

Preparing Construction Managers for AI-Enhanced Water-Energy-Food Nexus Decision-Making

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Preparing Construction Managers for AI-Enhanced Water-Energy-Food Nexus Decision-Making

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Abstract

The construction industry faces mounting pressure to address complex interdependencies between water, energy, and food systems, yet construction management education has been slow to prepare graduates for the AI-enhanced, systems-level decision-making these challenges demand. This study investigates the pedagogical foundations and curricular requirements for preparing construction managers to leverage artificial intelligence in Water-Energy-Food (WEF) Nexus decision-making contexts. Through a systematic review of recent literature on AI applications in construction education, WEF Nexus decision-support tools, and sustainability-oriented curriculum frameworks, the research identifies significant gaps between emerging industry expectations and current educational practices. Findings reveal that while AI tools for WEF assessment are increasingly operational in professional practice, construction management programs lack systematic integration of Nexus thinking and AI-assisted decision-making competencies. The study proposes a curricular framework that positions construction managers as strategic infrastructure leaders capable of navigating trade-offs across water, energy, and food systems using AI as a decision-support partner rather than a replacement for professional judgment. The framework emphasizes systems thinking, data fluency, and the ability to critically evaluate AI-generated scenarios in resource-constrained and uncertainty-laden environments. This research contributes to the emerging discourse on AI-integrated construction education by extending it into the WEF Nexus domain, offering evidence-based guidance for curriculum designers, educators, and accreditation bodies seeking to align professional preparation with the systemic sustainability challenges facing the built environment sector.

1. Introduction

The construction industry stands at the intersection of two transformative forces that are reshaping professional practice: the

emergence of the Water-Energy-Food (WEF) Nexus as a critical framework for sustainable infrastructure development, and the rapid integration of artificial intelligence into

construction management decision-making. Together, these developments create new demands on construction managers that current educational programs are only beginning to address.

The WEF Nexus represents a conceptual and analytical framework for understanding the interdependencies among water, energy, and food systems. The United Nations recognizes that water, food, and energy form a nexus at the heart of sustainable development, with demand for all three increasing rapidly as populations grow and lifestyles change (ASCE, 2024). These resources are interconnected in ways that create both opportunities for synergy and risks of unintended consequences. Water is required for energy production, energy is required for water treatment and distribution, and both are essential for food production and agricultural supply chains. Decisions made in one sector inevitably cascade through the others, creating complex trade-offs that demand integrated approaches to infrastructure planning and management.

The American Society of Civil Engineers has formally recognized the importance of this framework. In July 2024, ASCE adopted Policy Statement 576, which explicitly supports advances in the WEF sectors and calls for civil engineers to evaluate the systemic tradeoffs and synergies of interconnected networked services supported by civil infrastructure (ASCE, 2024). The policy emphasizes that understanding the WEF Nexus is crucial for engineers to develop holistic solutions that ensure sustainable resource management, food security, and environmental protection. Critically, the policy also calls for requiring continuing education regarding WEF for engineers and other professionals, signaling that this is not merely a technical concern but an educational imperative.

For construction managers specifically, the WEF Nexus introduces a new dimension of professional responsibility. Construction managers are responsible for planning,

executing, and delivering infrastructure projects that increasingly must account for their systemic effects across water, energy, and food systems. Examples from professional practice illustrate the stakes. The Atotonilco wastewater treatment plant in Mexico treats wastewater for irrigation across tens of thousands of hectares while generating biogas to power its own operations, linking sanitation, agricultural reuse, and energy recovery in a single facility. The Braunschweig Model in Germany operates a long-term circular system connecting wastewater treatment, agricultural reuse, and biogas energy production. These examples demonstrate that construction managers are increasingly expected to navigate these interdependencies, yet the educational pathways to prepare them for such systemic decision-making remain underdeveloped.

Simultaneously, artificial intelligence is fundamentally transforming how construction decisions are made. The construction industry has historically relied on heuristics and prior project experience rather than purely theoretical approaches when confronting new cases (IEEE, 2025). This reliance on experience-based decision-making is now being supplemented, and in some cases challenged, by AI-driven tools capable of analyzing vast datasets, identifying patterns invisible to human analysts, and generating scenarios that can inform more robust decisions. The field is actively developing AI applications specifically for WEF decision-making. A comprehensive edited volume published in 2025 explores the application of AI techniques to address problems associated with the WEF nexus, with chapters addressing AI applications in water, energy, and food sectors individually and collectively (Jafarinejad & Shahrinia, 2025).

Recent research has begun to examine how AI can enhance WEF nexus management under climate change. Silva and colleagues (2025) conducted a systematic review of AI methodologies applicable to water resources management within the WEF nexus, finding

that AI-driven models can improve water demand forecasting, optimize energy usage in irrigation, and support the design of resilient food production systems. Their findings indicate that effective AI integration can significantly reduce economic losses in critical sectors, boost productivity, and foster sustainable societal development.

Despite these advances, a significant gap persists in the preparation of construction managers for AI-enhanced WEF Nexus decision-making. Research on digital and educational readiness of construction managers for AI implementation has found that while the push for digitization brings new challenges and opportunities, the competency profiles necessary for successful AI adoption remain unevenly developed across the sector (IEEE, 2025). A bibliometric review of generative AI in engineering and construction management education found that while Gen AI has advanced rapidly in professional practice, its translation into educational settings has been uneven and fragmented (Agha & Oluniyi, 2026). Engineering and construction management programs are beginning to acknowledge Gen AI as a transformative force, yet the extent to which students are being prepared to engage with these technologies critically and effectively remains unclear.

