of machine learning and predictive analytics for forecasting disaster development and identifying operational vulnerabilities. These technologies may support more proactive and resilience-oriented disaster-management strategies by enabling earlier interventions and more adaptive response planning.

AI is also expected to contribute to automation and distributed operational coordination through intelligent monitoring systems, autonomous platforms, and multi-agent coordination mechanisms. Such developments may significantly increase operational efficiency in complex and resource-constrained environments.

At the same time, the expansion of AI within disaster management introduces important challenges related to transparency, operational trust, ethical considerations, cybersecurity, and human-machine interaction. Future professionals will therefore require interdisciplinary competencies allowing them to critically evaluate AI-supported operational systems and integrate them effectively within real disaster-management workflows.

AI and machine-learning methods are expected to play an increasingly important role in anomaly detection, disaster forecasting, weak-signal identification and evidence-based decision-making. These capabilities can support earlier detection of threats and improve the quality of operational decisions before disasters fully develop [31] [32] .

These developments demonstrate the growing importance of integrating AI-related competencies, operational understanding, and adaptive digital literacy within future disaster-management education across both HED and LLL environments.

4.2. IoT and Distributed Sensing

The expansion of IoT systems and distributed sensing infrastructures is expected to play a central role in the future evolution of disaster-management ecosystems. Increasing numbers of interconnected sensors, monitoring devices, UAVs, remote observation platforms, and communication systems are transforming how operational information is collected, transmitted, and utilised during disaster preparedness and response activities.

Future disaster-management environments will increasingly depend on real-time situational awareness enabled through distributed sensing networks capable of continuously monitoring environmental conditions, infrastructure stability, operational risks, and emergency

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developments. IoT technologies are expected to strengthen early-warning capabilities, improve operational coordination, and support faster and more adaptive decision-making processes. Integration between UAV systems, IoT infrastructures, geospatial technologies, remote sensing platforms and multispectral monitoring systems is expected to significantly strengthen real-time situational awareness and environmental monitoring capabilities.

The growing use of UAVs, distributed sensing infrastructures, smart devices, mobile systems, airborne monitoring platforms and data-fusion architectures is expected to significantly enhance disaster situation awareness capabilities. Future disaster-management ecosystems will increasingly rely on heterogeneous multi-source sensing environments capable of supporting real-time situational analysis. Data fusion systems combining satellite observation, UAV sensing, IoT infrastructures, smart devices, GIS systems and field-based sensors are expected to become increasingly important for improving operational awareness, detection accuracy and adaptive response coordination [17] [23] .

Another important trend is the growing integration of heterogeneous sensing systems within interconnected operational platforms. Smart infrastructures, remote monitoring technologies, mobile sensing devices, and distributed communication systems are expected to contribute to more resilient and data-driven disaster-management operations.

Future disaster-management ecosystems are expected to increasingly integrate distributed environmental monitoring systems capable of supporting radiological, chemical and biological threat detection through interconnected sensing infrastructures and real-time situational analysis platforms.

The increasing use of UAVs and autonomous observation systems is also expected to expand operational monitoring capabilities, particularly in hazardous or inaccessible environments where traditional observation methods may be limited or unsafe.

At the same time, the growing complexity of distributed sensing ecosystems introduces important challenges related to interoperability, cybersecurity, communication reliability, data management, and operational scalability. Future professionals will therefore require stronger interdisciplinary competencies related to digital infrastructures, sensing technologies, and workflow-oriented operational integration.

These developments highlight the growing importance of integrating IoT systems, sensing technologies, and distributed operational awareness within future disaster-management education and interdisciplinary competence development.

Future disaster-management ecosystems will increasingly depend not on isolated technologies, but on convergence between AI, distributed sensing, geospatial systems, autonomous platforms, digital twins, cloud infrastructures and resilient cybersecurity architectures. This technological convergence is illustrated in the following figure:

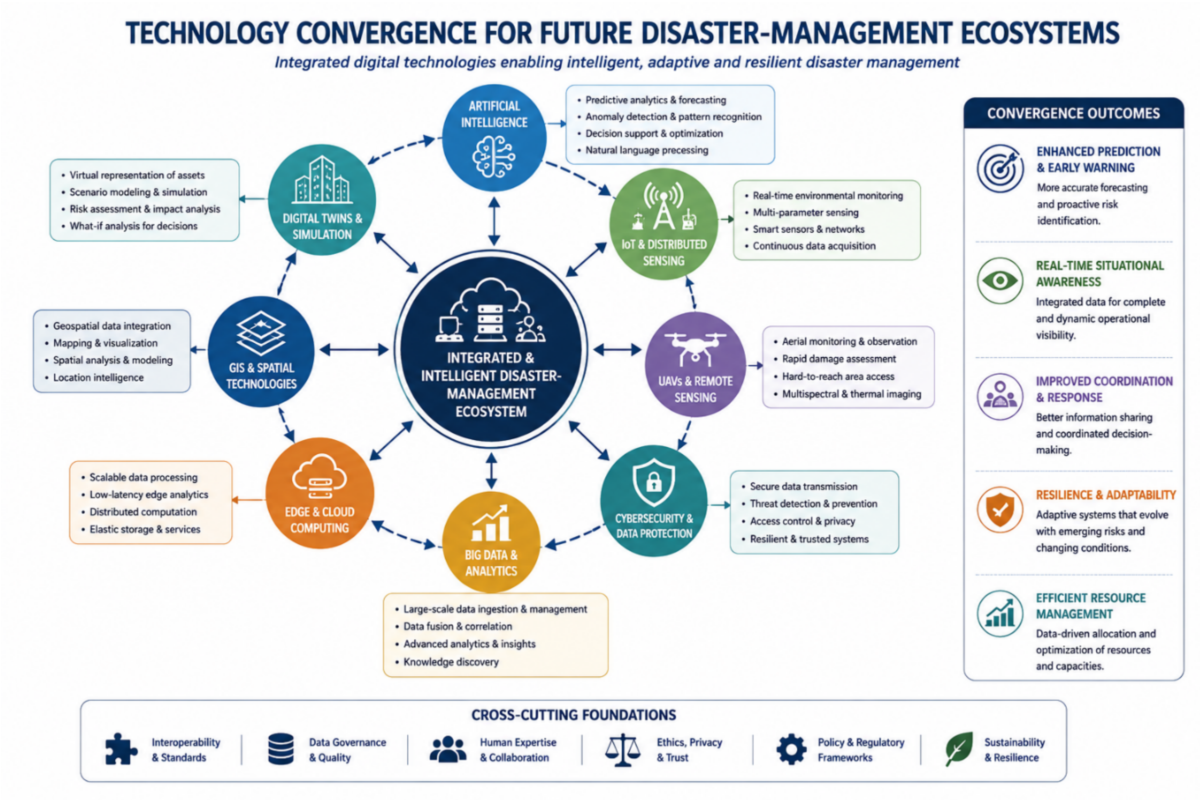

Figure 3. Technology convergence within future disaster-management ecosystems

4.3. Autonomous and Multi-Agent Systems

Autonomous systems and multi-agent coordination technologies are expected to become increasingly important within future disaster-management ecosystems. Advances in AI, distributed computing, robotics, UAV technologies, and intelligent coordination systems are enabling the development of operational environments where multiple autonomous entities can cooperate dynamically during disaster preparedness and response activities.

Future disaster-management operations are likely to involve distributed networks of intelligent agents capable of monitoring environments, exchanging operational information, supporting decision-making, and coordinating response activities in real time. These systems may include autonomous UAVs, mobile sensing platforms, intelligent monitoring infrastructures, and distributed communication agents operating collaboratively across complex operational environments. Future UAV ecosystems are expected to increasingly integrate autonomous navigation, AI-supported decision-making, connected IoT architectures and adaptive coordination capabilities supporting disaster monitoring, logistics, rescue missions and infrastructure inspection activities.

Swarm-based UAV systems, Advanced Air Mobility (AAM) architectures and autonomous multi-agent operational ecosystems are expected to create new opportunities for large-scale disaster monitoring, distributed sensing, autonomous logistics and adaptive coordination of disaster-response activities. Future disaster-management environments may increasingly integrate autonomous aerial systems, connected vehicles, smart mobile devices and distributed operational agents within coordinated cyber-physical disaster-response ecosystems [24] [25] .

Multi-agent systems are expected to improve operational scalability and adaptive coordination, particularly during large-scale or rapidly evolving disaster scenarios involving multiple stakeholders and geographically distributed operational activities. Intelligent coordination mechanisms may support resource allocation, situational awareness, operational synchronisation, and resilience-oriented response planning.
Another important trend is the increasing integration between autonomous systems and human operational actors. Future disaster-management ecosystems will likely depend on hybrid operational models combining human expertise, AI-supported analytics, and distributed autonomous coordination systems.
At the same time, these developments introduce important challenges related to operational trust, interoperability, cybersecurity, ethical governance, communication reliability, and human-machine collaboration. Disaster-management professionals will therefore require stronger interdisciplinary understanding of both technological systems and operational coordination processes.
The increasing use of autonomous aerial systems additionally creates new operational and security challenges related to critical infrastructure protection, coordinated airspace management, and resilient operational control architectures. Future disaster-management ecosystems will increasingly require integrated approaches balancing the operational benefits of autonomous systems with cybersecurity, safety, and infrastructure-protection requirements.
These trends highlight the growing importance of integrating autonomous systems, distributed coordination logic, and adaptive operational thinking within future disaster-management education and interdisciplinary competence development.

