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AI-DRIVEN POLYCRISIS MITIGATION STRATEGIES IN RESIDENTIAL HIGH-RISE BUILDINGS: A CRITICAL LITERATURE ANALYSIS

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Abstract— In the context of escalating global polycrises, residential high-rises face unprecedented challenges that threaten infrastructure and occupant safety. This literature review examines the role of Artificial Intelligence (AI) in managing these crises within vertical communities. Covering studies from 2014 to 2024, the review utilized a comprehensive search strategy across Web of Science, Scopus, IEEE Xplore, Google Scholar, and PubMed, focusing on AI, polycrisis, and high-rise buildings. The analysis identified 87 relevant studies showcasing the potential of AI technologies — such as machine learning, natural language processing, and computer

Polycrisis, Urban Resilience	vision — to enhance crisis management. Key findings indicate that AI can significantly improve emergency preparedness, real-time information dissemination, and resource optimization. Computer vision advances hazard detection accuracy, facilitating faster evacuations and better safety. The integration of IoT sensor networks with predictive analytics reduces false alarms and enhances early threat detection. However, the review also highlights challenges, including data privacy, cybersecurity, scalability, and the balance between AI autonomy and human oversight. Future research should address these limitations by focusing on real-world case studies to assess AI performance across diverse crisis scenarios. Development of more robust AI models and their integration with existing crisis management frameworks is essential. Ethical considerations, particularly regarding privacy and bias, must also be scrutinized to ensure that AI solutions are both effective and equitable. This review provides valuable insights into using AI to bolster urban resilience and support Sustainable Development Goals in high-rise residential settings, emphasizing the need for strategic AI integration and ongoing research to address current gaps and challenges.

I. Introduction

We are at a critical juncture characterized by global climate change that highlights energy crisis, humanitarian issues and the mpox pandemic from Africa, a situation now referred to as polycrisis [1]. A polycrisis is the simultaneous occurrence of multiple interrelated crises that intensify each other, creating a complex challenge that requires a comprehensive, coordinated approach for effective management [2].

In high-rise urban environments, compounded challenges jeopardize safety and functionality. Addressing polycrisis impacts on Sustainable Development Goals (SDGs) and utilizing artificial intelligence (AI) for crisis management are the essence of effective urban strategies.

A. Background on Polycrisis and SDGs

Polycrisis can significantly impact progress on SDGs. The convergence of multiple global crises is further jeopardizing Asia and the Pacific's ability to achieve the SDGs by 2030 [3], according to a report released in 2023 by the Economic and Social Commission for Asia and the Pacific (ESCAP), the Asian Development Bank (ADB), and the United Nations Development Programme (UNDP). Environmental disasters exacerbate the impacts of climate change, undermining SDG 13 (Climate Action). Infrastructure failures disrupt access to clean water and sanitation (SDG 6) and impact quality education (SDG 4). Health emergencies, such as pandemics, challenge SDG 3 (Good Health and Well-being) and can affect economic stability (SDG 8) and inequality reduction (SDG 10). Security compromised through cyber threats and social disruptions further complicate efforts to achieve SDG 11 (Sustainable Cities and Communities) and SDG 16 (Peace, Justice, and Strong Institutions). This interconnected impact requires integrated crisis management strategies that address the overlap of these global objectives.

B. Challenges in High-Rise Buildings

High-rise residential buildings present unique challenges in crisis management due to their vertical structure, high occupancy, and complex systems. The increasing frequency of extreme weather events, coupled with rising cyber threats and recent global health crises, highlights the need for robust and adaptive crisis management strategies [4]. These buildings require specialized approaches to ensure effective management and response to crises.

C. Role of AI in Addressing Challenges

AI has emerged as a promising tool for enhancing crisis management in high-rise buildings. AI applications in smart buildings have shown potential in areas such as energy management, predictive maintenance, and security enhancement [5]. However, the application of AI for polycrisis mitigation in these settings remains an evolving field. AI can provide valuable support by analyzing complex data, predicting issues, and streamlining response strategies. Integrating AI into crisis management frameworks can enhance resilience and improve effectiveness of responses to the multifaceted challenges posed by polycrisis.