The educational gap is particularly acute for WEF Nexus decision-making. A curriculum analysis of sustainability-focused construction management education revealed critical gaps in post-occupancy evaluation methods, real-time performance data integration, and human-centered design instruction (Ghorbani, 2026). Faculty support for AI integration was strong, yet student uncertainty remained significant, and both groups identified infrastructure, professional development, and structured support as critical implementation requirements. These findings suggest that while the will to integrate AI and sustainability exists, the educational infrastructure to do so effectively is still developing.

This study addresses these interconnected gaps by examining the pedagogical foundations and curricular requirements for preparing construction managers to leverage AI in WEF Nexus decision-making contexts. The research is guided by the following objectives: first, to synthesize the current state of knowledge on AI applications in WEF Nexus decision-making and their implications for construction management practice; second, to identify the competencies construction managers require to effectively use AI tools for WEF decision-making; third, to examine the current state of WEF and AI integration in construction management education; and fourth, to propose a curricular framework that positions construction managers as strategic infrastructure leaders capable of navigating WEF trade-offs using AI as a decision-support partner.

The significance of this research extends beyond the immediate context of construction management education. As institutions of higher education grapple with how to responsibly and effectively integrate AI technologies into teaching and learning, and as professional bodies such as ASCE mandate continuing education regarding WEF, empirical evidence on the pedagogical pathways that connect these domains becomes essential. The construction industry, with its complex, interdisciplinary nature and its direct role in shaping the built infrastructure that mediates WEF relationships, provides a particularly illuminating context for examining these questions.

The structure of this paper proceeds as follows. Section two reviews the relevant literature on the WEF Nexus, AI in construction and WEF decision-making, and construction management education. Section three describes the methodology. Section four presents the findings from the systematic review and curriculum analysis. Section five discusses the implications for curriculum design and professional preparation. Section six concludes

with a summary of contributions, limitations, and directions for future research.

2. Literature Review

The literature relevant to this study spans three interconnected domains: the conceptual and policy foundations of the WEF Nexus, the application of artificial intelligence to WEF decision-making, and the current state of construction management education regarding sustainability and AI integration.

The Water-Energy-Food Nexus: Concepts and Policy Foundations

The WEF Nexus has evolved from an academic concept to a recognized framework for sustainable development policy and practice. The United Nations water, food, and energy form a nexus at the heart of sustainable development, with demand for all three resources increasing rapidly (ASCE, 2024). To withstand current and future pressures, governments and other stakeholders must ensure integrated and sustainable management of water, food, and energy to balance the needs of people, nature, and the economy.

The conceptual foundations of the Nexus rest on recognition of interdependence. Each resource influences the others, creating opportunities for collaboration and challenges that require integrated solutions (ASCE, 2024). Scenarios where WEF interconnectedness should be considered include increasing populations and changing lifestyles that drive up demand for all three resources, leading to potential conflicts over allocation and sustainability. Water use is directly related to energy use in cities, including energy used by water infrastructure for conveying, treating, and distributing water and collecting, treating, and disposing of wastewater. Many reservoirs are multi-purpose systems operated to balance trade-offs arising from irrigated agriculture, municipal and industrial water supply, hydropower generation, recreational activities, and water for downstream aquatic ecosystems.

Policy Statement 576 from ASCE articulates the professional obligations that flow from this understanding. The policy supports requiring private and public entities to evaluate the systemic tradeoffs and synergies, sustainability, and resilience of interconnected networked services supported by civil infrastructure (ASCE, 2024). It calls for updating infrastructure design codes, standards, and permitting to include WEF supply chain sustainability and/or resilience, modernizing life-cycle analysis and engineering workflows, and requiring continuing education regarding WEF for engineers and other professionals.

The policy provides concrete examples of scenarios where WEF interconnectedness should be considered in infrastructure decisions. Navigation dam removal or dam failure may constrain grain exports if alternative distribution systems are not available or affordable, suppressing domestic grain prices and increasing international grain prices. When levels of groundwater used for irrigated agriculture and municipal and industrial water supplies are drawn down during drought periods, energy requirements for pumping increase. Irrigation with recycled wastewater and recovery of nutrients during wastewater treatment could support additional crop cultivation and diversify portfolios for water resources, but with risks of increased energy needs and environmental impacts (ASCE, 2024).

A recent call to action in the Journal of Water Resources Planning and Management provides concrete examples of how civil engineers should consider WEF trade-offs in infrastructure design. The authors note that the suitability of reclaimed water as a sustainability approach within the WEF nexus is highly sensitive to the state-level policy environment, with some policies hindering water reuse (ASCE, 2025). Modeling of water reuse in different hydrologic contexts has shown that in some basins, reclaimed water use had marginal streamflow impacts, presenting minimal risk to

grain and cargo shipping, while in others, pronounced streamflow impacts increased risk to critical aquatic species. These cases illustrate the need for both private and public entities to consider trade-offs and synergies through WEF systems thinking within context.

The same source provides an example of stormwater infrastructure in the context of multiple WEF trade-offs. In planning and designing urban green-blue infrastructure, civil engineers should expressly consider benefits and trade-offs associated with WEF systems. Green roofs are primarily designed to reduce stormwater runoff, but they also provide insulation to buildings and reduce urban heat island effects, thereby reducing energy demands for heating and cooling. Intensive green roofs may also feature vegetable gardens, directly contributing to the urban food system while reducing impervious surfaces. These interdependencies mean that infrastructure decisions have cascading effects across sectors that may not be apparent when each sector is considered in isolation.

The WEF Nexus thus represents both an analytical challenge and a professional obligation for construction managers. Understanding these interdependencies is crucial for developing holistic solutions that ensure sustainable resource management, food security, and environmental protection for present and future generations (ASCE, 2024). The question for construction management education is how to prepare graduates who can navigate this complexity in their professional practice.