4.4. Edge Computing and Real-Time Operations

Edge computing is expected to become an increasingly important component of future disaster-management ecosystems due to the growing need for real-time operational responsiveness, distributed data processing, and resilient digital infrastructures. As disaster-management operations rely on expanding volumes of sensing data and interconnected digital systems, centralised processing approaches may become insufficient for dynamic and resource-constrained operational environments.
The increasing digitalisation of disaster-management ecosystems is expected to strengthen the importance of resilient event-driven architectures, distributed synchronisation mechanisms, operational consistency management and secure digital-twin infrastructures capable of supporting adaptive real-time coordination [21] .
Future disaster-management systems are likely to depend on distributed edge infrastructures capable of processing operational information closer to the point of data generation. This approach can improve response speed, reduce communication delays, strengthen operational continuity, and support adaptive decision-making during rapidly evolving disaster scenarios.
Edge computing is also expected to strengthen the operational integration of IoT systems, distributed sensing networks, UAVs, AI-supported analytics, and autonomous coordination systems. Real-time local processing may improve situational awareness and operational resilience, particularly in environments where communication reliability or access to centralised infrastructures is limited.

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The growing interconnection between critical infrastructure protection, nuclear safety, digital monitoring systems and hybrid-threat environments is expected to significantly strengthen the importance of resilient security architectures capable of supporting operational continuity during complex crisis scenarios.

Another important trend is the growing role of decentralised operational architectures within disaster management. Distributed digital infrastructures may contribute to greater system resilience by reducing dependence on single centralised systems and improving adaptability during infrastructure disruptions or communication failures.

At the same time, edge computing introduces challenges related to interoperability, cybersecurity, infrastructure scalability, distributed coordination, and integration between local and centralised operational systems. Future disaster-management professionals will therefore require stronger competencies related to distributed digital infrastructures and workflow-oriented operational integration.

These developments highlight the increasing importance of edge computing and resilient real-time operational systems within future disaster-management education and interdisciplinary competence development.

4.5. Climate Change and Cascading Disasters

Climate change is expected to significantly influence the future evolution of disaster-management ecosystems by increasing the frequency, intensity, and unpredictability of extreme events. Rising temperatures, changing weather patterns, floods, droughts, wildfires, storms, and other climate-related hazards are creating increasingly complex operational environments requiring stronger resilience and adaptive preparedness capacities.

One of the most important future challenges is the growing occurrence of cascading disasters, where disruptions in one system or infrastructure generate secondary impacts across interconnected operational, technological, environmental, and societal domains. Critical infrastructures such as energy systems, transportation networks, communication platforms, healthcare systems, and industrial facilities are becoming increasingly interdependent, amplifying the potential consequences of disaster events.

Future disaster-management operations will therefore require more integrated and interdisciplinary approaches capable of addressing simultaneous and interconnected hazards. Traditional linear disaster-response models are expected to become increasingly insufficient for managing highly dynamic and multi-dimensional disaster environments.

Climate-related risks are also expected to intensify pressures on urban environments, industrial infrastructures, and resource management systems, creating growing need for resilience-oriented operational planning and adaptive coordination mechanisms.

Another important trend is the increasing importance of predictive monitoring, real-time situational awareness, and data-driven preparedness systems capable of supporting earlier interventions and more adaptive operational responses within uncertain environmental conditions. Community-based disaster-management approaches are expected to become increasingly important for strengthening local resilience, participatory preparedness, public awareness and collaborative disaster-response capacities.

These developments highlight the growing importance of integrating climate resilience, systems thinking, interdisciplinary coordination, and adaptive operational preparedness within future disaster-management education across both HED and LLL environments.

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4.6. Digital Resilience and Critical Infrastructure Protection

Digital resilience and protection of critical infrastructures are expected to become increasingly central priorities within future disaster-management ecosystems. Modern societies are becoming progressively dependent on interconnected digital systems, communication networks, energy infrastructures, transportation systems, healthcare platforms, industrial facilities, and data-driven operational environments. As a result, disruptions affecting digital infrastructures may generate significant cascading operational and societal impacts.

Digital technologies are increasingly recognised as enablers of climate resilience for critical infrastructure. Integrated risk models, resilient monitoring systems, secure data platforms and adaptive decision-support tools can improve the ability of infrastructure systems to anticipate, absorb and recover from climate-related and technological disruptions [30] [33] .

Future disaster-management environments will therefore require stronger resilience-oriented approaches capable of maintaining operational continuity under conditions of cyber-physical disruption, infrastructure failure, communication breakdown, or large-scale disaster events. The increasing integration of AI, IoT systems, edge computing, and distributed sensing networks further amplifies the importance of resilient and secure digital infrastructures.

Cybersecurity is expected to become an increasingly important component of disaster preparedness and operational coordination. Disaster-management organisations will need to address risks related to cyberattacks, unauthorised access, data manipulation, communication disruptions, and vulnerabilities within interconnected digital ecosystems.

Another important trend is the growing need for redundancy, decentralisation, and adaptive operational architectures capable of maintaining functionality during infrastructure failures or degraded operational conditions. Distributed digital systems and resilient communication mechanisms are expected to play a critical role in future preparedness and response strategies.

The protection of critical infrastructures will also require stronger interdisciplinary cooperation between technological experts, operational responders, infrastructure operators, public authorities, and resilience specialists. Effective preparedness increasingly depends on integrated understanding of both technological systems and operational workflows.

These developments highlight the growing importance of digital resilience, cybersecurity awareness, infrastructure protection, and adaptive operational coordination within future disaster-management education and interdisciplinary competence development.

4.7. Lifelong Learning and Continuous Upskilling

The rapid evolution of digital technologies and the increasing complexity of disaster-management environments are expected to significantly increase the importance of lifelong learning and continuous professional upskilling. Future disaster-management professionals will need to continuously adapt to emerging technologies, evolving operational workflows, new risk environments, and changing resilience requirements throughout their careers.

Traditional educational models based solely on initial academic qualification are becoming increasingly insufficient within digitally transformed operational ecosystems. AI, IoT systems, sensing technologies, edge computing, autonomous coordination systems, and data-driven

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operational platforms are developing rapidly, creating constant need for updated competencies and interdisciplinary knowledge.

Future disaster-management education is therefore expected to rely more heavily on flexible and adaptive lifelong learning ecosystems capable of supporting professionals across different operational sectors and educational backgrounds. Continuous upskilling will become increasingly important for emergency responders, public authorities, infrastructure operators, technical specialists, educators, and organisational decision-makers.

Digital learning environments and remote educational platforms are also expected to play a growing role in supporting accessibility, scalability, interdisciplinary collaboration, and international knowledge exchange within disaster-management education. Hybrid learning models combining online education, collaborative activities, practical exercises, and workflow-oriented methodologies are likely to become increasingly common.

Another important trend is the growing need for interdisciplinary competence development rather than narrowly specialised technical training. Future professionals will increasingly require systems thinking, operational adaptability, collaborative coordination skills, and understanding of interconnected technological and organisational ecosystems.

These developments highlight the importance of integrating lifelong learning, adaptive educational methodologies, and continuous competence development within the future-oriented educational architecture of SUDEM.

4.8. Increasing Importance of Interdisciplinary Education

The growing complexity of disaster-management ecosystems is expected to significantly increase the importance of interdisciplinary education in the coming years. Future disaster scenarios will increasingly involve interactions between technological systems, operational infrastructures, environmental risks, communication networks, organisational coordination processes, and societal resilience mechanisms. As a result, single-domain educational approaches are becoming increasingly insufficient.

Future disaster-management professionals will require competencies extending beyond traditional disciplinary boundaries. Technical specialists will need stronger understanding of operational workflows and coordination processes, while operational actors will increasingly require digital literacy and understanding of AI, IoT systems, sensing technologies, and data-driven decision-support mechanisms.

Another important trend is the increasing integration between technological and organisational dimensions of disaster management. Effective preparedness and response will depend not only on advanced technologies, but also on collaborative coordination, adaptive decision-making, communication reliability, and workflow-oriented operational understanding.

Interdisciplinary education is also expected to become increasingly important for strengthening systems thinking and resilience-oriented approaches. Learners will need to understand how different infrastructures, technologies, operational actors, and societal systems interact within interconnected and rapidly evolving disaster environments.

Collaborative learning methodologies, practical exercises, scenario-based activities, and workflow-oriented educational approaches are expected to become more central within future educational ecosystems. Such methodologies can support stronger communication, interdisciplinary cooperation, and adaptive problem-solving capabilities.

