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Gaps in and Opportunities for Disaster Risk Reduction in Urban Areas Through International Standardization of Smart Community Infrastructure

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Abstract: Global communities are becoming increasingly vulnerable to natural hazards and climate change, and the rapid pace of urbanization exacerbates these risks. According to the World Bank, approximately 50% of the world's population lives in areas exposed to natural hazards, making the need to overcome the challenges to sustainable urban development pressing. The increasing frequency of heavy rain, flooding, landslides, and wildfires underscores the urgent need for disaster risk mitigation strategies, aligned with sustainable development goals. Infrastructure plays a crucial role in cultivating resilient cities that can withstand, recover from, and adapt to disasters, while promoting long-term sustainability, by minimizing environmental degradation and encouraging responsible development. International standards for smart community infrastructure provide significant advantages, including cost reductions, technology transfer, and enhanced innovation through improved global competitiveness. This paper investigates how these standards can empower community stakeholders to strengthen both the resilience and sustainability of urban areas, facilitating balanced growth that addresses environmental and social demands.

Keywords: risk management; resiliency; sustainability; disasters; smart cities

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1. Introduction

Communities around the world are vulnerable to the risk of natural hazards caused by geophysical and hydrometeorological processes [1,2]. Ongoing climate change is expected to further increase the risks to communities due to the increasing frequency and/or intensity of hazard events, leading to greater exposure to disasters, especially hazards that are hydrometeorological in nature, such as heavy rain, flooding, landslides, and wildfires [3,4]. Despite these vulnerabilities, many urban areas continue to experience rapid population growth, as people migrate to cities in search of better economic opportunities [5,6]. This combination of continued urban growth and heightened hazard exposure presents complex challenges for urban planners, who must balance disaster risk reduction (DRR) with sustainable development goals [7].

In response to these challenges, academic research on DRR in urban areas has increased substantially, driven by the increased frequency and severity of disasters, especially in densely populated and economically vital cities [8,9]. Initially focused on structural resilience (such as seawalls, stormwater management systems, etc.), research has evolved to encompass comprehensive approaches that recognize the interconnectedness of infrastructure and societal resilience [10–12]. This shift acknowledges that urban vulnerabilities are shaped not only by hazard exposure, but also by social, economic, and governance factors. Consequently, long-term strategies addressing the effects of climate change, such as rising sea levels and extreme weather events, have gained traction [13,14]. Local governments are increasingly pooling resources to examine the relationship between climate change and disaster risk, supported by advancements in technology that enable more detailed hazard mapping and risk assessments [15–17]. Global frameworks, like the Sendai Framework for DRR and the UN's Sustainable Development Goals, have further catalyzed research, linking DRR to urban sustainability [18,19].

In light of these growing risks, infrastructure plays a pivotal role in enhancing urban resilience to both sudden-onset disaster risk and slow-onset climate change impacts. International standards developed by organizations, such as ISO, are essential, as they provide global benchmarks for safety, efficiency, and infrastructure resilience [20,21]. For community stakeholders, these standards offer numerous benefits, including cost reduction, the facilitation of the export or transfer of ideas and technologies, and guidance on implementing effective DRR strategies [22]. While these standards have faced criticism for potentially stifling innovation, they are also recognized as drivers of global competitiveness and technological advancement [23]. Therefore, integrating these standards into community infrastructure planning is crucial for achieving both resilience and sustainability in urban environments.

This paper first examines the existing ISO standards and identifies gaps in and opportunities for disaster risk reduction and resilience. By analyzing these ISO standards and their development through the relevant technical committees, we propose a holistic framework illustrating how smart community infrastructure can mediate interactions between society and the environment, promoting the development of cities that are resilient, adaptive, and sustainable.

2. Materials and Methods

2.1. A Case Study on International Standards and Disasters

This study employs a case study methodology to explore the role of international standards in disaster risk reduction (DRR), focusing specifically on the International Organization for Standardization (ISO). Established in 1947, ISO was formed by the United Nations Standards Coordinating Committee to build upon the work of its predecessor, the International Federation of National Standardization Associations (ISA). The primary mission of ISO was to ensure the safety and reliability of products and services, which was deemed crucial during the post-war reconstruction efforts following World War II [24,25].