D. Research Gaps

Despite the growing body of literature and advancements on AI in building management and individual crisis response, several significant gaps remain in the context of polycrisis mitigation for high-rise residential buildings, as summarised in Table 1.

Table 1: Research Gaps

No.	Research Gap
1	Limited research on integrating AI systems to address multiple, simultaneous crises [6]
2	Insufficient exploration of AI’s capacity for rapid, context- aware decision-making in evolving crises [7]
3	Lack of understanding in scaling and adapting AI systems to diverse high-rise characteristics [8]
4	Unclear optimal balance between AI-driven decisions and human oversight [9]
5	Inadequate examination of ethical implications and privacy concerns in residential AI implementations [10]

Table 1 is highly relevant as it identifies critical gaps in the current understanding and application of AI in managing complex crisis situations. Addressing these gaps will be crucial for advancing the field, particularly in the context of integrating AI solutions for multiple simultaneous crises, improving decision-making processes, and ensuring ethical considerations are met. By focusing on these research gaps, future studies can develop more robust and effective AI systems for crisis management, particularly in high-stakes environments like high-rise residential buildings.

E. Research Objectives

Referring to the research gaps in Table 1, the research objectives (RO) are:

i. To evaluate the efficacy of specific AI technologies (machine learning, natural language processing (NLP), and computer vision) in enhancing polycrisis preparedness, detection, and response in high-rise residential buildings.

ii. To critically examine the technical feasibility, ethical implications, and regulatory challenges of implementing AI-driven polycrisis mitigation strategies in residential high-rises, with a focus on data privacy, system scalability, and human-AI interaction.

iii. To synthesize best practices and propose a research agenda for advancing AI integration in high-rise polycrisis management, emphasizing interdisciplinary approaches and adaptive AI systems capable of learning from past scenarios.

II. Methodology

The search strategy, data extraction and analysis, data synthesis and reporting are discussed.

A. Search Strategy

A comprehensive literature review was conducted encompassing peer-reviewed literature published between 2014 and 2024, a timeframe chosen to capture recent advancements in AI and the emergence of polycrisis scenarios in urban environments. A combination of keywords and Boolean operators were used, including: *("artificial intelligence" OR "AI" OR "machine learning" OR "predictive analytics" OR "sensor networks") AND ("polycrisis" OR "multi-hazard" OR "cascading disasters") AND ("high-rise buildings"" OR "residential towers" OR ""vertical cities") AND ("crisis management" OR "emergency response" OR "disaster mitigation").*

A multi-database search was conducted via electronic databases: Web of Science, Scopus, IEEE Xplore, Google Scholar, due to comprehensive coverage of scientific and technical literature [11], shown in Table 2.

Table 2: Databases and Rationale

No.	Database	Rationale
1	Web of Science	Broad inter- discipline coverage and citation tracking, providing a comprehensive view of research trends in AI and crisis management [12]
2	Scopus	Extensive peer-reviewed technical literature and cutting-edge research in engineering, AI, and crisis management [13]
3	IEEE Xplore	Repository of peer-reviewed technical literature and research in engineering, AI, and crisis management [14]
4	Google Scholar	Provides access to a broad range of academic and grey literature, offering insights into emerging trends and ongoing research in AI for crisis scenarios [11]
5	PubMed	Offers key insights into human factors and emergency response through life sciences and biomedical literature [11]

B. Inclusion and Exclusion Criteria

The initial search yielded 1,247 papers. After applying inclusion criteria listed in Table 3 and exclusion criteria listed in Table 4, as well as removing duplicates, 87 studies were selected for in-depth analysis.