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The growing importance of lifelong learning further reinforces the need for flexible interdisciplinary educational frameworks capable of integrating HED, professional training, and continuous competence development within one adaptive educational ecosystem. These developments strongly support the interdisciplinary educational philosophy of SUDEM and the project's focus on integrated, workflow-oriented, and digitally enabled disaster-management education.

5. Future Needs

5.1. Operational Needs

Future disaster-management ecosystems will require increasingly adaptive, interconnected, and resilience-oriented operational structures capable of functioning effectively under complex and rapidly evolving conditions. Modern disaster scenarios are expected to involve stronger interdependencies between technological infrastructures, communication systems, environmental risks, organisational coordination mechanisms, and societal resilience capacities.

Future disaster-management ecosystems will increasingly require adaptive operational coordination systems capable of automatically generating operational demands, prioritizing response tasks and dynamically allocating resources under uncertain and resource-constrained disaster conditions [18] .

One of the most important future operational needs is improved situational awareness supported through real-time monitoring, distributed sensing infrastructures, AI-supported analytics, and integrated communication systems. Disaster-management organisations will increasingly depend on accurate and timely operational information in order to support adaptive decision-making and coordinated response activities.

Future disaster-management systems will increasingly require preparedness capabilities related to radiological, chemical and biological emergencies, including evacuation coordination, contamination monitoring, population protection, infrastructure continuity management and long-term environmental recovery planning. They will also require stronger integration between climate adaptation policies, resilience planning, critical-infrastructure protection, early-warning systems and coordinated multi-level governance frameworks.

Another critical operational need is stronger interoperability between organisations, technological systems, and operational workflows. Future disaster-management environments will require more integrated communication standards, collaborative coordination mechanisms, and shared operational platforms capable of supporting multi-stakeholder response activities across different sectors and geographical regions.

Operational resilience and continuity management will also become increasingly important. Disaster-management systems must remain capable of functioning under conditions of infrastructure disruption, communication instability, cyber-physical threats, and cascading operational failures. This creates growing need for resilient digital infrastructures, decentralised operational architectures, and adaptive coordination models.

Future operational environments will additionally require stronger integration between human decision-making and intelligent technological systems. AI-supported operational coordination, distributed sensing, autonomous platforms, and workflow-oriented digital

ecosystems are expected to become increasingly central within disaster-management operations.
Future disaster-management ecosystems will also require stronger preparedness approaches related to cultural and built heritage protection. Historic buildings, cultural infrastructures, and heritage environments are increasingly exposed to climate-related risks, floods, fires, warfare-related destruction, and cascading infrastructure failures. This creates growing need for interdisciplinary disaster-management competencies integrating resilience planning, digital monitoring, risk assessment, and adaptive protection methodologies for heritage environments.
Future technological integration should include unified standards, adaptive systems, specialised data-integration platforms, common data formats, modern encryption, two-factor authentication, regular security audits, continuous threat monitoring and incident-response planning. These measures are necessary to ensure that disaster-monitoring platforms remain interoperable, secure and resilient [28] [29] [30] .
These developments demonstrate the need for future professionals capable of combining technological understanding with operational coordination, systems thinking, resilience-oriented planning, and adaptive response capabilities within complex digitally enabled disaster-management ecosystems.

5.2. Technological Needs

Future disaster-management ecosystems will require significantly stronger integration between technological systems, operational workflows, communication infrastructures, and decision-support mechanisms. As digital technologies continue to expand across preparedness and response activities, isolated technological implementations will become increasingly insufficient for supporting effective and resilient disaster-management operations. Future technological ecosystems will increasingly require integration between AI, IoT, big-data analytics, UAV systems, geospatial infrastructures, remote sensing technologies and adaptive digital coordination platforms capable of supporting resilient disaster-management operations.
The convergence of distributed sensing infrastructures, AI-supported analytics, interoperable communication systems, digital-twin technologies and adaptive operational coordination platforms can be conceptualised as one integrated digital disaster-management ecosystem, illustrated in the following figure:

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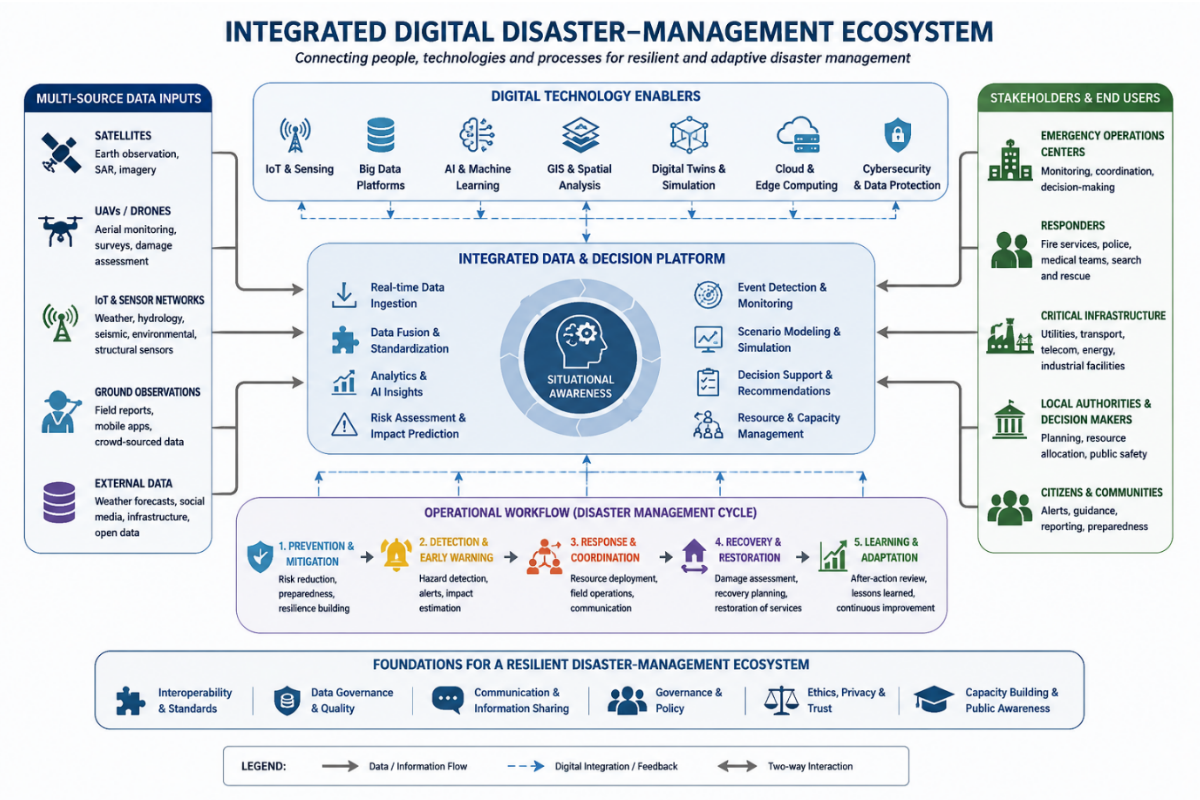

Figure 4. Integrated digital disaster-management ecosystem

One of the key future needs is interoperability between heterogeneous digital systems, including IoT infrastructures, sensing platforms, AI-supported analytics, UAVs, communication networks, and operational coordination systems. Future operational environments will require seamless information exchange and coordinated functionality across multiple technological and organisational domains.

Another important need is integration between real-time data collection, distributed processing, and adaptive operational decision-making. Monitoring systems, edge-computing infrastructures, and intelligent analytical platforms must increasingly function within unified workflow-oriented ecosystems capable of supporting dynamic operational coordination under uncertain conditions.

Future disaster-management operations will also require stronger integration between human operational actors and intelligent technological systems. AI-supported decision-support tools, autonomous coordination mechanisms, and distributed sensing infrastructures must be implemented in ways that enhance rather than complicate operational workflows and collaborative response activities.

Future disaster-management architectures will require integrated digital ecosystem platforms capable of combining process automation, distributed sensing, GIS systems, digital twins, AI-supported optimisation, workflow monitoring and adaptive decision-support systems within one coordinated operational environment. Real-time data fusion, event-driven operational architectures and digital-twin synchronisation mechanisms are expected to become increasingly important for maintaining situational awareness, operational traceability and adaptive coordination during rapidly evolving disaster scenarios [16] [21] [22] .

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Cybersecurity, digital resilience, and operational continuity will become increasingly important components of technological integration strategies. Future disaster-management infrastructures must remain secure, adaptive, and operationally reliable even during large-scale disruptions or cyber-physical incidents.
Future disaster-management ecosystems will increasingly require integrated risk-assessment platforms capable of combining probability analysis, damage estimation, safety indices, environmental monitoring and operational decision-support systems within coordinated preparedness architectures. Adaptive risk matrices and generalised safety-index methodologies may support prioritisation of preparedness investments, critical-infrastructure protection measures and regional disaster-management planning activities.
Another major future need is educational integration. Professionals will increasingly require interdisciplinary competencies allowing them to understand both technological capabilities and operational implications of digitally enabled disaster-management ecosystems.
Future disaster-management ecosystems will increasingly require integrated digital decision-support architectures capable of combining live operational information, GIS-based situational awareness, distributed sensing infrastructures, satellite observation systems, UAV-supported monitoring, and real-time operational analytics within one coordinated framework. Such architectures will become essential for adaptive operational coordination, multi-level decision-making support, and resilient disaster-response management under rapidly evolving conditions.
These developments demonstrate the growing importance of integrated technological architectures and interdisciplinary educational frameworks capable of connecting digital innovation with operational preparedness, resilience, and adaptive disaster-management coordination.