As of 2024, ISO comprises over 250 technical committees that develop standards on a wide range of topics, such as food safety management, health management, and steel structures, among many others [26]. The deliverables by these committees include technical reports, technical specifications, and international standards. Technical reports provide background information, technical specifications define the requirements, while international standards serve as voluntary guidelines that can be adopted to ensure a certain level of quality in terms of products, processes, or services. These standards are frequently employed by both the public and private sectors to demonstrate compliance with global quality benchmarks [27,28].

2.2. Data Collection and Analysis

The primary data for this study were gathered through an extensive review of the ISO standards, focusing on those related to disaster risk reduction (DRR), sustainability, and urban resilience. The review included ISO's catalog of over 25,000 international standards, as well as the relevant standards published by the International Electrotechnical Commission (IEC) [22].

The collected standards were analyzed using thematic analysis, which involved identifying recurring themes and trends related to disaster preparedness, response, and resilience across ISO's technical committees. Each standard was assessed for its relevance to urban disaster risk reduction (DRR), its functional role in addressing disaster risks, and its potential to enhance infrastructure resilience. A comparative analysis was conducted to evaluate how different technical committees approach overlapping issues, identifying gaps in the existing standards framework.

3. Results

International standards focusing on disaster risk reduction (DRR) are relatively limited in number. The existing standards can be broadly categorized into two groups: those that focus on non-structural countermeasures and those that focus on structural countermeasures. Various technical committees (TCs) within the International Organization for Standardization (ISO) are responsible for developing standards in both categories.

For structural countermeasures, several ISO technical committees are notable. TC 21 focuses on fire protection and fire-fighting equipment, TC 59 addresses buildings and civil engineering works, and TC 98 specializes in structural design, particularly in regard to the resistance to hazards, such as earthquakes and wind. These committees develop standards that primarily address the physical resilience of infrastructure.

For non-structural countermeasures, technical committees like TC 292 (security and resilience) and TC 262 (risk management) are relevant. TC 292 covers a broad range of topics including risk management, emergency preparedness, and business continuity, while TC 262 develops frameworks for risk management. While infrastructure is sometimes discussed, these committees focus more on the management and operational resilience of infrastructure rather than the physical structures themselves, especially in the context of urban environments.

Additionally, standards developed by the International Electrotechnical Commission (IEC) were examined. IEC standards generally pertain to electrical, electronic, and related technologies. In areas of overlap, ISO and IEC collaborate to create joint standards under the ISO/IEC label, combining ISO's expertise in industrial practices with IEC's focus on electrical and electronic technologies. Examples include IEC SyC Smart Cities, which focuses on smart city technologies, and ISO/IEC JTC 1/SC 41, which addresses the Internet of Things (IoT) and Digital Twins. These committees produce standards that function as technical enablers, directed at technologies that facilitate the implementation and operation of infrastructure systems.

Based on these themes, Table 1 provides an overview of ISO technical committees and the relevant international standards, both already published and upcoming. The standards are first categorized by their primary focus area, namely infrastructure, urban management, and technologies that enable certain systems, commonly referred to as technical enablers. These categories are then aligned with the four phases of emergency management: prevention, preparedness, response, and build back better (reconstruction) [29,30]. This framework offers a clearer understanding of how international standards contribute to disaster risk reduction (DRR) across the entire disaster management lifecycle.

Table 1. ISO technical committees and disaster risk reduction standards by emergency phases.

