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Exploring Construction 5.0 Paradigms in the AEC Sector of New Zealand: Conceptual Foundations and Implications for Practice

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Abstract

The increasing emphasis on integrating technological advancements with human-centered and sustainable practices highlights the paradigm shift toward Construction 5.0 (C5.0) in the architecture, engineering, and construction (AEC) sector. Despite its potential, investigations about C5.0's key pillars, practical implications, and adoption challenges remain limited, with much existing research focusing on conceptual frameworks or literature reviews. This study addresses these gaps through an empirical investigation, incorporating insights from a focus group of 17 industry practitioners to explore C5.0's key pillars, core features, technological enablers, and implications. The findings highlight three core features of C5.0: human-centricity, sustainability-driven practices, and collaborative intelligence. Seventeen emerging digital technologies were identified as critical enablers of C5.0, with artificial intelligence/machine learning, digital twins, and collaborative robots ranked as the most impactful technologies. These technologies support 31 application domains and enable AEC organizations to achieve enhanced productivity, innovation, sustainability, worker safety and well-being, and competitive advantage. Under the enhanced sustainability category, improved compliance with environmental regulations and increased capacity to meet client demands for sustainable practices were emphasized as key outcomes. This study contributes both theoretically and practically to the understanding of C5.0. Theoretically, it defines the key pillars, core features, and technological enablers of C5.0, bridging gaps in the existing literature and advancing the academic discourse on the evolution to C5.0. Practically, it offers a roadmap for integrating critical technologies with human-centered and sustainability goals, enabling AEC practitioners to prioritize investments effectively. Future research should expand empirical studies to

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conduct a cost-benefit evaluation of C5.0 technologies and explore C5.0's impact on project management methodologies, stakeholder collaboration, and organizational strategy development.

1 Introduction

The architecture, engineering, and construction (AEC) industry is a major contributor to global economic growth, accounting for approximately 13% of global GDP (McKinsey & Company, 2020). However, it remains one of the least digitized sectors and continues to face challenges such as low productivity, high waste generation, and persistent safety concerns (Abioye et al., 2021; World Economic Forum, 2023). Further, the industry is responsible for nearly 40% of global greenhouse gas emissions (Ürge-Vorsatz et al., 2020), emphasizing a need for transformative practices to meet global sustainability targets. Addressing these challenges requires a transition towards greener and more proactive approaches in AEC practices, driven by advancements from technological revolutions that have evolved from mechanization to digitalization under the Construction 4.0 (C4.0) paradigm (Chen et al., 2023).

C4.0 introduced digital tools and solutions such as building information modeling (BIM), the Internet of Things (IoT), and digital fabrication, revolutionizing construction through automated and smart processes (Sawhney et al., 2020). However, C4.0 primarily focuses on efficiency, productivity, precision, and cost-effectiveness, while lacking a holistic approach to sustainability, particularly in addressing long-term environmental and social impacts. Inspired by the principles of Industry 5.0 (I5.0), the emerging Construction 5.0 (C5.0) paradigm highlights human-centricity, sustainability, and resilience (Yitmen et al., 2023). C5.0 seeks to transform the sector by integrating advanced technologies such as artificial intelligence (AI), digital twins, and collaborative robotics (cobots) to enhance operational efficiency, support environmental stewardship, and prioritize worker well-being (Müller, 2020).

The increasing focus on integrating technological advancements with human-centered and sustainable practices indicates a shift towards adopting C5.0 principles. For instance, Marinelli (2023) identified human-robot collaboration (HRC) as a central theme, while Yitmen et al. (2023) emphasized C5.0's role in promoting resource efficiency and client-tailored solutions. Similarly, Tunji-Olayeni et al. (2024) examined C5.0's potential for improving health, safety, and sustainability outcomes in construction projects, and Bello et al. (2024) investigated how transitioning from C4.0 to C5.0 can strengthen supply chain resilience through a human-centric approach.

Although C5.0 is regarded as a critical future direction for the AEC sector, several gaps persist in terms of practical implementation. These include a limited understanding of its key pillars, their practical implications for the sector, and the challenges involved in its adoption. Realizing the full potential of C5.0 requires collaborative efforts in education, technological integration, and cultural transformation. However, most current studies are predominantly conceptual or review-based, focusing on theoretical frameworks rather than empirical evidence from industry practices (e.g., Cisneros-Gonzalez et al., 2024; Ikudayisi et al., 2023). While early studies have examined the technological and economic dimensions of C5.0 (Biswas et al., 2024; Rane, 2023), ethical and societal concerns, such as data privacy and job displacement, remain underexplored. Further, despite the sustainability benefits highlighted in recent studies (e.g., Bello et al., 2024; Hu et al., 2023), there is a lack of comprehensive metrics or frameworks to evaluate the long-term environmental, social, and economic impacts of C5.0 technologies. Against this backdrop, this study investigates the foundations and implications of C5.0 in the AEC sector through an empirical approach that engages industry stakeholders. Specifically, it seeks to answer the following research questions:

1. What are the key pillars of C5.0, including its core features and technological enablers? How are these technologies implemented, and how do they align with its core features?
2. What implications does the C5.0 paradigm hold for AEC organizations, and how will it affect their project management practices?