5.3. Educational Needs

Future disaster-management ecosystems require educational models that are interdisciplinary, adaptive, technologically informed, and strongly connected to operational realities. Traditional educational structures are increasingly insufficient for preparing professionals capable of operating within digitally enabled and highly interconnected disaster-management environments.
One of the primary future educational needs is stronger integration between technological and operational learning domains. Future educational ecosystems will increasingly require modular digital curricula supporting interdisciplinary competence development in AI, IoT, big-data analytics, digital resilience, geospatial systems, UAV technologies, critical-infrastructure protection and adaptive disaster-management coordination. Educational programmes must increasingly combine AI, IoT systems, sensing technologies, edge computing, communication infrastructures, resilience engineering, and operational coordination within one coherent learning ecosystem.
Another important need is the transition toward workflow-oriented and systems-based educational approaches. Future learners must understand not only individual technologies or operational procedures, but also how monitoring, information processing, decision-making, operational response, and resilience mechanisms interact within real disaster-management workflows.

Practical and scenario-based learning will also become increasingly important. Future educational ecosystems should integrate collaborative exercises, simulations, workflow analyses, and real-life disaster scenarios capable of strengthening operational awareness, adaptive problem-solving, and interdisciplinary coordination skills.
Educational flexibility and scalability represent additional future needs. Disaster-management education must support both HED and LLL environments while enabling continuous professional upskilling and adaptation to emerging technological developments.
Digital learning environments and collaborative online platforms are expected to become increasingly important for accessibility, international cooperation, interdisciplinary interaction, and adaptive curriculum evolution. Educational ecosystems will need to support remote collaboration, hybrid learning methodologies, and continuous knowledge exchange between academic, professional, and institutional stakeholders.
Future educational ecosystems will increasingly require interdisciplinary competence development related to process automation, systems engineering, AI-supported optimisation, data-fusion methodologies, GIS systems, digital twins, operational modelling and workflow-oriented disaster-management architectures [15] [20] .
Future educational ecosystems will increasingly require interdisciplinary training related to radiation protection, CBRN preparedness, risk-assessment methodologies, critical-infrastructure resilience and hybrid-threat response capabilities. Such competencies are becoming increasingly important due to the growing complexity of geopolitical and technological risk environments.
These developments demonstrate the growing need for future-oriented interdisciplinary educational frameworks such as SUDEM that integrate technological innovation, operational preparedness, collaborative learning, and adaptive competence development within one coherent disaster-management educational ecosystem.

5.4. Skills and Competencies

Future disaster-management ecosystems will require a new generation of interdisciplinary competencies combining technological understanding, operational awareness, resilience-oriented thinking, and adaptive coordination capabilities. As digital transformation continues to reshape disaster-management processes, professionals will increasingly need to operate across interconnected technological and organisational environments.
One of the most important future competence needs relates to digital literacy and understanding of emerging technologies. Future professionals will require practical knowledge of AI-supported systems, IoT infrastructures, distributed sensing technologies, UAVs, edge computing, communication platforms, and data-driven operational environments. Disaster-management professionals will increasingly require competencies related to horizon scanning, anticipatory planning, emerging-technology assessment, digital systems integration and adaptive resilience-oriented decision-making.
At the same time, technological expertise alone will be insufficient. Disaster-management professionals will increasingly require workflow-oriented understanding, systems thinking, and the ability to coordinate effectively across multiple operational stakeholders and organisational structures. Adaptive decision-making, collaborative coordination, and resilience-oriented operational analysis will become increasingly important competencies.

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Another major future need is interdisciplinary competence development. Professionals must be capable of understanding how technological systems, communication infrastructures, operational workflows, and societal resilience mechanisms interact within complex disaster-management ecosystems.
Future educational ecosystems will also need to strengthen practical and scenario-based competencies through collaborative exercises, simulations, workflow analyses, and real-life disaster scenarios. Operational preparedness and adaptive problem-solving capabilities are expected to become increasingly important under rapidly evolving and uncertain disaster conditions.
Future disaster-management professionals will increasingly require competencies related to quantitative risk analysis, probabilistic assessment methodologies, infrastructure-vulnerability analysis and interdisciplinary coordination within high-risk operational environments.
The growing pace of technological change additionally creates increasing need for continuous upskilling and lifelong learning capacities. Future professionals will need flexible educational pathways capable of supporting continuous adaptation to emerging technologies, operational models, and resilience requirements across both HED and LLL environments.

5.5. HED and LLL Requirements

Future disaster-management education will require stronger integration between HED and LLL in order to support continuous competence development within rapidly evolving technological and operational environments. The growing pace of digital transformation, emerging disaster risks, and interdisciplinary operational requirements creates increasing need for educational ecosystems that remain flexible, scalable, and continuously adaptive.
Higher Education institutions will increasingly need to provide interdisciplinary programmes combining technological competencies, operational coordination, resilience-oriented thinking, and workflow-based disaster-management methodologies. Academic programmes must prepare learners not only for current operational environments, but also for future technological and organisational transformations affecting disaster-management ecosystems.
At the same time, Lifelong Learning will become increasingly important for supporting continuous professional upskilling and adaptation to emerging technologies such as AI, IoT systems, distributed sensing infrastructures, edge computing, and intelligent operational coordination systems. Disaster-management professionals will require continuous educational opportunities throughout their careers.
Future HED and LLL environments will also need to support more flexible and hybrid educational models combining digital learning platforms, collaborative online activities, practical exercises, simulations, and interdisciplinary workshops. Accessibility, scalability, and international cooperation are expected to become increasingly important educational requirements.
Another important future requirement is stronger collaboration between universities, professional organisations, public institutions, emergency-management stakeholders, and technological experts. Educational ecosystems must increasingly support interdisciplinary knowledge exchange and integration between academic learning and operational practice.

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The growing complexity of disaster-management ecosystems additionally requires educational frameworks capable of supporting adaptive curriculum evolution and continuous integration of emerging technologies and operational methodologies.
These developments strongly support the SUDEM educational philosophy, which combines interdisciplinary Higher Education and Lifelong Learning within one scalable, workflow-oriented, and digitally enabled disaster-management educational ecosystem.

6. Future Scenarios

The future development of disaster-management ecosystems may evolve along different technological, operational, and educational pathways depending on the pace of digital transformation, institutional adaptation, interdisciplinary cooperation, and resilience-oriented investment. The foresight analysis identifies several possible development scenarios that illustrate how future disaster-management environments and educational systems may evolve over the coming years.
These scenarios are not predictions, but strategic future perspectives intended to support understanding of possible development trajectories and their implications for disaster-management education, operational preparedness, and interdisciplinary competence development.
A major differentiating factor between the scenarios is the degree of integration between technological systems, operational workflows, educational ecosystems, and resilience-oriented coordination mechanisms. The scenarios also reflect differences in digital maturity, interoperability, institutional cooperation, and adaptability of educational structures across HED and LLL environments.
The future scenarios additionally help identify the educational and operational conditions under which digitally enabled disaster-management ecosystems can function effectively and sustainably. Particular attention is given to the role of AI, IoT systems, distributed sensing infrastructures, edge computing, workflow-oriented coordination, interdisciplinary education, and continuous professional upskilling.
The preferred future direction identified through the foresight analysis is an advanced integrated scenario characterised by strong interoperability, interdisciplinary cooperation, adaptive educational ecosystems, resilient digital infrastructures, and workflow-oriented disaster-management operations supported by continuous learning and technological integration.
These scenarios provide the strategic context for the development of the SUDEM curriculum architecture, Knowledge Transfer framework, and future-oriented educational methodologies.

6.1. Conservative Scenario

In the conservative scenario, disaster-management ecosystems continue to evolve slowly and remain characterised by fragmented operational structures, limited interoperability, and uneven technological integration. Digital transformation progresses gradually, but many organisations continue to rely on traditional operational procedures and isolated technological systems.

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AI, IoT systems, distributed sensing infrastructures, and advanced communication platforms are adopted selectively rather than systematically across disaster-management environments. Technological implementation remains uneven between institutions, sectors, and regions, limiting the effectiveness of integrated operational coordination and real-time situational awareness.

Educational systems also evolve slowly within this scenario. Many HED programmes continue to operate within traditional disciplinary boundaries, while interdisciplinary integration between technological and operational domains remains limited. LLL opportunities exist, but are fragmented and insufficiently connected to rapidly evolving operational and technological requirements.