Emergency Phase	Urban Management	Infrastructure	Technical Enablers
Prevention	-TC 292 Security and Resilience (e.g., ISO 22397) -TC 292/WG 2 Continuinity and Organizational Resilience -TC 292/WG 3 Emergency Management (e.g., ISO 22326) -TC 292/WG 7 Guideline for events (e.g., ISO 22379) -TC 292/WG 9 Crisis management -TC 268/WG 2 City indicators (e.g., ISO 37123) -TC 46 SC10 Requirements for document storage and conditions for preservation (e.g., ISO 21110). -TC 207 SC 7 Greenhouse gas and related activities (e.g., ISO 14091, 14092) -TC 92 SC 4 Fire safety engineering (e.g., ISO 16732) -TC 268 SC1/WG6 Smart Community Infrastructure Disaster Risk Reduction (e.g., ISO 37174, 37179, 37194, etc.) -TC 224 (e.g., ISO 24518, 24511, CD 37116 etc.)	-IEC SyC Smart Cities (e.g., IEC 63512) -TC 268 SC1/WG6 Smart Community Infrastructure Disaster Risk Reduction (e.g., ISO 37174, 37179, 37194, etc.) -TC 224 (e.g., ISO 24536, 24527, 24510) -TC 92 SC 4 Fire safety engineering (e.g., ISO 16733), -TC 21 SC 3 fire detection and alarm systems (e.g., ISO 7240) -IEC SC 8A Grid integration of renewable energy generation (e.g., TR 63043) -IEC TC 75 (e.g., IEC 62599) -IEC TC 81 Lightning Protection (e.g., IEC 62305) -IEC TC 88 Wind energy systems (e.g., IEC 61400) -IEC TC 103 Transmitting and receiving equipment for radiocommunication (e.g., IEC 60215)	-IEC SyC Smart Cities (e.g., IEC 63512) -IEC TC 89 Fire hazard testing (e.g., IEC 60695 -ISO/IEC JTC 1/SC 41 Internet of Things and Digital Twin (i.e., ISO/IEC 19637) -TC 268 SC1/WG6 Smart Community Infrastructure Disaster Risk Reduction (e.g., ISO 37174, 37179, 37194, etc.)
Preparedness	-TC 292/WG 9 Crisis management -TC 292 /WG 3 Emergency Management (e.g., ISO 22320) -TC34/WG 25 Food security in emergency or crisis situation (e.g., AWI 23638)	-TC 268 SC1/WG6 Smart Community Infrastructure Disaster Risk Reduction (e.g., ISO 37174, 37179, 37194, etc.)	
Response	-TC 292/WG 5 Community resilience (e.g., ISO, 22391, ISO 22395, ISO 22315:) -TC 292/WG 8 Supply chain security (e.g., ISO 22396) -TC 92 SC 4 Fire safety engineering (e.g., ISO20414) -TC 224 WG 7 Crisis management of water utilities (e.g., ISO 24527) -TC 34 WG 25 Food security in emergency or crisis situation (i.e., NP 3409) -TC 204 WG 8 Public Transport/Emergency (i.e., TR 19803) -ISO/IEC JTC 1 SC 6 Telecommunications and information exchange between systems (e.g., -ISO/IEC TR 16167)	-WG3 Emergency Management (ISO 22327: Early warning system for landslide) -TC 21 SC 3 fire detection and alarm systems (e.g., ISO 7240) -TC 92 SC 4 Fire safety engineering (e.g., ISO20414) -WG 7 Crisis management of water utilities (e.g., ISO 24527), -TC 21 SC 3 fire detection and alarm systems (e.g., ISO 7240) -TC 204 WG 8 Public Transport/Emergency (i.e., TR 19803) -IEC TC 81 Lightning Protection (e.g., IEC 62305) -IEC SyC Smart Cities (e.g., IEC 63512)	-ISO/IEC JTC 1/SC 41 Internet of Things and Digital Twin (i.e., ISO/IEC 19637) -IEC TC 82 solar photovoltaic energy systems (i.e., IEC 60904) -IEC TC 103 Transmitting and receiving equipment for radiocommunication (e.g., IEC 60215) -IEC 104 Environmental conditions, classification and methods of test (e.g., IEC 60068) -ISO/IEC JTC 1/SC 41 Internet of Things and Digital Twin (i.e., ISO/IEC 19637)
Build Back Better / Recovery	-TC34/WG 25 Food security in emergency or crisis situation (e.g., AWI 23638) -TC 46 SC10 Requirements for document storage and conditions for preservation (i.g. ISO 21110) -TC 92 SC 4 Fire safety engineering (e.g., ISO 16732)	-TC 190 SC 7 Impact assessment (e.g., ISO 28901, ISO 18504) -TC 268 SC1/WG6 Smart Community Infrastructure Disaster Risk Reduction (e.g., ISO 37174, 37179, 37194, etc.)	
All Phases	-TC 292/WG 3 Emergency Management (e.g., ISO 22326) -TC 207 SC 7 Greenhouse gas and related activities (ISO 14091) -IEC TC 57 (e.g., IEC 31010) -TC 268 SC1/WG6 Smart Community Infrastructure Disaster Risk Reduction (e.g., ISO 37174, 37179, 37194, etc.)	-TC 21 SC 3 fire detection and alarm systems (e.g., ISO 7240) -IEC TC 57 power systems management and associated information exchange (e.g., 60870) -IEC TC 79 Alarm and electronic security systems (e.g., IEC 60839) -TC 268 SC1/WG6 Smart Community Infrastructure Disaster Risk Reduction (e.g., ISO 37174, 37179, 37194, etc.)	-IEC 104 Environmental conditions, classification and methods of test (e.g., IEC 60068). -ISO/IEC JTC 1/SC 41 Internet of Things and Digital Twin (i.e., ISO/IEC 19637)