2 Literature Review

2.1 Industry 5.0 and Construction 5.0 Paradigms

The I5.0 concept emerges as a strategic initiative to address the limitations of Industry 4.0 (I4.0) while advancing digital and green transitions in the manufacturing sector. According to the European Commission (Müller, 2020), I5.0 introduces a human-centered and value-driven perspective, prioritizing technologies that align with ethical principles and societal needs. It emphasizes a balance between technological advancement and the well-being of people and the environment. Ivanov (2023) highlights I5.0 as a framework connecting resilience, sustainability, and human-centricity to create adaptable and regenerative industrial ecosystems. According to Zizic et al. (2022), I5.0 integrates stakeholder-driven socio-technological changes, focusing on sustainable production, workplace inclusion, and ethical considerations. Maddikunta et al. (2022) describes I5.0 as employing human creativity in interaction with intelligent and efficient machines, enabling hyper-customization and resource-efficient manufacturing. Core technologies include cobots, digital twins, wearable technology, and 5G/6G networks, which allow efficient human-machine collaboration and adaptive industrial processes (Chen et al., 2024a). Ghobakhloo et al. (2022) further addresses the focus of I5.0 on human dignity and workplace equality while deploying cognitive cyber-physical systems (CPS) to achieve sustainable industrial practices. Xu et al. (2021) positions I5.0 as an evolution that combines human intelligence and advanced technologies to enhance inclusivity, resilience, and innovation in manufacturing systems. These perspectives establish I5.0 as a transformative model, advancing beyond automation to balance technological progress with societal and environmental priorities.

C5.0 builds upon C4.0 by integrating the human-centric, collaborative, and sustainability-focused principles of I5.0, positioning it as the AEC industry's counterpart to I5.0 (Marinelli, 2023; Yitmen et al., 2023). C5.0 combines human expertise with advanced technologies such as digital twins and cobots to enhance efficiency, resilience, and tailored project delivery (Nahavandi, 2019; Yitmen et al., 2023). Central to this evolution is HRC, which addresses complex and hazardous tasks, enabling safer and more precise operations in dynamic environments (Ohueri et al., 2024). Furthermore, C5.0 inherits I5.0's emphasis on sustainability and resilience, with applications in waste management, supply chain adaptability, and environmental forecasting to meet societal and ecological goals (Bello et al., 2024; Tunji-Olayeni et al., 2024). By integrating advanced technologies with human ingenuity, C5.0 redefines construction processes to address the industry's unique challenges while promoting sustainable and collaborative innovation.

C5.0 emphasizes HRC through cohesive interaction enabled by advanced communication protocols and real-time data exchange, addressing dimensions of human well-being and the societal impact unacknowledged in previous paradigms (Ohueri et al., 2024). Grounded in sustainability, human-centricity, and resilience, C5.0 marks a shift from the focus of C4.0 on automation to a more holistic and technology-driven framework supported by empirical modeling (Marinelli, 2023; Yitmen et al., 2023). Although applications are primarily at the prototype stage, they lay a strong foundation for practical implementation (Chen et al., 2024b). For example, integrated systems utilizing human digital twins, smart sensors, and AI enhance worker safety and well-being by monitoring workers' physical, mental, and emotional states (Davila-Gonzalez & Martin, 2024). Similarly, virtual-real interaction models using 3D modeling, BIM, and digital twins are being validated for various construction stages (Wang et al., 2022). These developments emphasize the transformative potential of C5.0 in advancing sustainable construction practices and workforce development.

Despite its transformative potential, the implementation of C5.0 faces considerable technological, organizational, and cultural challenges. Limited digitalization, insufficient R&D investment, and fragmented workflows hinder the cohesive integration of advanced technologies like IoT, AI, robotics, and BIM, particularly in dynamic and uncontrolled construction environments (Brozovsky et al., 2024; Chen et al., 2024c; Marinelli, 2023). Workforce readiness is also a critical challenge, requiring extensive upskilling and interdisciplinary training to effectively use cobots, exoskeletons, and neuro-responsive systems (Almusaed et al., 2024; Hadi et al., 2023). Additionally, resistance to change, cultural apprehensions about automation, and ethical concerns surrounding privacy and data security further complicate adoption (Musarat et al., 2023; Rane, 2023). Sustainability, a core pillar of C5.0, demands integrating lean principles and circular economy practices like design for disassembly and material passports, which remain underdeveloped (Hadi et al., 2023). Collaboration between academia and industry is essential to align technological advancements with practical applications and promote skill development (Brozovsky et al., 2024). Generative AI and advanced systems offer opportunities to enhance decision-making, collaboration, and occupant-centered designs, but scalability and ethical challenges persist (Almusaed et al., 2024; Rane, 2023). Overcoming these barriers is critical for the AEC sector to fully realize the sustainable, human-centric, and resilient transformation envisioned by C5.0.