Artificial Intelligence for WEF Nexus Decision-Making

The application of artificial intelligence to WEF Nexus challenges has emerged as a vibrant area of research and development. A comprehensive edited volume published in 2025 provides a systematic overview of this emerging field (Jafarinejad & Shahirinia, 2025). The volume begins with an introduction

to WEF nexus concepts, frameworks, assessment methodologies, challenges, trends, and future perspectives. It then addresses AI applications in each sector individually before examining the application of AI to the nexus as a whole. The final chapter reviews the application of AI techniques to address problems associated with the WEF nexus, drawing together the sector-specific discussions into an integrated framework.

Within the water sector, AI techniques are being applied to water treatment, wastewater treatment, water quality monitoring, water resource management, and smart agriculture and irrigation (Jafarinejad & Shahirinia, 2025). Real-world applications include predictive maintenance, leak detection, demand forecasting, and water distribution optimization. The energy sector has seen AI applications in load monitoring, load demand forecasting, smart grids, energy optimization and process control, and energy storage systems. The food industry has applied AI techniques in areas including organoleptic properties, nutrition, toxicology, food chemistry, biotechnology processes, food processing and manufacturing, conservation and storage conditions, supply chain management, and distribution.

Research specifically addressing AI for the WEF nexus has begun to demonstrate the potential of integrated approaches. Silva and colleagues (2025) conducted a systematic review of AI methodologies applicable to water resources management within the WEF nexus, employing PRISMA framework guidelines to analyze publications from 2012 to 2021. Their review selected 83 original papers, categorized into water (37 papers), energy (24 papers), food (5 papers), and ecosystems (17 papers). The research question guiding their analysis was how AI can enhance decision-making processes for water security in different sectors.

The findings from Silva and colleagues (2025) indicate that effective AI integration can

significantly reduce economic losses in critical sectors, boost productivity, and foster sustainable societal development. AI-driven models can improve water demand forecasting, optimizing energy usage in irrigation, and supporting the design of resilient food production systems. Climate challenges, such as extreme weather unpredictability and data scarcity, complicate water management, but AI offers opportunities by analyzing complex datasets to predict scenarios and enhance decision-making. Furthermore, these technologies provide valuable insights for ecosystem preservation by monitoring biodiversity and assessing environmental impacts, enabling more sustainable and proactive strategies.

The review highlights the importance of interdisciplinary collaboration and capacity building to maximize AI's benefits. These insights offer a pathway to enhanced resilience, adaptive capacity, and long-term sustainability in WEF management under changing climate conditions, consistent with Sustainable Development Goals 6 (water), 7 (energy), and 13 (climate action) (Silva et al., 2025). The implication for construction management education is that graduates will need both technical AI competencies and the ability to collaborate across disciplinary boundaries.

Decision support systems for WEF management are also being developed. The CGIAR Nexus Gains Initiative has produced a Decision Support System that integrates surface and groundwater models with detailed land use and crop data to generate spatially explicit information on key hydrological and agricultural variables (Sikka et al., 2025). The DSS includes a WEF Scenario Generator and a WEF Trade-off Index calculator, which allow users to explore different interventions while evaluating their implications across water, energy, food, and ecosystem. The tool has been applied in the Ganges River Basin, India, demonstrating how such a framework can support local and regional decision-making.

The developers note that the WEF-Nexus DSS is useful in making policy decisions for improving cross-sectoral planning and resource management in complex and resource-constrained environments (Sikka et al., 2025).

The NEXOGENESIS project, which concluded in August 2025, represents a major European effort to advance WEF nexus governance through AI-enhanced decision support. The project produced the NExus Policy Assessment Tool, a web-based decision-support platform that enables users to design and evaluate policies across the WEF nexus (NEXOGENESIS, 2025). NEPAT allows testing of policy packages under diverse climate and socio-economic futures, presenting results through indicators, Nexus Footprint indices, and visual maps. Its AI-driven insights guide users in balancing trade-offs and strengthening cross-sectoral sustainability. The project also developed a WEF Nexus Footprint composite indicator that captures and visualizes the intricate interactions between water, energy, food, and ecosystems.

These tools represent a significant advance in operationalizing WEF Nexus thinking for practical decision-making. For construction managers, they offer the promise of more robust, evidence-based approaches to infrastructure planning that account for systemic interdependencies. However, using these tools effectively requires competencies that current construction management curricula may not adequately develop. The challenge for educators is to design learning experiences that prepare graduates to work with these tools critically and effectively.

Construction Management Education: Sustainability and AI Integration

The literature on construction management education reveals a field in transition, grappling with how to integrate sustainability and AI into curricula that have traditionally emphasized technical and managerial competencies. A systematic review of technology-enhanced

learning approaches in construction engineering and management education examined 28 studies published between 2013 and 2023 (Marchiori et al., 2025). The review found a predominant focus on hard skills, particularly in safety training and project management, with limited attention to soft skills development. Immersive environments such as virtual reality and building information modeling emerged as the most commonly employed technologies. A key finding was that instructors often refrain from adopting technology-enhanced learning approaches due to insufficient knowledge about how to use these technologies effectively and the high investment required for implementation.

Research specifically addressing AI integration in construction management education has accelerated in recent years. A bibliometric literature review of generative AI in engineering and construction management education from 2015 to 2025 found that while Gen AI has advanced rapidly in professional practice, its translation into educational settings has been uneven and fragmented (Agha & Oluniyi, 2026). The review notes that engineering and construction management programs are beginning to acknowledge Gen AI as a transformative force, yet the extent to which students are being prepared to engage with these technologies critically and effectively remains unclear. The authors argue that without a consolidated understanding of what has already been studied and how students are actually engaging with Gen AI, educators risk developing fragmented curricula that lag behind industry needs.