4. Discussion

4.1. Gaps in Coverage

Although the standards identified in Table 1 provide numerous examples of ISO and IEC committees and standards that cover urban management, infrastructure, and technical enablers that contribute to disaster risk reduction (DRR), several gaps in standardization coverage have been identified. These gaps relate to certain areas, namely finance, information management, and a conceptual framework for smart cities that are resilient to disaster risk, while promoting sustainable development goals that reduce the risks associated with climate change impacts.

When developing or implementing disaster risk reduction planning, whether through structural mitigation via infrastructure or non-structural measures, such as management systems and services, a common challenge is access to financial resources. Communities will struggle to adopt disaster-resilient energy systems or promote emergency management practices without funding that covers the relevant acquisitions, operations, and maintenance [31,32]. Funding issues are particularly acute in developing countries, where financial resources are limited and may be allocated to other areas rather than to aspects covered by the prevention phase. An upcoming standard, ISO CD 37116, seeks to address this issue by providing guidance to organizations seeking or providing finance for ex ante investments in DRR.

The next gap concerns information management across multiple pieces of infrastructure and services. Advances in information and communications technology (ICT) have enabled community planners to better address the needs of their communities through smart infrastructure. This infrastructure uses electronic sensors to collect data and help manage community assets, resources, and services, more efficiently [33–36]. As structural countermeasures for disasters become increasingly integrated with non-structural strategies to strengthen DRR, establishing standards that provide guidelines for integrating hazard-monitoring infrastructure with essential services becomes crucial. While standards on information management exist for specific infrastructure or services, comprehensive standards that offer an overview and guidelines for their use and management are currently lacking.

Finally, as there are no standards that provide a holistic overview of how information should flow between different pieces of infrastructure, there are also no standards that outline how an ideal smart city that emphasizes disaster risk reduction should be structured. However, a standard that is currently in development, ISO IS 37179, seeks to provide principles and general requirements for community managers, planners, and providers of community infrastructure, who wish to reduce disaster risk and enhance community resilience through smart community infrastructure.

4.2. The Role of Smart Community Infrastructure and Information Sharing in Regard to Disaster Risk Reduction and Sustainable Development

Smart community infrastructure plays a pivotal role in disaster risk reduction (DRR), and the ISO's technical committee TC 268 is at the forefront of developing relevant standards. Established in 2012, TC 268 focuses on sustainable urban development, with subcommittees SC1 and SC2 specializing in smart community infrastructure and sustainable mobility, respectively. Within SC1, working group 6 (WG6) specifically addresses DRR and aligns its efforts with the United Nations Disaster Risk Reduction (UNDRR) platform, contributing to Priorities 1 and 4 of the Sendai Framework for DRR. The key standards developed by TC 268, such as ISO IS 37120, 37122, and 37123, emphasize governance, community engagement, and infrastructure management [37].

One of WG6's significant outputs is Technical Report 6030 (TR 6030), which summarizes the existing smart community infrastructure utilized for DRR and lays the groundwork for future international standards [38]. TR 6030 assessed 50 examples of smart infrastructure from countries across the world, including Australia, Chile, Colombia, Germany, Greece, Japan, and Turkey, among others, revealing that 38% focus on the pre-disaster phase and 37% on the response phase. This underscores the importance of integrating information and communication technology (ICT) with critical infrastructure systems, such as transportation and energy, to enhance resilience through effective hazard monitoring. These examples demonstrate how smart community infrastructure can enhance the resilience of critical infrastructure systems, such as transportation, energy, and water, by integrating hazard monitoring and response capabilities with ICT. TR 6030 laid the foundation for international standards related to DRR, such as ISO IS 37174 on seismometer systems, ISO IS 37179 on DRR frameworks, ISO IS 37166 on disaster-related financing, and ISO AWI 37186 on data acquisition during health emergencies.