2.2 Implications of Construction 5.0

C5.0 technologies aim to revolutionize operational efficiency, decision-making, and sustainability by integrating advanced tools such as AI, IoT, robotics, and digital twins (Almusaed et al., 2024; Bello et al., 2024). Adopting C5.0 technologies requires a practical understanding of their applications, benefits, limitations, and the connection between human expertise and advanced systems. Despite significant progress in developing robotic systems, AI-driven tools, and blockchain-based frameworks, challenges persist in bridging the knowledge gap between practitioners and technology developers, particularly in dynamic and fragmented construction environments (Hu et al., 2023; Ikudayisi et al., 2023; Rane, 2023).

Table 1 summarizes recent studies on C5.0 technologies, highlighting the diverse technologies explored and their implications across technological, social, economic, and environmental dimensions. Technologies such as AI, machine learning (ML), digital twins, and BIM demonstrate significant potential to improve safety, efficiency, and resource optimization but face barriers such as technical immaturity, workforce readiness, and integration costs. Other technologies, including cobots, HRC, Human-CPS (HCPS), and generative AI, remain underutilized due to limited practical knowledge and misconceptions about their capabilities. The findings emphasize the need for multi-disciplinary collaboration and targeted training to bridge these gaps and ensure the progressive adoption and implementation of C5.0 practices.

Source	Article Type	C5.0 Technology	Implication
Almusaed et al. (2024)	Questionnaire Survey	AI, BIM, Brain-Computer Interface, Digital Twins	Enhances comfort and well-being; streamlines processes; optimizes energy use; reduces emissions.
Bello et al. (2024)	Literature Review	AI, Cobots, IoT	Improves supply chain resilience; enhances safety; reduces physical strain; increases efficiency; supports sustainability.
Biswas et al. (2024)	Literature Review	BIM, Digital Twins, ICT, IoT, ML	Enhances lifecycle management; improves precision; encourages collaboration through advanced data integration.

Cisneros-Gonzalez et al. (2024)	Systematic Literature Review	Automation and Robotics, Cobots, Wearable Devices, Prefabrication	Boosts productivity and precision; reduces waste; streamlines processes; minimizes reliance on human labor.
Hadi et al. (2023)	Literature Review	Cobots, Lean-Offsite Construction, Exoskeletons	Improves efficiency; reduces delays and costs; emphasizes design for disassembly and resource recovery.
Hu et al. (2023)	Theoretical Analysis; Questionnaire Survey	Green Intelligent Building Materials	Reduces waste and emissions; improves cost-efficiency; enhances convenience and comfort for end-users.
Ikudayisi et al. (2023)	Literature Review	BIM, Blockchain, Digital Twins, Modular Integrated Construction	Facilitates integration; reduces waste; enhances collaboration and transparency; supports sustainable design.
Jiménez Rios et al. (2024)	Systematic Literature Review	AI, Digital Twins, HRC, Renewable Energy, Smart Materials	Improves cultural heritage conservation; enhances monitoring systems; addresses climate challenges; supports ethical and sustainable practices.
Marinelli (2023)	Literature Review	HRC	Increases precision and safety; promotes ergonomics; reduces costs; optimizes resource use.
Musarat et al. (2023)	Literature Review	AI, Big Data, Cobots, Digital Twins, IoT, Smart Materials	Improves efficiency and collaboration; enhances safety; reduces costs; supports eco-friendly practices.
Ohueri et al. (2024)	Systematic Literature Review	AI, HRC, VR	Enhances safety in hazardous processes; reduces risks and costs; promotes material reuse and recycling.
Rane (2023)	Literature Review	Generative AI	Accelerates decision-making; improves communication; optimizes costs and efficiency; supports sustainability.
Saradara et al. (2024)	Literature Review	Blockchain, Smart Relational Contracts	Promotes circularity and collaboration; improves stakeholder integration; reduces waste.
Tunji-Olayeni et al. (2024)	Literature Review	6G, AI, Big Data, BIM, Blockchain, Cobots, CPS, Digital Sensors, Wearable Devices	Enhances safety and waste management; improves environmental forecasting; emphasizes collaboration and sustainability.
Yitmen et al. (2023)	Questionnaire Survey	HRC, HCPS	Promotes human-machine collaboration; supports societal benefits; reduces waste; improves resource efficiency and sustainability.

Table 1: Summary of studies on C5.0 in the existing literature

3 Research Methodology

This study adopts a qualitative focus group method to understand the key pillars of C5.0 and examine its implications for AEC organizations and practices. The focus group approach is particularly well-suited for investigating emerging topics where existing knowledge of a subject is limited. Its interactive nature encourages the exchange of perspectives based on participants' prior knowledge while enabling the co-construction of new insights informed by their experiences (O.Nyumba et al., 2018). Given the varied needs, challenges, and levels of technological maturity across organizations and professional backgrounds, this method offers a more comprehensive understanding of how industry professionals perceive the core features of C5.0. It captures their literacy regarding C5.0 technologies while revealing firsthand accounts of the real-world challenges, barriers, and gaps professionals face in adopting C5.0 technologies. Figure 1 illustrates the research process aligned with the predefined research questions, including research design, sampling, data collection, and analysis.