A study on digital and educational readiness of construction managers for AI implementation examined the digital competencies and educational readiness of managers in the construction industry (IEEE, 2025). The research, based on questionnaire data collected from professionals in construction organizations, found that the push for digitization brings new challenges as well as

opportunities. Construction project management has become more dynamic and increasingly complex, with project managers expected to make timely, reflective decisions under pressure. Heuristics often dominate decision-making in this environment, and many managers lean on prior project experience rather than purely theoretical approaches when confronting new cases. The implication for education is that preparing managers for AI implementation requires not only technical training but also attention to the cognitive and decision-making processes that AI tools are intended to support.

Research on AI-driven assistants for construction project management competencies has examined how these tools can enhance professional skills from both academic and industry perspectives (Enhancing construction project management competencies, 2025). A systematic literature review identified 35 core competencies required for effective construction project management, categorized by their relevance to planning, execution, monitoring, and closure phases. A structured questionnaire administered to 135 managers from academia and industry found that AI tools have a positive impact on technological innovation capacity, scheduling efficiency, resource allocation, and project reporting. Significant differences were observed in the perceived applicability of AI based on participants' roles and levels of experience, but there was overall consensus on AI's important role in enhancing competencies for managing construction projects.

The specific intersection of AI and sustainability in construction management education has received some attention. A thesis investigating AI integration in LEED-focused construction management education at East Carolina University employed a three-part investigation encompassing curriculum analysis, systematic literature review, and stakeholder survey research (Ghorbani, 2026). The curriculum analysis revealed critical gaps

in post-occupancy evaluation methods, real-time performance data integration, and human-centered design instruction. A systematic review of approximately 50 peer-reviewed publications identified four primary AI application categories with demonstrated educational effectiveness: energy performance optimization tools, AI-enhanced Building Information Modeling, indoor environmental quality monitoring systems, and predictive analytics for building performance assessment, with documented learning outcome improvements of 25-45 percent. Survey results from faculty and students revealed strong faculty support for AI integration (86 percent) alongside significant student uncertainty (39 percent neutral), with both groups identifying infrastructure, professional development, and structured support as critical implementation requirements (Ghorbani, 2026).

The literature on WEF Nexus education specifically is more limited but growing. Research on faculty development programs for the food-energy-water nexus examined factors influencing faculty interest in adopting instructional resources and faculty experience with professional development (Mostacedo-Marasovic & Forbes, 2024). The study found that over three quarters of participants would use curricular resources to make connections between complex socio-hydrologic issues, enhance place-based learning, data analysis and interpretation, and engage in evidence-based decision-making. Participants' knowledge about these issues remained relatively constant, but their self-efficacy to teach about them improved by the end of the workshop. The results provide evidence of the importance of institutional support to improve instruction about the FEW nexus.

A related study assessed undergraduate students' systems thinking skills in a food-energy-water nexus module featuring a data visualization tool called Hydroviz (Mostacedo-Marasovic et al., 2025). Results showed moderate enactment of systems thinking skills,

with students emphasizing problem framing and goal setting while prioritizing technical over contextual aspects. Curricular resources effectively supported data exploration, system connections, leveraging prior knowledge, and identifying management solutions. The authors concluded that students may need additional support to better frame decision-making problems and to provide more in-depth and localized descriptions, including the use of collected evidence to support their analysis (Mostacedo-Marasovic et al., 2025).

Another study examining undergraduate students' decision-making about complex socio-hydrologic issues supported by Hydroviz found that factors supporting decision-making outcomes included students' personal values and experiences and scaffolding elements of the module that allowed them to decompose the problem, prioritize different values, and question initial approaches (Mostacedo-Marasovic et al., 2025). No differences between demographic groups were observed. The study provides insights to enhance instructors' use of curricular resources and curricular design to foster student engagement in decision-making about socio-hydrologic issues.

Gaps in the Literature

Despite the growing body of research on AI in construction management education, on WEF Nexus decision-making, and on sustainability education, several gaps remain. First, the literature has not adequately addressed the specific competencies construction managers require to use AI tools for WEF Nexus decision-making. While research has identified general AI competencies for construction managers and general systems thinking skills for WEF education, the intersection of these domains remains underexplored. Second, there is limited research on how to design curricula that integrate AI, sustainability, and systems thinking in construction management programs. The existing literature tends to address these domains separately rather than examining how they can be integrated

pedagogically. Third, the literature has not adequately addressed the challenges and limitations of AI-enhanced WEF decision-making, including issues of data quality, model interpretability, and the potential for AI to obscure rather than illuminate the value judgments inherent in resource allocation decisions.

This study addresses these gaps by synthesizing the relevant literature, identifying the competencies required for AI-enhanced WEF decision-making, examining the current state of educational preparation, and proposing a curricular framework that integrates these domains. The findings contribute to the theoretical understanding of how AI and sustainability education intersect in professional programs while also providing practical guidance for curriculum design.

3. Methodology

This study employed a systematic literature review and curriculum analysis to examine the preparation of construction managers for AI-enhanced WEF Nexus decision-making. The methodology was designed to synthesize evidence across three domains—WEF Nexus concepts and policy, AI applications for WEF decision-making, and construction management education—and to identify the competencies and curricular requirements that emerge at their intersection.

Research Design

The study employed a qualitative synthesis design combining systematic literature review with document analysis. Systematic review is appropriate when the goal is to synthesize evidence across a dispersed literature base and identify patterns, gaps, and emerging themes. The approach followed established guidelines for systematic reviews in education research, including transparent search strategies, explicit inclusion and exclusion criteria, and structured data extraction and synthesis procedures.

Search Strategy

Searches were conducted across multiple databases and outlets central to construction management, engineering education, and sustainability research. Sources included the American Society of Civil Engineers (ASCE) Library, the American Society for Engineering Education (ASEE) proceedings, IEEE Xplore, ScienceDirect, and the Education Resources Information Center (ERIC). The search strategy combined terms related to the WEF Nexus (e.g., "water-energy-food nexus," "WEF nexus," "WEFE nexus") with terms related to artificial intelligence (e.g., "artificial intelligence," "machine learning," "decision support systems") and terms related to construction management education (e.g., "construction management education," "curriculum," "competencies," "professional preparation").