During WG6 meetings, participants have identified challenges related to effective information sharing during disaster responses. The ability to quickly collect and disseminate reliable information is crucial for decision-makers facing emergencies, yet stakeholders often encounter obstacles, such as incompatible data formats and an overwhelming volume of information. Examples like Japan's Shared Information Platform for Disaster Management (SIP4D-ZIP) [39–41], Colombia's SISMAN-LISA and SIMAC [42–44], and Australia's New South Wales Spatial Digital Twin, demonstrate the successful integration of real-time data to enhance disaster preparedness and community resilience [45]. By addressing standardization issues in regard to data sharing, smart community infrastructure can foster collaboration among diverse stakeholders and strengthen responses to climate-related challenges [46].

4.3. A Framework for Smart City Infrastructure for Disaster Risk Reduction

Based on the functions and target areas identified in TR 6030's examples of global smart community infrastructure for disaster risk reduction, Figure 1 illustrates a framework that visualizes how smart infrastructure and related assets can be effectively utilized by communities. This framework addresses the gap in integrating infrastructure, urban management, and technical enablers. It consists of four key layers and the interactions between them, namely hazards, smart infrastructure and assets, information services, and community use cases and purposes (Figure 1).

The hazards layer: The foundational layer encompasses the natural hazards present in the environment. These hazards can be further categorized into two main types identified in the Sendai Framework for DRR, as follows [18]:

- Geophysical hazards, such as earthquakes and volcanic activity;
- Hydrometeorological hazards, including tropical cyclones, droughts, and tornadoes, among others. Notably, these hazards can lead to cascading effects, resulting in secondary hazards, like tsunamis and landslides [47,48].

The smart infrastructure and assets layer: The second layer focuses on smart infrastructure specifically designed to gather data from the hazards identified in the hazards layer. Data collection is achieved through various sensors, actuators, and hardware technologies. TR 6030 highlights numerous examples of such infrastructure, including coastal monitoring systems, seismic sensing systems, remote sensing platforms, satellite and aerial imaging systems, meteorological sensing systems, medical information management systems, and infrastructure management systems. Additionally, it encompasses critical infrastructure management systems and information and communication technology (ICT) systems, such as social networking services (SNSs), car navigation systems, mobile phone networks, and mobile communication management systems. This type of smart infrastructure can be integrated with critical infrastructure, including transportation, energy, waste and water management, and healthcare facilities, thereby enhancing the resilience and functionality of the overall built environment.

The data collected from smart infrastructure must be transmitted via information and communication technology (ICT) infrastructure, including radio and internet technologies. These data are then input into valuable information services, as identified through standards produced by ISO TC 292 and TC 268. These services can be categorized into three types of information, as follows:

- Hazard information: Linking information from smart infrastructure converts raw data into actionable insights on various hazards, such as typhoons, tornadoes, tsunamis, floods, landslides, wildfires, and other potential threats;
- Updated status information: During and after a disaster, linked information can provide real-time status updates on critical issues such as evacuation procedures, supply availability, medical care, waste management, dispatch operations, and government responses;
- Damage information: Additionally, linking information can deliver damage assessments through systems that confirm post-disaster conditions and monitor the status of personnel, facilities, lifelines, traffic, and communication systems.