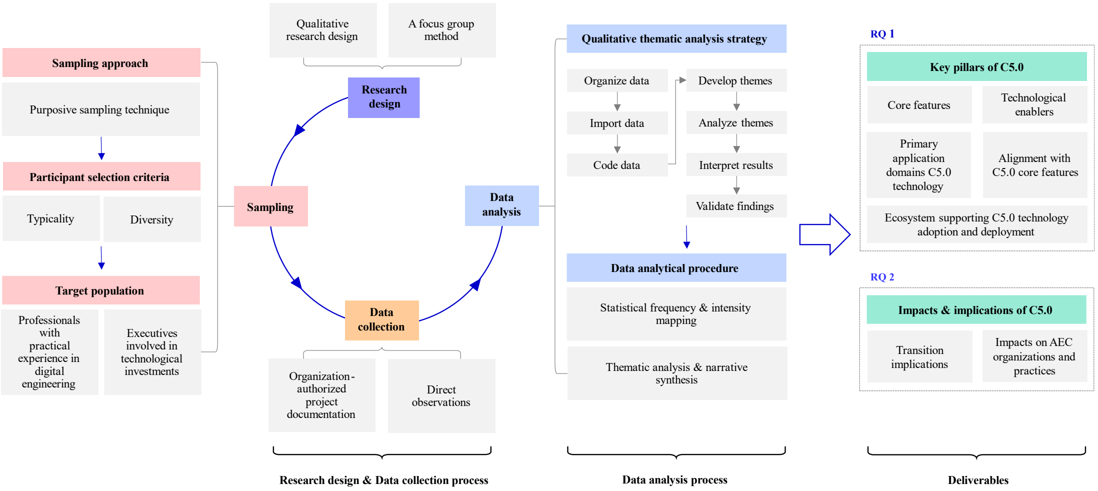


Figure 1: Overview of the research process

A purposive sampling strategy was employed to select participants, targeting professionals actively engaged in emerging technology implementation within AEC projects or organizational roles and firm leaders responsible for technological investments. This sampling approach ensured the inclusion of individuals capable of providing both operational and strategic insights. To achieve a representative and diverse sample, participants were further screened based on their expertise with advanced technologies and their roles across various organizational contexts, such as firm types and project domains.

The study drew on data from a broader research project examining the transition from C4.0 to C5.0. In the earlier phase of the project, background information on participants, such as job roles, professional experience, company profiles, and technology adoption practices, was gathered. For the current phase, the contact database was screened to identify eligible candidates. Potential participants were then emailed with an explanation of the study's objectives and invitations to participate. Based on positive responses, 17 participants were selected for focus group observations. Figure 2 illustrates the demographic composition of the finalized focus group participants.

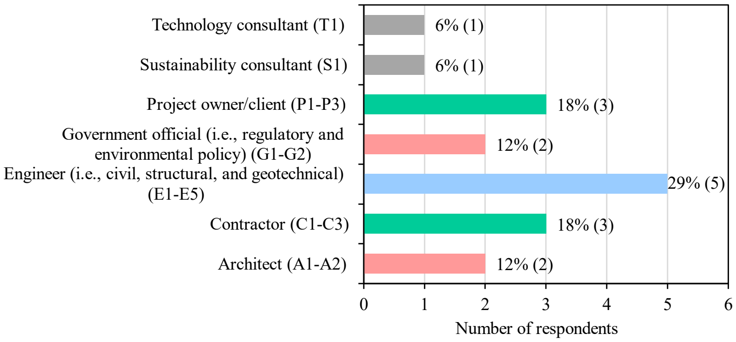


Figure 2: Demographic profile of the participants

The focus group session covered two main themes: (1) the key pillars of C5.0 and (2) its implications for AEC organizations and practices. Regarding the first theme, participants shared insights on three core areas: (i) their understanding of C5.0's core features, (ii) the enabling technologies they identified as critical for advancing the C5.0 paradigm, and (iii) the success factors they identified as critical for promoting the transition from C4.0 to C5.0. For the second theme, participants provided feedback on the anticipated benefits of transitioning to C5.0 for their organizations and the potential impacts of adopting C5.0 technologies on their projects.

A mixed-methods approach was employed for data analysis, integrating both quantitative and qualitative techniques. The quantitative analysis focused on mapping the frequency and intensity of technologies within the C5.0 framework, examining their implementation across application areas, integration with C4.0 technologies, and deployment outcomes aligned with C5.0 core objectives. Subsequently, qualitative thematic analysis and narrative synthesis were conducted to explore and describe the applications and impacts of these technologies within C5.0 environments.