The search was limited to publications from 2015 to 2026 to capture the period during which both the WEF Nexus and AI integration in construction education emerged as significant areas of research and practice. This timeframe aligns with the period covered by recent bibliometric reviews of generative AI in construction education (Agha & Oluniyi, 2026). Searches were conducted in English, and only peer-reviewed publications, book chapters, conference proceedings, and authoritative policy documents were included.

Inclusion and Exclusion Criteria

Studies and documents were included if they addressed at least one of the following: (a) conceptual or policy foundations of the WEF Nexus relevant to infrastructure and construction; (b) applications of artificial intelligence to WEF or WEFE decision-making; (c) competencies required for construction managers in the context of AI or sustainability; (d) educational approaches for teaching WEF, sustainability, or AI in construction management or related engineering fields.

Documents were excluded if they focused exclusively on technical AI development without educational or professional competency implications, addressed WEF Nexus issues without relevance to construction or infrastructure, or were not available in English.

Data Extraction and Synthesis

Data were extracted from included documents using a structured template that captured bibliographic information, document type, key concepts and definitions, relevant findings, and implications for construction management education. The extracted data were organized thematically around three domains: WEF Nexus concepts and policy, AI for WEF decision-making, and construction management education. Cross-cutting themes were then identified by examining the intersections between these domains.

The synthesis employed a narrative approach, organizing findings around the research objectives: synthesizing current knowledge on AI applications in WEF decision-making, identifying competencies for construction managers, examining the current state of educational preparation, and proposing a curricular framework. This approach is appropriate for integrating evidence across diverse literatures and for generating actionable recommendations for curriculum design.

Limitations

Several limitations of the methodology should be acknowledged. The search strategy, while comprehensive within the databases and outlets selected, may not have captured all relevant publications, particularly those in languages other than English or in outlets not indexed in the databases searched. The qualitative synthesis approach, while appropriate for integrating diverse evidence, does not provide quantitative estimates of effect sizes or enable meta-analytic conclusions. The curriculum analysis component relied on publicly available

documents and published research rather than direct observation of educational programs, which may limit the depth of understanding of current practices.

4. Results

This section presents the findings from the systematic literature review and curriculum analysis, organized around the research objectives. The findings address the current state of knowledge on AI applications in WEF decision-making, the competencies required for construction managers, the current state of educational preparation, and the elements of a proposed curricular framework.

AI Applications for WEF Nexus Decision-Making

The literature review identified several categories of AI applications relevant to WEF Nexus decision-making. These applications span the individual sectors of water, energy, and food, as well as integrated applications that address the nexus as a whole.

Within the water sector, AI techniques are being applied across a range of functions. Jafarinejad and Shahirinia (2025) identify applications in water treatment, wastewater treatment, water quality monitoring, water resource management, and smart agriculture and irrigation. Real-world applications include predictive maintenance for water infrastructure, leak detection in distribution systems, demand forecasting, and water distribution optimization. These applications have direct relevance to construction managers responsible for water infrastructure projects, as they offer tools for designing and operating systems that are more efficient, resilient, and responsive to changing conditions.

The energy sector has seen analogous developments. AI applications address load monitoring, load demand forecasting, smart grids, energy optimization and process control, and energy storage systems (Jafarinejad &

Shahirinia, 2025). For construction managers, these applications are relevant to the design and operation of energy infrastructure, as well as to the energy performance of buildings and other constructed facilities. The integration of renewable energy sources and the optimization of energy use in buildings are areas where AI tools can support more informed decision-making.

In the food sector, AI applications address organoleptic properties, nutrition, toxicology, food chemistry, biotechnology processes, food processing and manufacturing, conservation and storage conditions, supply chain management, and distribution (Jafarinejad & Shahirinia, 2025). While these applications may seem distant from the traditional concerns of construction managers, they are connected through the infrastructure that supports food production, processing, and distribution. Agricultural irrigation systems, food processing facilities, and cold chain infrastructure all involve construction decisions that have implications for water and energy use.

The most directly relevant applications for WEF Nexus decision-making are those that address the nexus as a whole. Silva and colleagues (2025) found that AI-driven models can improve water demand forecasting, optimize energy usage in irrigation, and support the design of resilient food production systems. Their systematic review indicated that effective AI integration can significantly reduce economic losses in critical sectors, boost productivity, and foster sustainable societal development. Climate challenges, such as extreme weather unpredictability and data scarcity, complicate water management, but AI offers opportunities by analyzing complex datasets to predict scenarios and enhance decision-making.

Decision support systems represent a particularly important category of AI application for WEF Nexus decision-making. The CGIAR Nexus Gains Initiative has developed a Decision Support System that

integrates surface and groundwater models with land use and crop data to generate spatially explicit information on hydrological and agricultural variables (Sikka et al., 2025). The DSS includes a WEF Scenario Generator and a WEF Trade-off Index calculator, allowing users to explore interventions such as expanding irrigated area, crop diversification, and improvements in irrigation efficiency while evaluating their implications across water, energy, food, and ecosystem. The tool has been applied in the Ganges River Basin, demonstrating how such a framework can support local and regional decision-making.

The NEXOGENESIS project has produced the NEXus Policy Assessment Tool, a web-based decision-support platform that enables users to design and evaluate policies across the WEF nexus (NEXOGENESIS, 2025). NEPAT allows testing of policy packages under diverse climate and socio-economic futures, presenting results through indicators, Nexus Footprint indices, and visual maps. Its AI-driven insights guide users in balancing trade-offs and strengthening cross-sectoral sustainability. The project also developed a WEF Nexus Footprint composite indicator that captures and visualizes interactions between water, energy, food, and ecosystems.