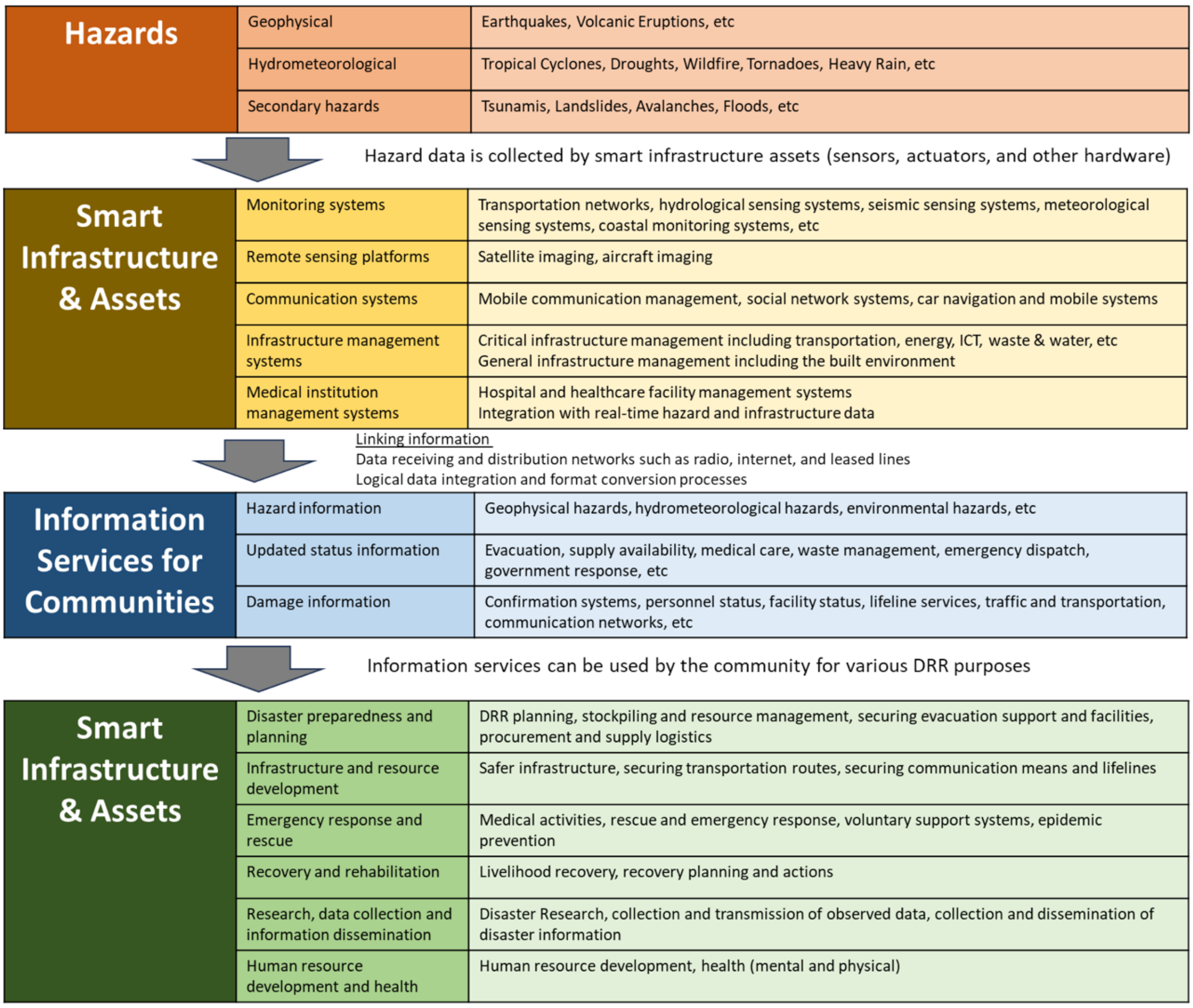

Figure 1. A framework that visualizes how smart infrastructure interacts with natural hazards and community infrastructure, to produce useful services that strengthen community resilience.

The community use cases and purposes layer: Finally, the bottom layer illustrates how the information produced from the preceding layer can be applied by the community. As much of the works produced by ISO TC268 SC1 WG6 are guided by the Sendai Framework for DRR, deliverables produced by this working group are intended to fulfill actions identified in the document. Table 2 identifies the use cases for smart community infrastructure for DRR and its relevancy to the Sendai Framework for DRR.

Table 2. A compilation of use cases for smart community infrastructure for DRR and related actions in the Sendai Framework for Disaster Risk Reduction.