4 Findings and Discussion

4.1 Conceptual Foundations of Construction 5.0

(1) Core Features

Figure 3 presents the key pillars of C5.0, synthesizing insights from the 17 participants. Building on the foundation of C4.0, C5.0 introduces three core features: human-centricity, sustainability-driven practices, and collaborative intelligence. These features represent a paradigm shift in addressing long-standing challenges in the AEC industry. Human-centricity focuses on improving worker well-being and safety by integrating technologies such as wearable devices, cobots, and HCPS (Cisneros-Gonzalez et al., 2024; Yitmen et al., 2023). Participant P3 remarked, "*One of the significant benefits of wearable devices lies in their ability to adapt to workers' needs, providing real-time data to prevent accidents and ensure well-being*." Similarly, Participant E2 highlighted the transformative potential of cobots, stating, "*Collaborative robots are game-changers for reducing physical strain in repetitive tasks. They don't replace people. They augment people's capabilities, especially in high-risk operations*." Extended reality (XR) technologies further support this human-centric feature by offering immersive training simulations and virtual site inspections. As respondent C1 observed, "*VR or AR gives workers hands-on experiences without taking any risk. It bridges knowledge gaps and ensures safety compliance*."

The sustainability-driven aspect of C5.0 prioritizes minimizing the environmental impact of construction processes while optimizing resource use. Digital twins, IoT-enabled smart systems, and

3D/4D printing promote energy efficiency, waste reduction, and circular construction practices (Ghobakhloo et al., 2022; Jiménez Rios et al., 2024). Participant E5 noted, "*Digital twins could give us a clearer view of where we can cut wastes and save resources*." Participant P2 emphasized the role of advanced machinery: "*It's not just labor savings with autonomous equipment. It's also fewer emissions and less wasted material*."

Collaborative intelligence emphasizes the integration of advanced technologies with human expertise, enabling interconnected systems that enhance decision-making and coordination. For instance, AI/ML, cognitive computing, and advanced communication networks (e.g., 5G and 6G) support real-time data sharing, decision-making, and dynamic planning (Tunji-Olayeni et al., 2024; Musarat et al., 2023). Participant E4 highlighted the transformative nature of this integration: "*The integration of AI and 5G could make the collaboration between human and machine smoother. Workers can control autonomous machinery remotely, safely, and precisely without any delay*." Participant G2 shared, "*Collaboration across teams will become easier with IoT and communication networks. Everyone is aligned because the data is instant and accessible*."