These tools represent a significant advance in operationalizing WEF Nexus thinking. For construction managers, they offer the promise of more robust, evidence-based approaches to infrastructure planning that account for systemic interdependencies. However, the literature suggests that using these tools effectively requires competencies that current construction management curricula may not adequately develop. The challenge for educators is to design learning experiences that prepare graduates to work with these tools critically and effectively.

Competencies for AI-Enhanced WEF Nexus Decision-Making

Synthesizing across the literature on AI competencies for construction managers, systems thinking skills for WEF education, and decision-making under complexity, several competency domains emerge as essential for AI-enhanced WEF Nexus decision-making.

The first domain is systems thinking. The WEF Nexus is fundamentally a systems concept, requiring the ability to understand interconnections, feedback loops, and cascading effects across sectors. Research on WEF education has found that students may need additional support to better frame decision-making problems and to provide more in-depth and localized descriptions, including the use of collected evidence to support their analysis (Mostacedo-Marasovic et al., 2025). The study assessing systems thinking skills found moderate enactment of these skills, with students emphasizing problem framing and goal setting while prioritizing technical over contextual aspects. This suggests that systems thinking is a competency that requires deliberate development, not merely exposure to WEF concepts.

The second domain is data literacy and AI fluency. Construction managers working with AI tools for WEF decision-making need the ability to understand what these tools can and cannot do, to interpret their outputs critically, and to recognize the limitations and assumptions embedded in AI models. Research on digital readiness of construction managers found that heuristics often dominate decision-making, and many managers lean on prior project experience rather than purely theoretical approaches (IEEE, 2025). This reliance on experience-based decision-making may create resistance to AI tools that challenge or supplement traditional approaches. Education for AI-enhanced WEF decision-making must therefore address not only technical skills but also the cognitive and attitudinal dimensions of working with AI systems.

The third domain is decision-making under uncertainty and value pluralism. WEF Nexus

decisions involve trade-offs between competing values and interests, and AI tools may obscure rather than illuminate these value judgments if used uncritically. Research on undergraduate decision-making about socio-hydrologic issues found that factors supporting decision-making outcomes included students' personal values and experiences and scaffolding elements of the module that allowed them to decompose the problem, prioritize different values, and question initial approaches (Mostacedo-Marasovic et al., 2025). This suggests that education for WEF decision-making must help students develop the ability to recognize and reason about value trade-offs, not merely to apply technical tools.

The fourth domain is interdisciplinary collaboration. The WEF Nexus is inherently interdisciplinary, and effective decision-making requires the ability to communicate and collaborate across disciplinary boundaries. Research on AI for WEF nexus management emphasizes the importance of interdisciplinary collaboration and capacity building to maximize AI's benefits (Silva et al., 2025). For construction managers, this means developing the ability to work with water resource engineers, energy analysts, agricultural specialists, and other professionals in integrated project teams.

The fifth domain is ethical reasoning and professional responsibility. AI tools for WEF decision-making raise ethical questions about data privacy, algorithmic bias, transparency, and accountability. Construction managers need the ability to recognize these issues and to make decisions that are not only technically sound but also ethically defensible. Research on AI integration in LEED-focused construction management education found strong faculty support for AI integration alongside significant student uncertainty, suggesting that ethical and professional dimensions of AI use require explicit attention in curricula (Ghorbani, 2026).

Current State of Educational Preparation

The literature review revealed significant gaps between the competencies required for AI-enhanced WEF decision-making and the current state of construction management education.

The integration of AI into construction management education remains uneven and fragmented. A bibliometric review of generative AI in engineering and construction management education found that while Gen AI has advanced rapidly in professional practice, its translation into educational settings has been uneven (Agha & Oluniyi, 2026). Engineering and construction management programs are beginning to acknowledge Gen AI as a transformative force, yet the extent to which students are being prepared to engage with these technologies critically and effectively remains unclear. The review notes that without a consolidated understanding of what has already been studied and how students are actually engaging with Gen AI, educators risk developing fragmented curricula that lag behind industry needs.

Sustainability education in construction management programs faces similar challenges. A curriculum analysis of LEED-focused construction management education revealed critical gaps in post-occupancy evaluation methods, real-time performance data integration, and human-centered design instruction (Ghorbani, 2026). The study found strong faculty support for AI integration, with 86 percent of faculty respondents expressing support, but significant student uncertainty, with 39 percent of students expressing neutral attitudes. Both groups identified infrastructure, professional development, and structured support as critical implementation requirements.

Research on technology-enhanced learning in construction engineering and management education found a predominant focus on hard skills, particularly in safety training and project management, with limited attention to soft skills development (Marchiori et al., 2025). A

key finding was that instructors often refrain from adopting technology-enhanced learning approaches due to insufficient knowledge about how to use these technologies effectively and the high investment required for implementation. This suggests that faculty development and institutional support are essential prerequisites for effective curriculum change.

The integration of WEF Nexus concepts into construction management education appears to be particularly limited. While research on WEF education exists, it is predominantly situated in geoscience, environmental science, and agricultural education rather than construction management. Research on faculty development programs for the FEW nexus found that over three quarters of participants would use curricular resources to make connections between complex socio-hydrologic issues, enhance place-based learning, data analysis and interpretation, and engage in evidence-based decision-making (Mostacedo-Marasovic & Forbes, 2024). However, participants' knowledge about these issues remained relatively constant, while their self-efficacy to teach about them improved. This suggests that faculty development can increase confidence and willingness to teach WEF topics, but may not substantially deepen content knowledge without more intensive intervention.

The educational gap is compounded by the fact that the tools and approaches for AI-enhanced WEF decision-making are still evolving. The NEXOGENESIS project and other initiatives have produced decision support tools, but these are relatively new and have not been widely integrated into educational settings (NEXOGENESIS, 2025; Sikka et al., 2025). The challenge for educators is not merely to teach existing tools but to prepare students for a rapidly evolving technological landscape in which the specific tools they will use professionally may not yet exist.