Table 3: Inclusion Criteria

No.	Inclusion Criteria
1	Peer-reviewed journal articles, conference proceedings, and book chapters
2	Studies focusing on AI applications in high-rise building management or crisis response
3	Research addressing multiple crisis scenarios or integrated response systems
4	Publications discussing ethical, privacy, or regulatory aspects of AI in residential settings
5	Relevance to high-rise residential contexts or adaptable to such environments
6	English language publications

Table 4: Exclusion Criteria

No.	Exclusion Criteria
1	Studies focusing solely on low-rise buildings or non-residential structures
2	Papers discussing AI without practical applications or empirical data
3	Publications without a clear focus on polycrisis or multi-hazard scenarios
4	Studies focusing solely on commercial or industrial buildings
5	Publications not addressing crisis management or emergency response
6	Non-English language publications

C. Data Extraction and Analysis

A standardized data extraction form was developed to systematically collect relevant information from each selected publication. The form included fields for bibliographic information, study objectives and research questions, methodological approach, AI technologies and algorithms discussed, types of crises addressed, key findings and conclusions, and finally, limitations and future research directions. The extracted data was then synthesized using a thematic analysis approach [15]. This method allowed for the identification of recurring themes, trends, and gaps in literature. The analysis focused on current applications of AI in high-rise building management, proposed AI strategies for polycrisis mitigation, challenges and limitations of AI implementation, ethical and regulatory considerations, and finally, future research needs and potential innovations

D. Synthesis and Reporting

The findings from the thematic analysis and quality assessment were synthesized to provide a comprehensive overview of the current state of knowledge on AI-driven polycrisis mitigation strategies in residential high-rise buildings. The synthesis focused on identifying consensus, contradictions, and gaps in literature, as well as emerging trends and future research directions. The results of this critical literature review are reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [16] to ensure transparency and reproducibility of the review process through evidence weigh.

III. The Review – Main Contents

A. Current State of AI in Building Management

AI applications in high-rise residential building management have shown significant progress in recent years. These systems primarily focus on enhancing energy efficiency, improving occupant comfort, and optimizing maintenance schedules. Energy Management: AI-driven systems have demonstrated the ability to reduce energy consumption by 20% to 30% in high-rise buildings through predictive control of HVAC systems and smart lighting [6]. For instance, Google's DeepMind AI reduced cooling energy use in data centers by 40% [17]. Machine learning algorithms can predict equipment failures with up to 99% accuracy, allowing for proactive maintenance and reducing downtime [18]. IBM's Watson IoT platform has been used in residential towers to predict elevator malfunctions and optimize maintenance schedules [19]. AI systems can learn occupant preferences and adjust environmental conditions accordingly. Studies have shown that this can lead to a 60% increase in occupant satisfaction [20].

B. AI Strategies for Polycrisis Mitigation

Recent research has begun to explore AI applications for managing multiple, simultaneous crises in high-rise residential settings. Integrated Sensor Networks: AI-powered sensor networks can monitor multiple building systems simultaneously, detecting anomalies that may indicate the onset of a polycrisis. A deep learning model had been proposed that can identify patterns indicative of cascading failures across electrical, water, and HVAC systems with 95% accuracy [21]. AI algorithms can process large amounts of data from various sources to provide real-time decision support during crises. developed A reinforcement learning model that can generate optimal evacuation strategies in response to multiple simultaneous threats (e.g., fire and structural damage) had also been developed in high-rise buildings [22]. Machine learning models can forecast potential crisis scenarios based on historical data and current conditions. An AI system had demonstrated that it could predict the likelihood of multiple system failures in a high-rise building with 85% accuracy up to 24 hours in advance [7]. Some researchers have proposed fully autonomous AI systems for crisis response. For example, a multi-agent reinforcement learning system can control building systems during a polycrisis without human intervention [23], showing a 40% reduction in response time compared to traditional methods.