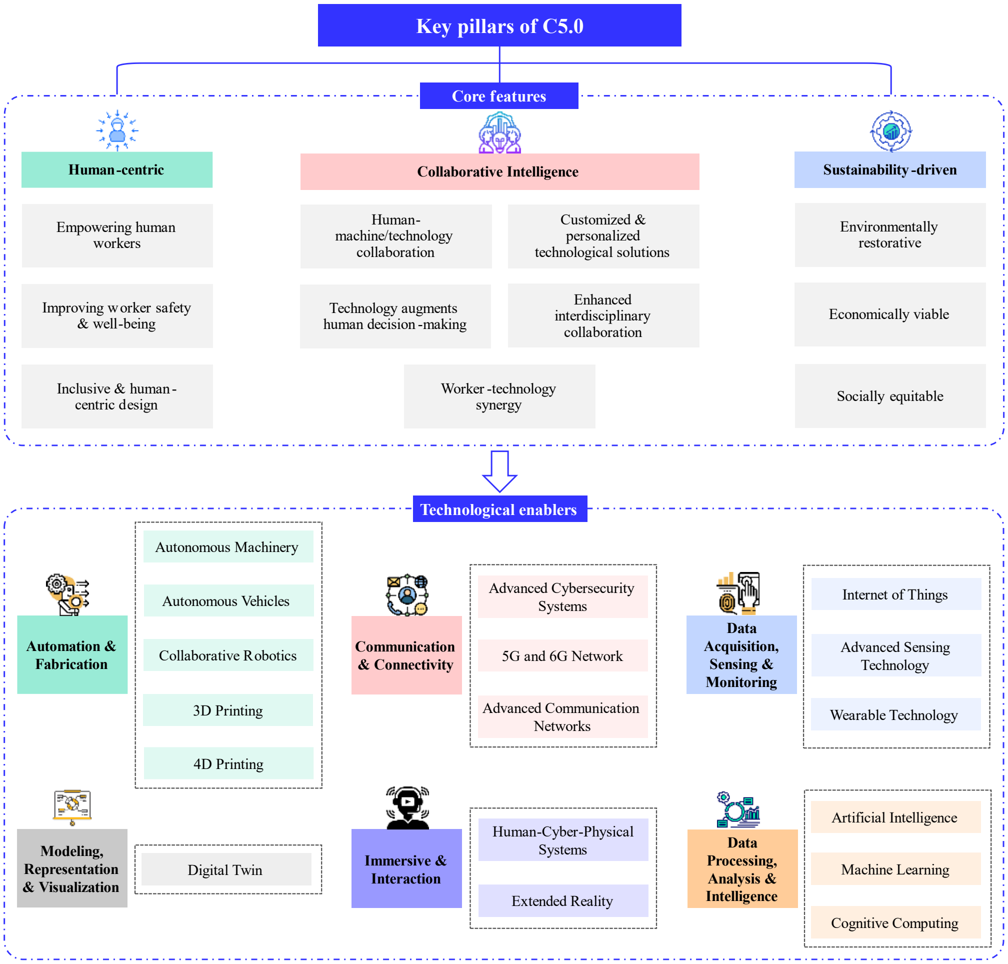
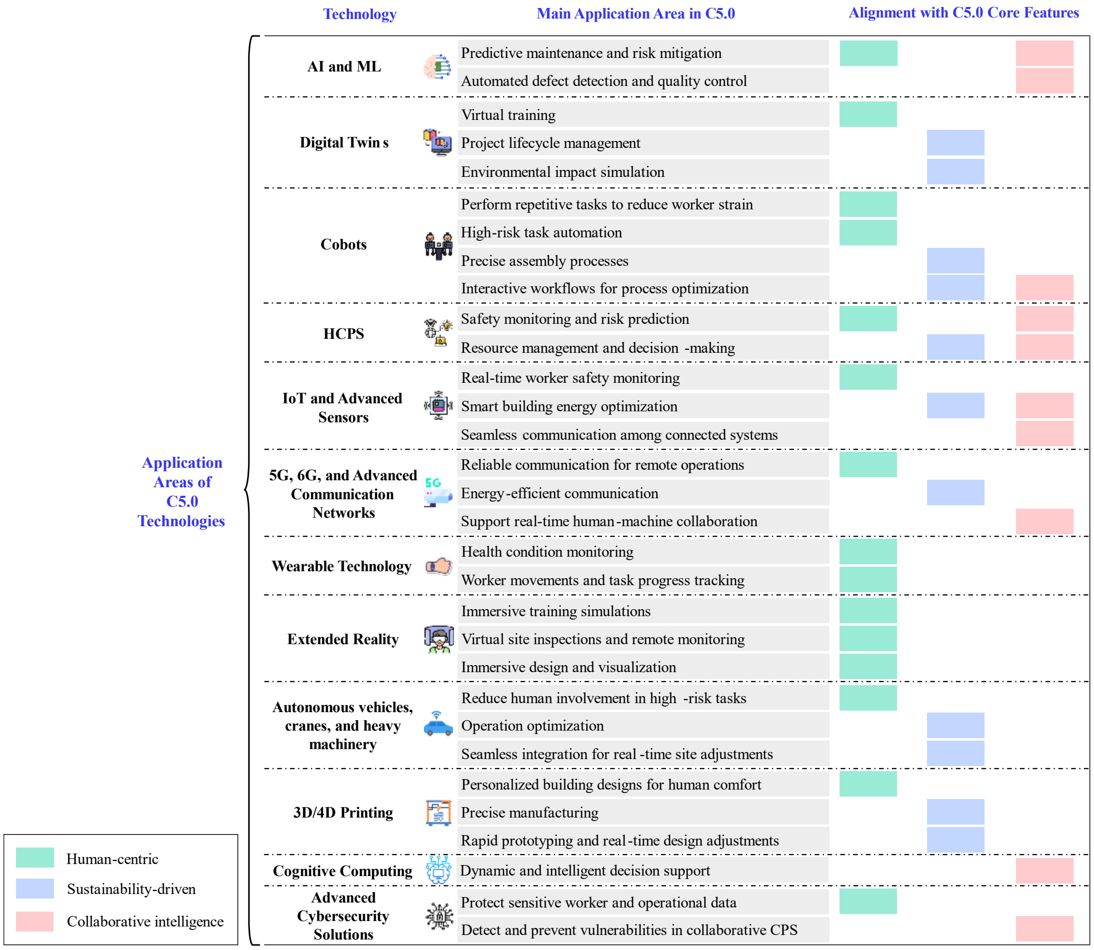