Elements of a Curricular Framework

Synthesizing the findings on required competencies and the current state of educational preparation, a curricular framework for preparing construction managers for AI-enhanced WEF decision-making can be articulated. This framework is organized around four interconnected elements: foundational knowledge, technical competencies, critical reasoning, and professional identity.

Foundational knowledge encompasses the conceptual foundations of the WEF Nexus, including the interdependencies among water, energy, and food systems, the policy frameworks that govern these sectors, and the infrastructure systems that mediate their relationships. Students need to understand not only the technical dimensions of these systems but also the institutional, economic, and social factors that shape resource management decisions. The ASCE Policy Statement 576 provides a useful organizing framework for this knowledge, identifying the scenarios and considerations that should inform WEF-aware infrastructure decisions (ASCE, 2024).

Technical competencies include the ability to use AI tools for WEF decision-making, including data visualization and analysis tools, decision support systems, and scenario modeling platforms. The Hydroviz tool used in WEF education research provides an example of the kind of tool students should learn to use, as do the DSS developed by CGIAR and the NEPAT platform from NEXOGENESIS (Sikka et al., 2025; NEXOGENESIS, 2025). However, technical competencies should not be limited to specific tools. Students need to develop the ability to learn new tools, to understand the logic and limitations of different types of AI systems, and to evaluate the appropriateness of tools for different decision contexts.

Critical reasoning encompasses the ability to evaluate AI outputs critically, to recognize the value judgments embedded in technical analyses, and to reason about trade-offs under uncertainty. Research on WEF education found

that students may need additional support to better frame decision-making problems and to provide more in-depth and localized descriptions, including the use of collected evidence to support their analysis (Mostacedo-Marasovic et al., 2025). The scaffolding elements of the module—decomposing the problem, prioritizing different values, and questioning initial approaches—provide a model for how critical reasoning can be developed through structured learning experiences.

Professional identity involves the development of a sense of professional responsibility that encompasses WEF Nexus thinking and AI-enhanced decision-making. Students need to see themselves as professionals who are accountable not only for the technical success of projects but also for their systemic effects across water, energy, and food systems. The ASCE policy calling for continuing education regarding WEF for engineers signals that this is an emerging dimension of professional identity (ASCE, 2024). Education for AI-enhanced WEF decision-making should help students internalize this dimension of professional responsibility.

The four elements of the framework are interconnected and mutually reinforcing. Foundational knowledge provides the context for technical competency development. Technical competencies enable students to engage with real-world decision problems. Critical reasoning ensures that technical tools are used thoughtfully rather than mechanically. Professional identity provides the motivation and ethical grounding for applying these competencies in practice.

5. Discussion of Findings

The findings of this study reveal both significant opportunities and substantial challenges in preparing construction managers for AI-enhanced WEF Nexus decision-making. This section discusses the implications of the findings for curriculum design, faculty

development, and professional practice, and considers the limitations of the study and directions for future research.

The Case for Integration

The findings make a compelling case for integrating WEF Nexus thinking and AI competencies into construction management education. The policy landscape has shifted decisively: ASCE Policy Statement 576 now calls for civil engineers to evaluate systemic tradeoffs and synergies of interconnected infrastructure and to engage in continuing education regarding WEF (ASCE, 2024). This policy creates a professional expectation that construction managers will be prepared to consider WEF interdependencies in their work. Educational programs that do not address these expectations risk graduating professionals who are unprepared for the responsibilities their profession has embraced.

The technological landscape has also shifted. AI tools for WEF decision-making are no longer experimental; they are operational and increasingly accessible. The DSS developed by CGIAR and the NEPAT platform from NEXOGENESIS provide concrete examples of tools that construction managers may encounter or be expected to use in professional practice (Sikka et al., 2025; NEXOGENESIS, 2025). The edited volume on AI for the WEF Nexus provides a comprehensive overview of the applications that are now possible (Jafarinejad & Shahrinia, 2025). Preparing graduates who are unfamiliar with these tools and approaches would be a disservice to both students and the profession.

The educational landscape, however, has not kept pace. The literature reveals uneven and fragmented integration of AI into construction management education (Agha & Oluniyi, 2026), critical gaps in sustainability-focused curricula (Ghorbani, 2026), and limited attention to WEF Nexus concepts in construction management programs. Faculty support for AI integration is strong, but student

uncertainty is significant, and both groups identify infrastructure, professional development, and structured support as critical needs (Ghorbani, 2026). The challenge is not a lack of interest or will but a lack of the structures, resources, and pedagogical models needed to translate interest into effective education.

Pedagogical Implications

The findings suggest several pedagogical principles for integrating AI and WEF Nexus content into construction management education. First, integration should be deliberate and systematic rather than additive. Simply adding a module on WEF Nexus or a workshop on AI tools is unlikely to develop the integrated competencies that AI-enhanced WEF decision-making requires. The four-element framework proposed in this study—foundational knowledge, technical competencies, critical reasoning, and professional identity—suggests that these domains should be developed in an integrated manner, with learning experiences that require students to draw on multiple domains simultaneously.

Second, learning experiences should be scaffolded to support the development of systems thinking and critical reasoning. Research on WEF education found that students may need additional support to frame decision-making problems and to use evidence effectively (Mostacedo-Marasovic et al., 2025). The scaffolding elements identified in this research—decomposing problems, prioritizing values, and questioning initial approaches—provide concrete strategies that can be incorporated into construction management courses. Instructors should not assume that students will develop these skills through exposure alone; deliberate instructional design is required.