Operational coordination and interoperability challenges remain significant. Disaster-management organisations continue to face difficulties related to communication standardisation, data sharing, collaborative workflows, and integration between digital infrastructures and operational procedures.

Preparedness and resilience capacities improve incrementally but remain constrained by limited interdisciplinary cooperation and insufficient integration of adaptive digital technologies within operational ecosystems.

Within this scenario, disaster-management systems remain functional but relatively reactive rather than adaptive and predictive. Educational and operational structures struggle to fully respond to the growing complexity of interconnected disaster environments and digitally enabled operational challenges.

6.2. Transitional Scenario

In the transitional scenario, disaster-management ecosystems undergo moderate digital transformation and gradually move toward more integrated and interdisciplinary operational structures. Organisations increasingly recognise the importance of digital technologies, resilience-oriented coordination, and adaptive preparedness, although implementation remains uneven across sectors and regions.

AI-supported analytics, IoT systems, distributed sensing infrastructures, UAVs, and edge-computing technologies become more widely integrated into disaster-management workflows. Real-time monitoring, data-driven decision-support systems, and digital operational platforms improve situational awareness and operational coordination in many environments.

Educational systems also begin adapting more actively to emerging operational and technological needs. HED institutions introduce interdisciplinary programmes and stronger integration between technological and operational domains, while LLL initiatives expand to support continuous professional upskilling and digital competence development.

Collaborative learning methodologies, practical exercises, workflow-oriented educational approaches, and digital learning environments become increasingly common within disaster-management education. However, interoperability between institutions, educational systems, and operational stakeholders remains only partially developed.

Operational coordination improves through greater use of shared communication infrastructures, collaborative workflows, and integrated digital platforms. Nevertheless, differences in technological maturity, organisational adaptability, and institutional readiness continue to create limitations within some disaster-management ecosystems.

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Resilience and preparedness capacities strengthen progressively within this scenario, particularly in organisations investing in digital infrastructures, interdisciplinary cooperation, and adaptive operational planning. Disaster-management systems become more proactive and data-driven, although still facing challenges related to scalability, interoperability, and long-term coordination.

The intermediate future scenario may involve increasing integration of radiological-risk preparedness, critical-infrastructure protection and hybrid-threat coordination mechanisms within broader disaster-management ecosystems, particularly in regions exposed to geopolitical instability and strategic infrastructure vulnerabilities.

This transitional scenario represents an important intermediate stage toward more fully integrated and digitally resilient disaster-management ecosystems.

6.3. Advanced Integrated Scenario

In the advanced integrated scenario, disaster-management ecosystems evolve into highly interconnected, digitally enabled, and resilience-oriented operational environments supported by strong interdisciplinary cooperation and adaptive educational systems. Technological infrastructures, operational workflows, communication systems, and educational ecosystems become increasingly integrated within one coordinated disaster-management framework.

AI-supported analytics, IoT systems, distributed sensing infrastructures, UAVs, edge computing, and intelligent coordination platforms are fully integrated into operational preparedness and response activities. Real-time situational awareness, predictive operational analysis, adaptive decision-support systems, and distributed coordination mechanisms enable more proactive and resilient disaster-management operations.

Interoperability between organisations, communication systems, and operational infrastructures is significantly improved through shared standards, integrated digital platforms, and collaborative workflow-oriented operational models. Disaster-management systems become more adaptive, data-driven, and capable of responding effectively to complex cascading disaster scenarios.

HED and LLL ecosystems are also transformed within this scenario. Interdisciplinary educational frameworks integrate technological, operational, organisational, and resilience-oriented competencies within flexible and continuously evolving learning environments. Workflow-oriented educational methodologies, collaborative learning, practical simulations, and scenario-based activities become central components of disaster-management education.

Digital learning environments and adaptive educational platforms support continuous upskilling, international collaboration, remote participation, and knowledge co-creation across academic, professional, and institutional domains. The distinction between academic learning and professional training becomes increasingly integrated within one continuous educational ecosystem.

Train-the-Trainers methodologies and collaborative dissemination networks further strengthen societal preparedness and resilience awareness by expanding interdisciplinary disaster-management education beyond universities and into professional organisations, public institutions, schools, and community environments.

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In advanced integrated disaster-management ecosystems, AI-supported monitoring systems, distributed environmental sensing infrastructures, digital risk-assessment platforms and interdisciplinary preparedness frameworks support adaptive management of complex radiological, technological and hybrid-threat scenarios. Critical infrastructure protection, operational resilience and long-term societal preparedness become increasingly integrated within one coordinated disaster-management architecture.
Within this scenario, disaster-management ecosystems become increasingly proactive, predictive, interoperable, and resilience-oriented. Educational systems continuously adapt to emerging technologies and operational developments, creating a sustainable and future-oriented framework for digitally enabled disaster-management preparedness.
In the advanced integrated scenario, resilient disaster-monitoring systems combine AI, IoT, cloud computing, cybersecurity, digital risk models and integrated management platforms into one adaptive operational ecosystem. Such systems enable faster forecasting, more flexible coordination, improved security and more effective protection of lives and infrastructure [27] [30] [31] [33] . In these ecosystems, AI-supported monitoring systems, autonomous UAV infrastructures, digital learning modules, geospatial coordination platforms, integrated early-warning systems and adaptive resilience-oriented governance architectures operate within interconnected digital ecosystems supporting anticipatory and highly coordinated disaster response.
This advanced integrated scenario represents the preferred future direction identified by the SUDEM foresight analysis and forms the strategic basis for the SUDEM educational ecosystem, Knowledge Transfer framework, and curricular architecture.

7. The Role of SUDEM

The SUDEM project is designed as an interdisciplinary educational response to the future challenges, technological developments, and operational transformations identified through the foresight analysis. Its role is to support the development of a modern disaster-management educational ecosystem capable of integrating technological innovation, operational preparedness, resilience-oriented thinking, and adaptive learning within one coherent framework.
A central objective of SUDEM is to reduce fragmentation between technological and operational educational domains by introducing workflow-oriented and System-of-Systems (SoS) educational methodologies. The project connects AI, IoT systems, distributed sensing infrastructures, edge computing, operational coordination, resilience engineering, and disaster-management workflows within an integrated curricular architecture.
The project also responds directly to the growing need for interdisciplinary competence development. Through collaborative learning methodologies, practical exercises, scenario-based educational approaches, and digital learning environments, SUDEM supports systems thinking, operational awareness, adaptive decision-making, and interdisciplinary cooperation.
Another important role of SUDEM is strengthening integration between HED and LLL. The project promotes scalable and flexible educational structures capable of supporting university programmes, professional upskilling, Train-the-Trainers dissemination, and

continuous competence development within rapidly evolving disaster-management ecosystems.
The Moodle-based digital learning environment and Knowledge Transfer framework additionally support accessibility, collaboration, adaptive curriculum evolution, and international interdisciplinary knowledge exchange across academic, professional, and institutional environments.
Through its future-oriented educational philosophy, SUDEM contributes to the development of digitally resilient and operationally adaptive disaster-management ecosystems capable of responding effectively to increasingly complex and interconnected disaster scenarios.

7.1. Educational Response to Identified Challenges

SUDEM responds directly to the operational, technological, educational, coordination, and resilience challenges identified through the foresight analysis by developing an interdisciplinary and workflow-oriented educational ecosystem aligned with the realities of modern digitally enabled disaster-management environments.
One of the project’s primary educational responses is the integration of technological and operational domains within one coherent curricular structure. The SUDEM framework combines AI, IoT systems, distributed sensing infrastructures, edge computing, operational coordination, resilience engineering, and workflow-oriented disaster-management methodologies in order to reduce fragmentation between traditionally separated educational fields.
he SUDEM educational response can be conceptualised as an integrated interdisciplinary learning ecosystem combining Higher Education (HED), Lifelong Learning (LLL), digital technologies, workflow-oriented methodologies and collaborative knowledge co-creation processes, as illustrated in the following figure:

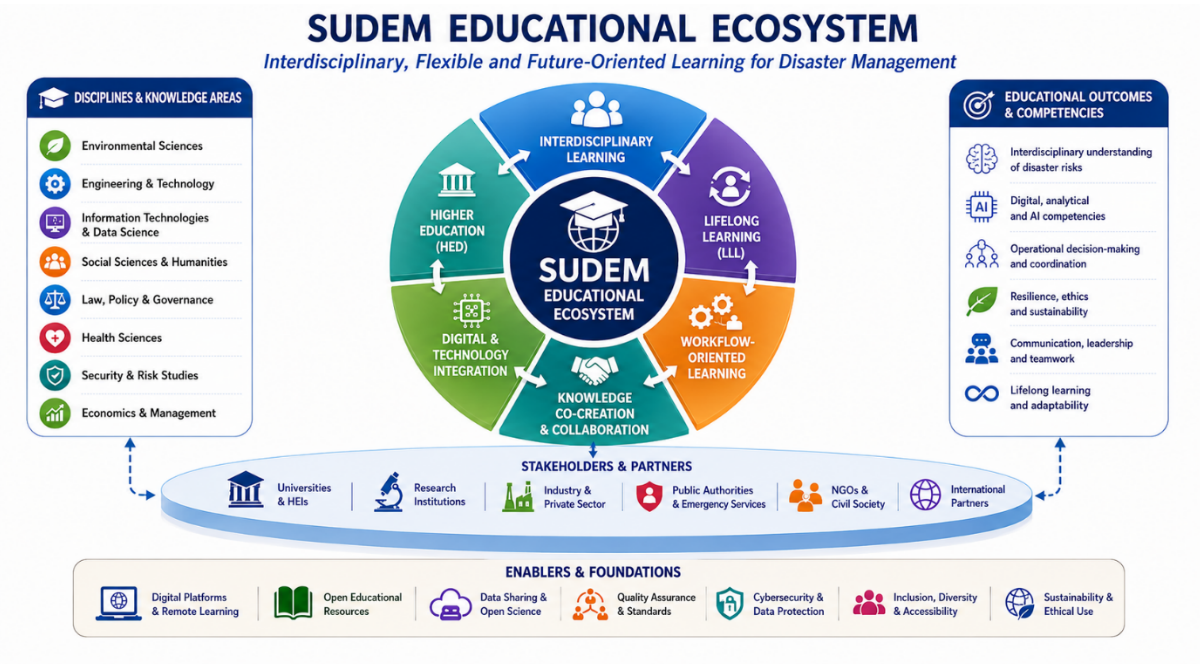

Figure 5. SUDEM educational ecosystem

The project also addresses the growing need for interdisciplinary competence development through collaborative learning methodologies, practical exercises, simulations, and scenario-based educational activities. These approaches help learners strengthen systems thinking, operational awareness, adaptive decision-making, and interdisciplinary coordination capabilities.

Another important educational response is the emphasis on workflow-oriented learning aligned with real disaster-management processes. The curriculum follows operational logic involving observation, information processing, interpretation, decision-making, operational response, and continuous learning, helping learners connect theoretical knowledge with practical operational environments.

SUDEM additionally responds to the need for scalable and continuously adaptive educational ecosystems by integrating HED, LLL, and Train-the-Trainers dissemination within one flexible educational framework.

The Moodle-based digital learning environment further supports accessibility, collaboration, interdisciplinary interaction, remote learning, and continuous curriculum adaptation in response to emerging technological and operational developments.

Through these integrated educational responses, SUDEM aims to strengthen future preparedness, resilience-oriented competence development, and digitally enabled disaster-management education across academic, professional, and institutional environments.

7.2. Interdisciplinary Curriculum Logic

The interdisciplinary curriculum logic of SUDEM is designed to reflect the interconnected nature of modern disaster-management ecosystems and the growing integration between technological, operational, organisational, and resilience-oriented domains. Rather than treating educational subjects as isolated disciplines, the curriculum is structured as one coherent learning ecosystem based on SoS principles and workflow-oriented educational methodologies.

The curriculum integrates topics such as AI, IoT systems, distributed sensing infrastructures, edge computing, communication networks, operational coordination, resilience engineering, and disaster-management workflows within interconnected educational structures. This approach helps learners understand how different systems, technologies, operational actors, and organisational processes interact during disaster preparedness and response activities.

A major objective of the interdisciplinary logic is to strengthen systems thinking and adaptive operational understanding. Learners are encouraged to analyse disaster-management challenges from multiple perspectives while recognising interdependencies between digital infrastructures, operational coordination mechanisms, resilience strategies, and societal systems.

The curriculum also promotes interdisciplinary collaboration through practical exercises, collaborative workshops, simulations, and scenario-based learning activities involving participants from different academic and professional backgrounds. These methodologies strengthen communication, teamwork, workflow-oriented analysis, and adaptive decision-making capabilities.

Another important aspect of the interdisciplinary logic is the integration of HED, LLL, and Train-the-Trainers dissemination within one scalable educational ecosystem. The curriculum

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is designed to remain flexible and continuously adaptable to emerging technologies and evolving operational requirements.
Through this interdisciplinary educational philosophy, SUDEM aims to prepare future professionals capable of operating effectively within increasingly complex, digitally enabled, and interconnected disaster-management environments.

7.3. Workflow-Oriented Learning

Workflow-oriented learning is one of the central educational principles of SUDEM and reflects the operational logic of modern disaster-management ecosystems. Rather than organising education around isolated theoretical domains, the SUDEM framework structures learning around interconnected operational processes involving observation, information processing, interpretation, decision-making, operational response, and continuous learning.
This educational approach helps learners understand how technological systems, operational actors, communication infrastructures, and resilience mechanisms interact within dynamic and uncertain disaster-management environments. The curriculum therefore mirrors real operational workflows rather than focusing only on isolated technical competencies or theoretical knowledge.
A major objective of workflow-oriented learning is to strengthen operational awareness and systems thinking. Learners analyse how information flows through disaster-management systems, how operational decisions are coordinated, and how digital technologies support adaptive preparedness and response activities.
The workflow-oriented structure also strengthens integration between technological and operational educational domains. Courses related to AI, IoT systems, sensing infrastructures, edge computing, resilience engineering, and operational coordination are connected through shared workflow logic and collaborative educational methodologies.
Practical exercises, simulations, collaborative workshops, and scenario-based activities further reinforce workflow-oriented learning by exposing participants to realistic operational environments involving uncertainty, multi-stakeholder coordination, and adaptive decision-making processes.
Another important aspect of this educational approach is its scalability across HED, LLL, and professional training environments. Workflow-oriented methodologies support continuous competence development and operational adaptability across different educational and professional contexts.
Through this approach, SUDEM aims to prepare future professionals capable of functioning effectively within interconnected, digitally enabled, and workflow-driven disaster-management ecosystems.

7.4. HED and LLL Integration

A central objective of SUDEM is the integration of Higher Education (HED) and Lifelong Learning (LLL) within one coherent and scalable educational ecosystem. The project recognises that future disaster-management environments require not only academic specialisation, but also continuous professional upskilling, adaptive competence development, and flexible interdisciplinary learning throughout different stages of professional careers.

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The SUDEM framework therefore combines university-level educational structures with continuous learning methodologies capable of supporting professionals, operational stakeholders, educators, public institutions, and technical specialists working within evolving disaster-management ecosystems.

Within Higher Education, SUDEM promotes interdisciplinary curricula integrating technological competencies, operational workflows, resilience-oriented thinking, and collaborative learning approaches. The project supports development of future professionals capable of understanding both digital infrastructures and operational disaster-management processes.

At the same time, the Lifelong Learning dimension addresses the growing need for continuous adaptation to emerging technologies such as AI, IoT systems, distributed sensing infrastructures, edge computing, and intelligent operational coordination systems. The framework supports flexible educational pathways for professional upskilling and interdisciplinary competence development.

The Moodle-based digital learning environment further strengthens HED and LLL integration by supporting accessibility, hybrid learning, collaborative educational activities, remote participation, and continuous curriculum adaptation across different educational contexts.

Another important component of this integration is the Train-the-Trainers methodology, which enables broader dissemination of SUDEM educational approaches across universities, professional organisations, public institutions, schools, and community-oriented preparedness activities.

Through this integrated HED and LLL philosophy, SUDEM establishes a flexible and continuously evolving educational ecosystem capable of supporting long-term disaster-management preparedness, resilience, and interdisciplinary competence development.

7.5. Train-the-Trainers

The Train-the-Trainers (TtT) component represents one of the key dissemination and sustainability mechanisms within the SUDEM educational ecosystem. Its purpose is to enable long-term transfer of interdisciplinary disaster-management knowledge, workflow-oriented educational methodologies, and digitally enabled operational competencies across academic, professional, institutional, and societal environments.

The TtT approach prepares educators, researchers, disaster-management professionals, technical experts, and institutional stakeholders to apply SUDEM educational principles within their own organisations and training contexts. This supports broader dissemination of interdisciplinary educational methodologies beyond the original project consortium.

A major objective of the TtT framework is to strengthen educational scalability and adaptability. Through collaborative methodologies, practical exercises, scenario-based learning, and workflow-oriented educational approaches, trainers are prepared to support future competence development across HED, LLL, professional training, and community preparedness activities.

The TtT approach also contributes to continuous educational evolution by promoting knowledge co-creation, interdisciplinary cooperation, and feedback-oriented curriculum adaptation. Participants are encouraged to adapt SUDEM educational content and methodologies according to local operational requirements, technological developments, and institutional contexts.

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The Moodle-based digital learning environment further supports the Train-the-Trainers model through accessible educational resources, collaborative online activities, surveys, and adaptable learning materials that can be reused and expanded across different geographical and organisational environments.
Through this dissemination-oriented educational strategy, SUDEM strengthens long-term sustainability, operational relevance, and broader societal impact of interdisciplinary disaster-management education.