Figure 3: Key pillars underpinning C5.0

(2) Technological Enablers

The transition to C5.0 introduces advanced technologies to redefine the AEC industry through human-centric design, sustainability-driven practices, and collaborative intelligence. Figure 3 presents some main technological enables and the associated application potential. Figure 4 summarizes the detailed application areas of these technologies, ranked by the criticality based on focus group feedback. Specifically, the use of AI and ML enhances predictive maintenance, safety monitoring, and automated defect detection and quality control, ensuring worker safety and promoting collaborative intelligence of humans and machines. The findings align with other regional surveys and global review studies, such as Almusaed et al. (2024), Bello et al. (2024), and Rane (2023), which emphasize the role of AI in facilitating informed decision-making throughout the project lifecycle. Similarly, digital twins enable virtual training, real-time lifecycle optimization, and scenario simulation, contributing to safety management, waste reduction, and energy efficiency. This is consistent with the review results of international studies by Biswas et al. (2024), highlighting the integration of digital twins, BIM, and IoT to provide precise data-driven insights for advancing sustainable project management processes. Cobots are particularly transformative in reducing physical strain on workers, enhancing operational safety and efficiency, and supporting construction process optimization. These outcomes are supported by Marinelli (2023), which emphasizes cobots' ability to promote worker ergonomics and productivity through a bibliometric analysis of international literature. Among the three core features of C5.0, human-centric emerges as the most prominent, with most identified technologies aligning closely with this feature. This supports the findings of Jiménez Rios et al. (2024), which identified human-centricity as the most distinguishing feature of I5.0 compared to I4.0 through a systematic literature review. Sustainability remains a core theme in C5.0, with technologies like 3D/4D printing and autonomous machinery enabling waste minimization and emissions reductions. Tunji-Olayeni et al. (2024) similarly identified these technologies as pivotal in advancing sustainable construction practices through reviewing international literature. Collaborative intelligence, another core feature of C5.0, is enabled by cobots, IoT and advanced sensors, advanced communication networks (5G/6G), cognitive computing, and advanced cybersecurity. As addressed by Musarat et al. (2023) through the review of international literature, collaborative intelligence encourages interconnected ecosystems, bridging human creativity with machine intelligence to meet the evolving industry demands. These insights invite further discussion on overcoming adoption barriers, developing ethical frameworks, and maximizing C5.0's potential to transform the AEC sector.



Application Areas of C5.0 Technologies

Technology	Main Application Area in C5.0	Alignment with C5.0 Core Features		
AI and ML	Predictive maintenance and risk mitigation	🟩		🟥
	Automated defect detection and quality control			🟥
Digital Twins	Virtual training	🟩		
	Project lifecycle management		🟦	
	Environmental impact simulation		🟦	
Cobots	Perform repetitive tasks to reduce worker strain	🟩		
	High-risk task automation	🟩		
	Precise assembly processes		🟦	
	Interactive workflows for process optimization		🟦	🟥
HCPS	Safety monitoring and risk prediction	🟩		🟥
	Resource management and decision-making		🟦	🟥
IoT and Advanced Sensors	Real-time worker safety monitoring	🟩		
	Smart building energy optimization		🟦	🟥
	Seamless communication among connected systems			🟥
5G, 6G, and Advanced Communication Networks	Reliable communication for remote operations	🟩		
	Energy-efficient communication		🟦	
	Support real-time human-machine collaboration			🟥
Wearable Technology	Health condition monitoring	🟩		
	Worker movements and task progress tracking	🟩		
Extended Reality	Immersive training simulations	🟩		
	Virtual site inspections and remote monitoring	🟩		
	Immersive design and visualization	🟩		
Autonomous vehicles, cranes, and heavy machinery	Reduce human involvement in high-risk tasks	🟩		
	Operation optimization		🟦	
	Seamless integration for real-time site adjustments		🟦	
3D/4D Printing	Personalized building designs for human comfort	🟩		
	Precise manufacturing		🟦	
	Rapid prototyping and real-time design adjustments		🟦	
Cognitive Computing	Dynamic and intelligent decision support			🟥
Advanced Cybersecurity Solutions	Protect sensitive worker and operational data	🟩		
	Detect and prevent vulnerabilities in collaborative CPS			🟥

🟩 Human-centric
🟦 Sustainability-driven
🟥 Collaborative intelligence

Figure 4: Summary of C5.0 technologies and their applications as reported by industry representatives

4.2 Impacts and Implications of C5.0 for AEC Organizations and Practices

As the 17 industry stakeholders highlighted, the transition from C4.0 to C5.0 would substantially improve the AEC sector in productivity, sustainability, human-technology collaboration, and worker safety and well-being. The transition implications are presented in Table 2. 86% of respondents noted that C5.0 improves workflows, optimizes resource allocation, and enhances operational efficiency, consistent with the findings of Hermann et al. (2016) on the benefits of digital transformation in construction. Further, 71% highlighted enhanced decision-making capabilities, enabling agile responses and real-time adjustments, echoing the content-centric synthesis results of literature by Ghobakhloo et al. (2022), which addressed the importance of data-driven decision-making in I5.0. However, only 36% reported increased customization in construction solutions that adapt to client needs and environmental conditions, reflecting findings from Müller (2020) on the complexities of integrating human-centric solutions in C5.0. Enhanced sustainability emerged as one of the most significant implications of the transition, with all respondents acknowledging C5.0's role in improving compliance with environmental regulations and meeting client demands for sustainable practices, aligning with the emphasis on sustainability in the systematic literature review by Davila-Gonzalez & Martin (2024). Furthermore, 93% noted reduced costs related to material usage, waste management, and energy consumption, indicating environmental and financial benefits. Additionally, 43% addressed increased attractiveness to clients and investors in prioritizing green and socially responsible projects, reflecting the growing demand for sustainable construction solutions.