Third, education should position AI as a cognitive partner rather than a replacement for professional judgment. The literature on AI

competencies for construction managers emphasizes the importance of critical evaluation and verification of AI outputs (IEEE, 2025). This stance is particularly important in the WEF Nexus context, where decisions involve value judgments about resource allocation that cannot be resolved by technical analysis alone. Students need to learn to use AI tools to inform their judgment, not to substitute for it.

Fourth, interdisciplinary collaboration should be embedded in learning experiences. The WEF Nexus is inherently interdisciplinary, and effective decision-making requires the ability to communicate and collaborate across disciplinary boundaries. This could be achieved through team-based projects that bring together students from construction management, environmental engineering, agricultural science, and other relevant disciplines. Such experiences would develop the collaboration skills that research on AI for WEF nexus management identifies as essential (Silva et al., 2025).

Challenges and Limitations

Several challenges must be acknowledged in pursuing the curricular integration proposed in this study. The first challenge is faculty capacity. Research on technology-enhanced learning found that instructors often refrain from adopting these approaches due to insufficient knowledge about how to use them effectively and the high investment required for implementation (Marchiori et al., 2025). WEF Nexus content is similarly outside the expertise of many construction management faculty. Professional development programs, such as the faculty development program examined by Mostacedo-Marasovic and Forbes (2024), can increase self-efficacy to teach WEF topics, but may not substantially deepen content knowledge without more intensive intervention. The need for faculty development is substantial and may require institutional investment that is not currently available.

The second challenge is curriculum crowding. Construction management curricula are already crowded with technical, managerial, and professional content. Adding WEF Nexus and AI content may require difficult decisions about what to remove or de-emphasize. The case for integration rests on the argument that these are not additional topics but rather essential dimensions of professional practice that should be woven through existing courses rather than treated as separate subjects. However, achieving this integration requires significant curriculum redesign and may encounter resistance from faculty who are protective of existing content.

The third challenge is the rapid pace of technological change. The AI tools available for WEF decision-making are evolving rapidly, and the specific tools that students learn to use in their education may be obsolete by the time they enter professional practice. This argues for focusing on transferable competencies—the ability to learn new tools, to understand the logic and limitations of AI systems, and to critically evaluate their outputs—rather than on specific tool training. However, developing transferable competencies is more difficult and time-consuming than training on specific tools.

The fourth challenge is the value-laden nature of WEF decisions. AI tools can analyze data and generate scenarios, but they cannot resolve the value conflicts inherent in resource allocation decisions. Education for WEF decision-making must help students develop the ability to recognize and reason about these value conflicts, not merely to apply technical tools. This requires attention to ethical reasoning and professional judgment that may be outside the traditional scope of construction management education.

Limitations of the Study

This study has several limitations. The systematic review, while comprehensive within the databases and outlets searched, may not have captured all relevant publications. The

qualitative synthesis approach does not provide quantitative estimates of effect sizes or enable meta-analytic conclusions. The curriculum analysis component relied on publicly available documents and published research rather than direct observation of educational programs, which may limit the depth of understanding of current practices. The proposed curricular framework is based on synthesis of literature rather than empirical testing, and its effectiveness in practice remains to be demonstrated.

The study also focused on the North American and European context, where the WEF Nexus and AI in construction education literatures are most developed. The findings may not be directly applicable to other contexts where institutional structures, professional standards, and educational systems differ.

6. Conclusion

This study examined the preparation of construction managers for AI-enhanced WEF Nexus decision-making, synthesizing literature across the domains of WEF Nexus concepts and policy, AI applications for WEF decision-making, and construction management education. The findings reveal a significant gap between the competencies required for effective AI-enhanced WEF decision-making and the current state of educational preparation.

The research makes several contributions to the field. First, it synthesizes knowledge across previously disconnected literatures, bringing together research on WEF Nexus concepts, AI applications, and construction management education to identify the competencies required for AI-enhanced WEF decision-making. Second, it proposes a curricular framework organized around four interconnected elements—foundational knowledge, technical competencies, critical reasoning, and professional identity—that can guide curriculum design and pedagogical practice. Third, it identifies the challenges that must be addressed in pursuing curricular integration,

including faculty capacity, curriculum crowding, rapid technological change, and the value-laden nature of WEF decisions.

The findings have implications for educators, curriculum designers, and professional bodies. For educators, the findings suggest the need for deliberate, systematic integration of WEF Nexus and AI content into construction management courses, with attention to scaffolding, critical reasoning, and interdisciplinary collaboration. For curriculum designers, the four-element framework provides a structure for organizing learning experiences that develop integrated competencies. For professional bodies such as ASCE, the findings reinforce the importance of continuing education regarding WEF and suggest that accreditation standards should encourage programs to address these domains.

Several limitations of the study suggest directions for future research. The proposed curricular framework should be empirically tested to assess its effectiveness in developing the competencies it is designed to cultivate. Research that implements and evaluates AI-enhanced WEF decision-making modules in construction management courses would provide valuable evidence on what works and what does not. Research on faculty development needs would help institutions design effective programs to build faculty capacity. Longitudinal research tracking graduates into professional practice would assess whether educational innovations translate into enhanced professional performance.

The preparation of construction managers for AI-enhanced WEF Nexus decision-making is not merely a pedagogical challenge but a professional imperative. As the construction industry confronts the need to build and maintain infrastructure that supports sustainable resource management, graduates will need the ability to navigate complex interdependencies and to use AI tools effectively in service of human judgment. The

stakes are high: infrastructure decisions made today will shape water, energy, and food systems for decades to come. Preparing construction managers who can make these decisions wisely is among the most important tasks facing engineering and construction education.

The integration of AI and WEF Nexus thinking into construction management curricula is not a

matter of adding new subjects to an already crowded curriculum. It is a matter of reorienting professional education toward the systemic, interdisciplinary, and technology-enhanced forms of decision-making that contemporary practice demands. This study provides a foundation for that reorientation, offering a synthesis of evidence, a framework for curriculum design, and a call to action for the field.

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