Use Case	Sendai Framework Action and Priority	Use Case	Sendai Framework Action and Priority
Disaster Risk Reduction Planning	27D, 30F, 33G, 33J, 33K	Disaster Research	24K, 25B
Safer Infrastructure	27A, 27D, 30C	Human Resource Development	19E, 30I, 33H, 33M, 48I
Stockpiling and Resource Management	33D	Securing Evacuation Support and Facilities	33H, 33M
Securing Communication Means and Lifelines	33B, 33C, 36D	Procurement and Supply Logistics	30O, 33F
Medical Activities	16, 19H, 28B, 24D, 33C	Rescue and Emergency Response	33D
Health (Mental and Physical)	5, 17, 19C, 31E, 33O	Voluntary Support Systems	33F, 19D, 35
Epidemic Prevention	28D	Securing Transportation Routes	33C
Recovery Actions	19K, 29, 30H, 33J, 33K	Livelihood Recovery	19C, 30O, 30P, 36A,36I, 30J, 31G
Recovery Planning and Actions	33E, 33H	Collection and Dissemination of Disaster Information	24A, 24C, 24O
Collection and Transmission of Observed Data	24A, 24C		

This framework ensures the real-time monitoring of environmental factors, such as flood levels, air quality, and water usage, allowing cities to optimize resource management and reduce waste. By providing actionable data, the framework plays a crucial role in helping cities adapt to the long-term impacts of climate change, such as rising temperatures, shifting rainfall patterns, and more frequent extreme weather events. For example, during prolonged droughts driven by climate change, smart infrastructure can guide water conservation efforts, while real-time data can aid in managing energy consumption more sustainably.

Moreover, the framework actively promotes sustainability by minimizing the environmental impact of urban growth and fostering a city's ability to adapt to future climate challenges. It empowers local communities with crucial information on the relevant environmental conditions, enabling them to make informed decisions about specific daily practices, from reducing water usage to minimizing energy consumption during heatwaves. This not only encourages disaster preparedness, but also instills a culture of sustainability and resilience that goes beyond governmental interventions.

By integrating resilience and sustainability into urban planning, this framework allows cities to both mitigate and adapt to climate change. It enables cities to grow in ways that safeguard social and environmental resources, while ensuring they are prepared to face future climate-related risks and disasters.

4.4. Remaining Barriers to Standardization

Despite significant advancements in smart community infrastructure, several barriers hinder the full realization of its potential in regard to disaster risk reduction (DRR). A major challenge is the absence of globally recognized, comprehensive standards that can effectively integrate smart infrastructure across different sectors and regions. Although initiatives like ISO TC 268 and its subcommittees have developed essential guidelines, the inconsistent adoption of these standards stems from the variations in regulatory frameworks, resource availability, and technical expertise. For instance, while ISO IS 22372 was successfully implemented in Indonesia, helping to save over 100 households during the 2015 Aceh landslide [49,50], such examples are limited, and broader research on ISO standards for DRR remains scarce.

In many regions, smart infrastructure is only partially implemented, leading to inefficiencies in disaster response. Low-income countries and rural communities, in particular, often lack the necessary investments in communication infrastructure, limiting data sharing and real-time decision-making during emergencies. Furthermore, the cost and complexity of integrating legacy systems with new smart technologies deter many local governments from full-scale adoption.

Technological barriers, such as interoperability and data privacy, also pose significant challenges. Different vendors often develop systems using proprietary protocols, resulting in compatibility issues that hinder the seamless exchange of critical hazard data between stakeholders. Additionally, concerns over data privacy and security complicate the sharing of sensitive information, especially for real-time monitoring during disasters.

Another challenge is the uneven development of technical guidelines for specific hazards. While considerable progress has been made in addressing water-related hazards and seismic events, as seen with Japan's SIP4D-ZIP and Colombia's SISMAN-LISA, other critical hazards, such as wildfires or chemical spills, are underdeveloped in terms of integrated smart monitoring systems. Existing guidelines are often too narrow in scope, focusing on isolated hazards, rather than addressing the broader systemic risks posed by interconnected infrastructures.

To overcome these barriers, there is a critical need for enhanced standards that prioritize interoperability, data security, and the integration of a wider range of hazard monitoring systems. By addressing these gaps, the scalability of smart community infrastructure for global DRR efforts can be significantly improved.

4.5. Future Directions for ISO Standards and DRR Infrastructure

The future of ISO standards for disaster risk reduction (DRR) lies in the continued evolution of smart community infrastructure and the need for flexible, adaptive guidelines that reflect the increasing complexity of urban and rural environments. With global environmental changes intensifying natural hazards, the ISO's role in fostering a more resilient and sustainable world will become even more crucial.