Regarding human-technology collaboration, 79% of respondents observed that delegating repetitive and hazardous tasks to machines improves workforce safety and productivity. This reflects the findings of Yitmen et al. (2023), based on surveys conducted in Europe, North America, and the Middle East, highlighting the potential of robotics and automation to enhance efficiency and minimize human involvement in dangerous tasks. 57% observed a shift in worker roles toward higher-level problem-solving, suggesting that workers are moving toward more strategic roles that combine data-driven insights with human expertise. Regarding worker safety and well-being, 64% recognized that transitioning to C5.0 could reduce the risk of injuries, minimize workplace hazards, and lead to a healthier and more motivated workforce. This suggests that adopting advanced safety technologies and delegating dangerous tasks to machines are key drivers in improving worker safety and well-being. These findings align with Marinelli (2023), which emphasizes the role of collaborative technology in improving workplace safety by reducing human exposure to hazardous conditions.

Impacts and Implications	Description	Respondent (N=17)
Improved Productivity and Innovation	Streamlined workflows, optimized resource allocation, and increased operational efficiency.	15 (86%)
	Enhanced decision-making capabilities that allow agile responses and real-time adjustments.	12 (71%)
	Greater customization in construction solutions that adapt to client needs, environmental conditions, and project specifications.	6 (36%)
Enhanced Sustainability	Improved compliance with environmental regulations and greater capacity to meet client demand for sustainable practices.	17 (100%)
	Reduced costs associated with material usage, waste management, and energy consumption.	16 (93%)
	Increased attractiveness to clients and investors prioritizing green and socially responsible projects.	7 (43%)
Improved Human-Technology Collaboration	Enhanced workforce safety, reduced fatigue, and improved productivity by assigning repetitive or hazardous tasks to machines.	13 (79%)
	Shift in worker roles toward higher-level problem-solving that combines data-driven insights with human expertise.	10 (57%)
	Creation of opportunities for upskilling and developing a more competent workforce.	4 (21%)
Enhanced Worker Safety and Well-being	Reduced risk of injuries, minimized workplace hazards, and a healthier and more motivated workforce.	11 (64%)
Competitive Advantage	Opportunities to position companies as industry leaders capable of managing complex, large-scale projects that require innovative, sustainable solutions.	4 (21%)

Table 2: Summary of the impacts and implications of the C5.0 transition highlighted by industry representatives

5 Conclusions

While C5.0 is recognized as a critical direction for the AEC sector, gaps remain in understanding its conceptual foundations and practical implications. Specifically, existing research in literature primarily focuses on conceptual frameworks or literature reviews, with limited empirical evidence from industry practices. This study addresses these gaps by empirically examining the foundations and implications of C5.0, incorporating insights from 17 industry practitioners through a focus group approach. It investigates C5.0's key pillars, core features, and technological enablers, analyzes the alignment of technology implementation with C5.0 goals, and explores the paradigm's implications for AEC organizations and project management practices.

The results identify three core features of C5.0: human-centricity, sustainability-driven practices, and collaborative intelligence. A total of 17 emerging digital technologies are highlighted as key enablers of the transition to C5.0, with 12 technologies deemed critical to achieving its objectives across 31 application domains. Among these, (1) AI/ML, (2) digital twins, and (3) cobots were identified as the most critical C5.0 technologies. The study also identifies five major implications for AEC organizations transitioning to C5.0: improved productivity and innovation, enhanced sustainability, strengthened human-technology collaboration, improved worker safety and well-being, and competitive advantage. Under the "Enhanced Sustainability" category, all industry representatives emphasized improved compliance with environmental regulations and a greater capacity to meet client demand for sustainable practices as key outcomes.

This research contributes theoretically and practically to understanding C5.0's pillars, technologies, and implications. Practically, identifying critical technologies enables AEC organizations to prioritize investments in tools essential for achieving C5.0 objectives. By linking technologies to specific C5.0 features, the study provides practitioners with a clear roadmap for integrating these tools to meet human-centric and sustainability goals. Theoretically, the study advances the understanding of C5.0 by defining its key pillars, core features, and technological enablers, bridging gaps in the existing literature. It also provides a foundation for exploring the interaction between technological advancements and human-centered principles, particularly by aligning technologies such as AI/ML, digital twins, and cobots with C5.0 objectives. Although the study is based on a focus group discussion among regional participants, the findings were compared with global references, aligning with global benefits like enhanced sustainability and human-centricity reported in European and North American contexts. Future research should focus on expanding empirical studies to explore C5.0's impact on project management and organizational strategies. Specific directions include:

1. Conducting a cost-benefit evaluation of C5.0 technologies and investigating how C5.0 can reshape project management methodologies, including decision-making, stakeholder collaboration, and risk management.
2. Developing strategies to integrate C5.0-driven agility into project workflows, addressing challenges in resource allocation and timeline optimization.

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