7.6. Knowledge Co-Creation

Knowledge co-creation represents a central principle of the SUDEM educational ecosystem and reflects the project's emphasis on collaborative, adaptive, and continuously evolving disaster-management education. Rather than treating learners as passive recipients of information, SUDEM promotes active participation of educators, researchers, professionals, operational stakeholders, and learners in the development and refinement of educational knowledge and methodologies.
The increasing complexity of digitally enabled disaster-management ecosystems requires continuous exchange between technological expertise, operational experience, resilience-oriented practices, and educational innovation. SUDEM therefore supports interdisciplinary collaboration and shared problem-solving across academic, professional, and institutional domains.
A major objective of the knowledge co-creation approach is to strengthen adaptive learning and continuous curriculum evolution. Participants are encouraged to contribute operational insights, technological perspectives, practical experiences, and interdisciplinary feedback that can improve the relevance and effectiveness of the educational ecosystem.
Collaborative workshops, scenario-based exercises, workflow analyses, interdisciplinary discussions, and digital learning activities all contribute to the co-creation of operational knowledge and educational practices. These methodologies also strengthen systems thinking, communication, and collaborative coordination capabilities.
The Moodle-based digital learning environment further supports knowledge co-creation by enabling continuous interaction, collaborative activities, feedback integration, and international interdisciplinary cooperation across different educational and professional environments.
Another important aspect of this approach is the connection between HED, LLL, and professional practice. SUDEM promotes continuous knowledge exchange between universities, disaster-management professionals, public institutions, and technological experts in order to maintain educational relevance within rapidly evolving operational ecosystems.
Through this collaborative educational philosophy, SUDEM supports development of a continuously adaptive and interdisciplinary disaster-management learning ecosystem aligned with future technological and operational transformation.

7.7. Digital Learning Platform

The SUDEM digital learning platform functions as the central technological infrastructure supporting the project's interdisciplinary educational ecosystem. Based on a Moodle

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environment, the platform enables integration of educational resources, collaborative activities, workflow-oriented learning, practical exercises, and adaptive educational methodologies within one accessible digital framework.

The platform supports both HED and LLL environments by enabling flexible access to course materials, interdisciplinary learning activities, simulations, collaborative assignments, and scenario-based educational exercises. This flexibility is particularly important for disaster-management education, where continuous upskilling and adaptive competence development are becoming increasingly necessary.

A major objective of the digital platform is to strengthen collaboration and knowledge exchange between learners, educators, researchers, operational stakeholders, and professional experts across different institutional and geographical environments. The platform enables interdisciplinary interaction and supports international cooperation within the SUDEM educational ecosystem.

The digital environment also supports workflow-oriented educational methodologies aligned with real disaster-management processes. Learners can participate in collaborative simulations, operational analyses, practical exercises, and adaptive learning activities reflecting dynamic disaster-management environments.

Another important function of the platform is continuous curriculum adaptation and educational improvement. Integrated surveys, learner feedback mechanisms, collaborative evaluation processes, and adaptive educational resources support ongoing refinement of the SUDEM curriculum and educational methodologies.

The platform additionally contributes to scalability and long-term sustainability by enabling reusable educational content, remote participation, hybrid learning models, and broader dissemination of interdisciplinary disaster-management knowledge through Train-the-Trainers activities and continuous professional education.

Through this digital educational infrastructure, SUDEM establishes a flexible, collaborative, and continuously evolving learning ecosystem capable of supporting future-oriented disaster-management education and interdisciplinary competence development.

8. Initial Curricular Framework Logic

The SUDEM Initial Curricular Framework is designed as the educational response to the future trends, operational challenges, and competence needs identified through the foresight analysis. Its purpose is to establish a coherent interdisciplinary curriculum architecture capable of supporting digitally enabled disaster-management education across HED, LLL, and professional training environments.

The curricular framework is based on SoS educational logic and workflow-oriented learning principles. Rather than functioning as a collection of isolated courses, the curriculum is structured as one interconnected educational ecosystem linking technological systems, operational workflows, resilience methodologies, and collaborative learning approaches.

The framework integrates educational domains related to AI, IoT systems, distributed sensing infrastructures, edge computing, operational coordination, resilience engineering, communication systems, and disaster-management workflows. These domains are connected through interdisciplinary educational methodologies and shared operational logic reflecting real disaster-management processes.

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A major objective of the curricular framework is to strengthen systems thinking, operational awareness, interdisciplinary cooperation, and adaptive decision-making capabilities among learners. Practical exercises, workflow analyses, collaborative learning activities, simulations, and scenario-based methodologies are integrated throughout the curriculum in order to connect theoretical learning with operational realities.
The curricular architecture is also designed to remain modular, scalable, and continuously adaptable to emerging technological developments and evolving disaster-management requirements. The integration of digital learning environments, Train-the-Trainers dissemination, and knowledge co-creation mechanisms further supports long-term sustainability and continuous curriculum evolution.
Through this future-oriented curricular logic, SUDEM establishes the foundation for a resilient, interdisciplinary, and digitally enabled disaster-management educational ecosystem aligned with future operational and societal needs.

8.1. The 13 SUDEM Courses

The SUDEM curriculum architecture is structured around 13 interconnected courses designed to collectively address the operational, technological, educational, and resilience-oriented challenges identified through the foresight analysis. The number and structure of the courses reflect the interdisciplinary and workflow-oriented educational philosophy of the project:

- Course 1: Workflow & Risk Mitigation
- Course 2: Disaster Monitoring
- Course 3: Data-Driven Decision-Making
- Course 4: IoT Principles
- Course 5: IoT in Disaster Management
- Course 6: AI in Disaster Management
- Course 7: Multi-Agent Systems
- Course 8: Edge Computing
- Course 9: System Resilience
- Course 10: Train-the-Trainers
- Course 11: Nuclear Safety
- Course 12: Disaster Management: Interdisciplinarity & Future
- Course 13: Disaster events & management: types and principles

Rather than developing isolated educational modules, the SUDEM framework organises the courses as one integrated learning ecosystem covering the full spectrum of modern digitally enabled disaster-management processes. Each course contributes to specific operational and technological domains while simultaneously supporting broader systems thinking and interdisciplinary competence development.
The course architecture was designed to ensure balanced integration between foundational disaster-management concepts, monitoring and sensing technologies, AI-supported analytics, operational coordination, resilience engineering, workflow-oriented learning, and future-oriented interdisciplinary perspectives.

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Several courses focus on technological infrastructures and digital transformation, including IoT systems, AI, edge computing, distributed sensing, and multi-agent systems. Other courses address operational workflows, resilience-oriented coordination, disaster-management principles, and adaptive preparedness methodologies. The Train-the-Trainers course additionally supports dissemination, scalability, and long-term sustainability of the educational ecosystem.

The 13-course structure also reflects the workflow logic of modern disaster-management environments involving observation, information processing, interpretation, decision-making, operational response, and continuous learning. Together, the courses provide interconnected educational coverage of these operational stages.

Another important reason for the selected architecture is scalability and adaptability across HED, LLL, and professional training contexts. The modular structure allows educational institutions and operational stakeholders to adapt the curriculum according to different learner profiles, technological developments, and institutional needs.

Through this integrated course architecture, SUDEM establishes a comprehensive interdisciplinary educational ecosystem capable of supporting future disaster-management preparedness, digital resilience, and adaptive competence development.

8.2. Course Interrelations

The 13 SUDEM courses are designed as an interconnected educational ecosystem rather than as independent educational units. Each course contributes to broader interdisciplinary learning objectives and supports understanding of how technological systems, operational workflows, resilience mechanisms, and organisational coordination processes interact within modern disaster-management environments.

The course interrelations are based on SoS educational logic and workflow-oriented learning principles. Foundational courses introduce disaster-management concepts, operational workflows, and systems thinking, while specialised courses progressively expand into monitoring systems, IoT infrastructures, AI-supported analytics, edge computing, resilience engineering, and adaptive operational coordination.

The curriculum architecture is organised in a way that allows learners to progressively develop interdisciplinary competencies across interconnected educational domains. Monitoring and sensing courses support situational awareness and information acquisition, while intelligence-oriented courses focus on data processing, analysis, operational interpretation, and decision-support mechanisms.

Operational and resilience-oriented courses further connect technological infrastructures with adaptive response, continuity management, workflow-oriented coordination, and resilience-building processes. The Train-the-Trainers component functions as an integrative dissemination layer supporting educational scalability and long-term sustainability.

Collaborative exercises, practical activities, simulations, and scenario-based methodologies strengthen the relationships between the courses by exposing learners to integrated operational workflows rather than isolated theoretical concepts. This interconnected structure helps participants understand the broader operational ecosystem within which modern disaster-management activities take place.

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The course interrelations additionally support flexibility and adaptability across HED, LLL, and professional training environments by enabling modular implementation while maintaining the overall coherence of the educational ecosystem.
Through this integrated curricular architecture, SUDEM strengthens systems thinking, interdisciplinary competence development, workflow-oriented operational understanding, and adaptive preparedness within digitally enabled disaster-management ecosystems.