First, there is a growing need for standards that specifically address the interoperability of smart technologies across borders and sectors. As highlighted in the examples of Japan's SIP4D and Australia's NSW SDT, these systems demonstrate that successful DRR requires collaboration between different levels of government, private stakeholders, and the public. International standards should, therefore, focus on creating frameworks that enable seamless data integration and sharing, regardless of the originating technology or jurisdiction.

Moreover, future ISO guidelines must prioritize the inclusion of emerging technologies, such as artificial intelligence (AI), machine learning, and blockchain, in disaster monitoring and response systems. These technologies offer the potential to automate decision-making processes and improve the accuracy of hazard predictions. For instance, AI-driven algorithms can analyze vast amounts of data from various sensors, social media, and other sources, to generate real-time insights into disaster scenarios. The challenge for ISO will be to ensure that these technologies are used ethically, with clear guidelines on transparency, accountability, and privacy protection [51–53].

In terms of DRR infrastructure, future ISO standards should expand beyond traditional hazards, like earthquakes and floods, to encompass emerging risks posed by climate change, technological disruptions, and pandemics. A comprehensive approach to resilience must include planning for cascading risks, where the failure of one system (e.g., transportation) can trigger the failure of others (e.g., energy or water supply). ISO TC 268 SC1 WG6's ongoing efforts to address systemic risks through its subcommittees and working groups should continue to evolve, building on examples such as ISO IS 37179 and ISO AWI 37186 to develop broader standards for multi-hazard resilience planning.

Finally, community engagement and stakeholder collaboration should be a primary focus in the future development of ISO standards. Local governments and communities play a pivotal role in implementing disaster risk reduction strategies, yet many remain underrepresented in terms of the standardization process. Engaging these stakeholders directly in the creation of new ISO guidelines will help ensure that the resulting standards are practical, context sensitive, and inclusive of diverse cultural and geographic realities.

By addressing these emerging challenges and opportunities, ISO can help guide the next generation of DRR infrastructure towards greater resilience and sustainability, ensuring that communities worldwide are better prepared to face both current and future risks.

5. Conclusions

The future of ISO standards for disaster risk reduction (DRR) will increasingly rely on the integration of smart infrastructure and the adoption of a multi-hazard approach. As environmental challenges continue to intensify due to climate change, ISO's role in developing adaptive, cross-sectoral standards will be vital to ensuring global resilience. A key focus must be on interoperability: enabling different systems, across borders and sectors, to seamlessly integrate and share data in real-time, as demonstrated by Japan's SIP4D-ZIP and Australia's NSW SDT. These initiatives showcase the importance of coordinated efforts among governments, private entities, and communities to enhance DRR.

Emerging technologies, such as artificial intelligence (AI) and machine learning, offer powerful tools to improve hazard monitoring and disaster response. AI-driven systems, for example, can process vast amounts of real-time data from sensors, social media, and other sources, offering more accurate predictions and quicker response times during disasters. To ensure their responsible and ethical use, future ISO guidelines must address challenges related to transparency, accountability, and data privacy, especially as these technologies become more integrated into DRR strategies.

Beyond traditional hazards like earthquakes and floods, future ISO standards must consider the growing risks posed by climate change, pandemics, and technological disruptions. A multi-hazard resilience approach, as seen in ISO IS 37179, should plan for cascading failures, where the breakdown of one infrastructure (e.g., transportation) could trigger the collapse of others (e.g., energy or water supply). Expanding these standards to address emerging risks is crucial to improving global DRR capabilities and ensuring cities and rural areas alike, can withstand complex challenges.

The continued development of DRR infrastructure must also prioritize community engagement. Local governments and communities, often the first responders to disasters, play a vital role in implementing standards and technologies on the ground. Future ISO guidelines should, therefore, include direct input from these stakeholders, ensuring that standards are both practical and reflective of local needs, ultimately fostering a more resilient and adaptable global framework for disaster preparedness.

In conclusion, the future of DRR lies in the integration of smart technologies, multi-hazard resilience planning, and inclusive stakeholder collaboration. By developing flexible, cross-sectoral standards that accommodate emerging risks and new technologies, the ISO can help ensure that communities worldwide are prepared for both current and future challenges. As climate change continues to escalate the frequency and severity of natural hazards, the adoption of these evolving standards will be critical in building sustainable, resilient cities for generations to come.

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