C. Implementation Challenges and Solutions

The promise of AI in mitigating polycrises within residential high-rises is undeniable; however, several critical challenges hinder its widespread implementation. Data integration from disparate building systems and external sources remains a significant hurdle, compounded by interoperability issues between AI systems and legacy building management infrastructure [8]. Moreover, AI models optimized for controlled environments often encounter difficulties when scaled to the complexity of real-world high-rise settings. To address these issues, innovative approaches such as federated learning have been proposed to enhance data privacy and model adaptability [24]. Additionally, ensuring the reliability and robustness of AI systems under extreme conditions and in the face of potential cyberattacks is imperative [25]. Beyond technical challenges, the successful integration of AI in high-rise crisis management necessitates careful consideration of ethical and operational aspects. Finding the optimal balance between AI autonomy and human oversight is crucial for effective decision-making [9]. Furthermore, addressing data privacy concerns, implementing robust cybersecurity measures, and ensuring the scalability of AI solutions across diverse building infrastructures are essential for realizing the full potential of this technology.

D. Ethical Considerations and Privacy Concerns

The implementation of pervasive AI systems in residential settings raises significant ethical and privacy concerns. The extensive data collection required for effective AI-driven crisis management may infringe on residents' privacy. A privacy-preserving AI framework had also been proposed using federated learning and differential privacy techniques, which can maintain 95% of the original system's performance while significantly enhancing data protection [10]. AI systems may inadvertently perpetuate or exacerbate existing biases, potentially leading to unfair treatment of certain resident groups during crisis responses. An AI auditing tool can be used to detect and mitigate bias in crisis response algorithms, reducing disparities in evacuation priorities by 60% [26]. The "black box" nature of some AI algorithms can make it difficult to understand and trust their decisions, especially in high-stakes crisis scenarios. Various explainable AI techniques can provide humaninterpretable justifications for AI decisions, increasing trust and adoption among building managers and residents [7].

E. Best Practices and Future Research

More real-world case studies are needed to understand how AI systems perform in diverse crisis situations. These studies will reveal practical challenges and limitations, helping refine strategies and improve system design. Developing more robust AI models is essential as current models may struggle with the complex, interrelated challenges of polycrises. Research into advanced algorithms and modeling techniques is necessary to improve accuracy and reliability. Development of standardised AI integration protocols for existing building systems is essential, learning from past polycrisis scenarios to improve future responses Integrating AI systems with existing crisis management frameworks and human expertise is an important collaborative model. Research should focus on how AI can complement human decision-making, enhancing overall crisis response rather than replacing it. A deeper examination of ethical and privacy considerations is needed as AI plays a larger role in crisis management. Research should address safeguarding sensitive information, ensuring transparency in AI decision-making, and tackling potential biases. Exploration of federated learning techniques to enhance data sharing while preserving privacy. These efforts shall assist the government in achieving the SDGs.

IV. Conclusion

In the context of polycrisis, residential high-rises face significant challenges that threaten infrastructure and occupant safety. This literature review highlights the potential of AI in enhancing crisis management within these vertical communities. AI technologies, including machine learning, NLP, and computer vision, can improve crisis preparedness, detection, and response. They streamline emergency procedures, enhance response times, and facilitate real-time information sharing, ultimately leading to safer and more resilient high-rise environments. However, the review also identifies critical challenges such as data privacy concerns, cybersecurity risks, and the need for a balance between AI autonomy and human oversight. To address these issues, the study recommends best practices, including the development of standardized AI integration protocols, exploration of federated learning for data privacy, and the creation of adaptive AI systems that learn from past crises. Future research should focus on real-world case studies to evaluate AI performance across diverse crisis scenarios, develop more robust AI models, and integrate AI with existing crisis management frameworks. Additionally, ethical considerations regarding privacy and bias must be examined to ensure that AI solutions are effective and equitable. By addressing these gaps, the integration of AI in polycrisis management can be advanced, enhancing urban resilience and supporting the Sustainable Development Goals.

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