8.3. Workflow Logic

The workflow logic of the SUDEM curricular framework is designed to reflect the operational structure of modern disaster-management ecosystems and to connect the 13 courses through a coherent educational sequence aligned with real disaster-management processes.
The curriculum follows the workflow-oriented educational principle:
Observe → Process → Interpret → Decide → Act → Learn
This workflow structure allows learners to understand how information, technologies, operational actors, and decision-making mechanisms interact within interconnected disaster-management environments.
The “Observe” stage is supported through courses related to disaster monitoring, IoT systems, distributed sensing infrastructures, and UAV-supported observation technologies. These courses focus on situational awareness and operational information acquisition.
The “Process” and “Interpret” stages are addressed through courses related to edge computing, AI-supported analytics, data-driven decision-making, and multi-agent systems. Learners analyse how operational data are processed, interpreted, and transformed into actionable operational intelligence within real-time disaster-management workflows.
The “Decide” and “Act” stages are connected to operational coordination, resilience-oriented planning, communication systems, and adaptive response processes addressed throughout the curriculum. Learners explore how coordinated decision-making and operational intervention occur under uncertain and dynamic conditions.
The “Learn” stage reflects the curriculum’s emphasis on resilience, adaptive learning, knowledge co-creation, and continuous educational evolution. Feedback mechanisms, practical exercises, collaborative learning activities, and Train-the-Trainers dissemination contribute to continuous competence development and operational adaptation.
This workflow-oriented logic also strengthens interdisciplinary integration between technological systems, operational procedures, resilience methodologies, and organisational coordination processes. Rather than focusing only on isolated educational domains, the curriculum mirrors interconnected operational ecosystems characteristic of future digitally enabled disaster management.
Through this workflow structure, SUDEM supports development of systems thinking, adaptive operational awareness, interdisciplinary cooperation, and resilience-oriented competence development across both HED and LLL environments.

8.4. System-of-Systems Perspective

The SUDEM curricular framework is strongly based on a System-of-Systems (SoS) educational perspective reflecting the interconnected nature of modern disaster-management ecosystems. Contemporary disaster environments increasingly involve

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interactions between technological infrastructures, communication systems, operational actors, organisational processes, environmental conditions, and societal resilience mechanisms. Effective disaster-management education must therefore support integrated understanding of these interdependencies.

The SoS perspective treats the curriculum not as a collection of isolated educational components, but as one interconnected learning ecosystem in which technological, operational, and resilience-oriented domains function together through shared workflows and collaborative methodologies.

Within the SUDEM framework, AI systems, IoT infrastructures, distributed sensing networks, edge computing, communication platforms, operational coordination mechanisms, and resilience processes are understood as interconnected subsystems contributing to broader disaster-management operations. Learners are encouraged to analyse how these systems interact, exchange information, adapt to disruptions, and support coordinated response activities.

A major objective of the SoS perspective is to strengthen systems thinking and interdisciplinary operational understanding. Future professionals must increasingly understand not only the functionality of individual technologies or procedures, but also the relationships and dependencies between interconnected operational ecosystems.

The System-of-Systems approach also supports workflow-oriented learning by aligning educational activities with real operational disaster-management processes involving monitoring, information processing, interpretation, coordination, operational response, and continuous learning.

Collaborative exercises, simulations, interdisciplinary workshops, and scenario-based methodologies further reinforce the SoS educational philosophy by exposing learners to complex and interconnected disaster-management environments characterised by uncertainty and multi-stakeholder coordination.

Through this System-of-Systems perspective, SUDEM establishes a future-oriented educational framework capable of supporting adaptive preparedness, digital resilience, interdisciplinary competence development, and coordinated disaster-management operations within increasingly complex and technologically interconnected societal environments.

8.5. Scalability and Adaptability

The SUDEM curricular framework is designed as a scalable and adaptable educational ecosystem capable of responding to evolving technological developments, operational requirements, and educational needs within modern disaster-management environments. Flexibility and continuous adaptation are considered essential due to the rapidly changing nature of digital technologies, disaster risks, and interdisciplinary operational ecosystems.

The modular structure of the curriculum allows courses and educational activities to be implemented across different educational and professional contexts, including HED, LLL, postgraduate programmes, professional training, and Train-the-Trainers dissemination activities. Educational institutions and operational stakeholders can adapt the framework according to learner profiles, institutional priorities, and local operational requirements while maintaining the overall interdisciplinary and workflow-oriented educational philosophy.

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Scalability is further strengthened through the integration of digital learning environments and collaborative educational methodologies. The Moodle-based platform enables remote participation, hybrid learning, international cooperation, and continuous access to educational resources, making the curriculum applicable across different geographical and institutional environments.

Another important aspect of adaptability is the framework's capacity to integrate emerging technologies and evolving disaster-management methodologies. AI-supported systems, distributed sensing infrastructures, edge computing, autonomous coordination platforms, and resilience-oriented operational models can be continuously incorporated into the curriculum as technological and operational ecosystems evolve.

The curriculum also supports adaptive educational evolution through knowledge co-creation, learner feedback mechanisms, collaborative evaluation processes, and interdisciplinary interaction between academic, professional, and institutional stakeholders.

Through this scalable and adaptable architecture, SUDEM establishes a sustainable educational ecosystem capable of supporting long-term disaster-management preparedness, interdisciplinary competence development, digital resilience, and continuous operational adaptation within future disaster-management environments.

9. Strategic Recommendations

The foresight analysis demonstrates that future disaster-management ecosystems will require stronger integration between technological innovation, operational coordination, resilience-oriented planning, and interdisciplinary education. Based on the identified trends, challenges, future needs, and development scenarios, several strategic recommendations emerge for the future development of disaster-management education and preparedness systems.

A primary recommendation is the adoption of interdisciplinary educational models capable of integrating AI, IoT systems, distributed sensing infrastructures, edge computing, operational coordination, resilience engineering, and workflow-oriented disaster-management methodologies within one coherent educational ecosystem. Future professionals will increasingly require systems thinking and interdisciplinary operational understanding rather than isolated technical specialisation.

Another important recommendation is strengthening integration between HED and LLL. Disaster-management education must support continuous competence development, flexible upskilling pathways, and adaptive learning environments capable of responding to rapidly evolving technological and operational conditions.

The foresight also highlights the importance of workflow-oriented and practical educational methodologies. Collaborative exercises, simulations, interdisciplinary workshops, scenario-based learning, and real operational analyses should become central components of future disaster-management educational ecosystems.

Strengthening digital resilience and interoperability is another critical recommendation. Future disaster-management systems should support resilient digital infrastructures, integrated communication platforms, adaptive operational coordination, and secure information exchange across organisational and geographical boundaries.

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The analysis additionally emphasises the importance of Train-the-Trainers dissemination and knowledge co-creation mechanisms for ensuring long-term scalability, sustainability, and societal impact of interdisciplinary disaster-management education.
Digital learning platforms and adaptive educational infrastructures should also be further developed to support accessibility, international cooperation, hybrid learning environments, and continuous curriculum evolution.
Finally, future disaster-management education should remain continuously adaptive to emerging technologies, environmental developments, operational transformations, and societal resilience requirements. Educational ecosystems must evolve dynamically alongside the disaster-management environments they are intended to support.
These strategic recommendations form the basis for the future-oriented educational philosophy and curricular architecture of SUDEM.

10. Conclusion

The SUDEM foresight analysis demonstrates that disaster-management ecosystems are entering a period of significant technological, operational, and educational transformation. Climate change, digitalisation, infrastructure interdependencies, cyber-physical risks, and increasing disaster complexity are reshaping the requirements for future preparedness, resilience, and operational coordination.
The analysis highlights that future disaster-management systems will increasingly depend on integrated digital infrastructures, AI-supported analytics, IoT systems, distributed sensing technologies, edge computing, adaptive coordination mechanisms, and workflow-oriented operational models. At the same time, technological advancement alone will not be sufficient. Future disaster-management ecosystems will require strong interdisciplinary cooperation, systems thinking, resilience-oriented planning, and adaptive operational understanding.
The foresight also identifies major educational challenges related to fragmentation between technological and operational domains, insufficient interdisciplinary integration, limited workflow-oriented learning, and growing need for continuous professional upskilling. These developments create increasing demand for scalable educational ecosystems capable of supporting both HED and LLL.
The preferred future scenario identified through the analysis is an advanced integrated ecosystem characterised by interoperability, resilient digital infrastructures, adaptive operational coordination, collaborative learning, and continuously evolving educational systems. Within this future perspective, disaster-management education becomes interdisciplinary, workflow-oriented, digitally enabled, and strongly connected to real operational environments.
The SUDEM project directly responds to these identified future needs through its interdisciplinary curricular framework, System-of-Systems educational philosophy, workflow-oriented methodologies, Train-the-Trainers dissemination approach, and Moodle-based digital learning environment.
Through the integration of technological innovation, operational preparedness, resilience-oriented thinking, collaborative methodologies, and adaptive educational structures, SUDEM establishes the foundation for a future-oriented disaster-management educational

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ecosystem capable of supporting long-term preparedness, digital resilience, interdisciplinary competence development, and societal resilience within increasingly complex and interconnected disaster environments.

More detailed information on the particular subdomains observed can be found in each partner's foresight documents attached

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