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Critical Systems Practice for Designing Society 5.0 Indicators in Construction

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A B S T R A C T

The transition toward Society 5.0 introduces a human-centric paradigm that integrates advanced digital technologies with social and industrial systems to balance economic growth with societal well-being. Within the construction industry, this vision offers significant opportunities for addressing persistent challenges such as inefficiencies, sustainability gaps, and stakeholder misalignment. This study employs Critical Systems Practice (CSP) as a meta-methodology to operationalise Society 5.0 principles in construction. Using the EPIC cycle (Explore, Produce, Intervene, Check), the research systematically engaged 11 experts to identify, refine, and validate a comprehensive set of performance indicators tailored to construction projects. The findings highlight 29 indicators that capture the multifaceted dimensions of Society 5.0 in construction, spanning cost, time, quality, sustainability, innovation, digital–physical integration, and stakeholder collaboration. By embedding Instrumental Stakeholder Theory into the CSP framework, the study ensured that both technical and social dimensions were addressed. The results demonstrate how CSP provides a structured yet flexible pathway for translating complex problem situations into actionable and context-sensitive solutions. This work contributes to the emerging discourse on Construction 5.0 by offering a systemic and participatory approach that enhances managerial decision-making, strengthens resilience, and aligns construction practices with the broader vision of Society 5.0.

Keywords

Critical Systems Practice; Society 5.0; Construction Industry; Stakeholder Engagement; Systemic Decision-Making.

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1. Introduction

Policymaking regarding demographic change affects other sectors, such as energy and the environment

As economies grow, life becomes more prosperous and convenient (Noorizadeh et al. 2019); the demand for energy and food increases, life expectancy rises population ageing advances (Mortazavi et al., 2020). In addition, economic globalisation is progressing, international competition is intensifying, and problems such as wealth concentration and regional inequality are on the rise (Gholian-Jouybari et al., 2024). The social issues that must be addressed alongside such economic development are becoming increasingly complex (Khazaei et al., 2025). Measures such as reducing greenhouse gas emissions, increasing food production and reducing food loss, lowering costs associated with an ageing population, supporting smart and sustainable industrialisation, redistributing wealth, and correcting regional disparities have all been proposed (Zeraati Foukolaei et al., 2026). However, simultaneously achieving economic growth and addressing these social challenges has proven difficult under the current social systems (Deguchi et al., 2020).

In the face of such profound global changes, new technologies such as the Internet of Things (IoT), robotics, artificial intelligence (AI), and big data, all of which can significantly influence societal progress, continue to evolve (Bonakdari et al., 2026). One of the most comprehensive and holistic approaches introduced in recent years is Japan's Society 5.0 development programme. Japan aims to realise Society 5.0 as a new type of society that integrates these emerging technologies across all industries and social activities, thereby achieving both economic development and solutions to pressing social issues in parallel (Fukuda, 2020).

In Society 5.0, the new value created through innovation eliminates regional, generational, gender (Marinelli, 2023), and linguistic gaps, enabling the provision of products and services that are highly tailored to diverse individual needs as well as latent demands (Fukuyama, 2018). In this way, it becomes possible to foster a society that simultaneously promotes economic development and provides solutions to social challenges (Salgues, 2018). Analogous to Industry 4.0, which represents the Fourth Industrial Revolution, Society 5.0 has been conceptualised as the next stage in a five-step social evolution (Potocan et al., 2020): (1) the hunting society, (2) the agrarian society, (3) the industrial society, (4) the information society, and (5) the super-smart society, known as Society 5.0 (Figure 1).

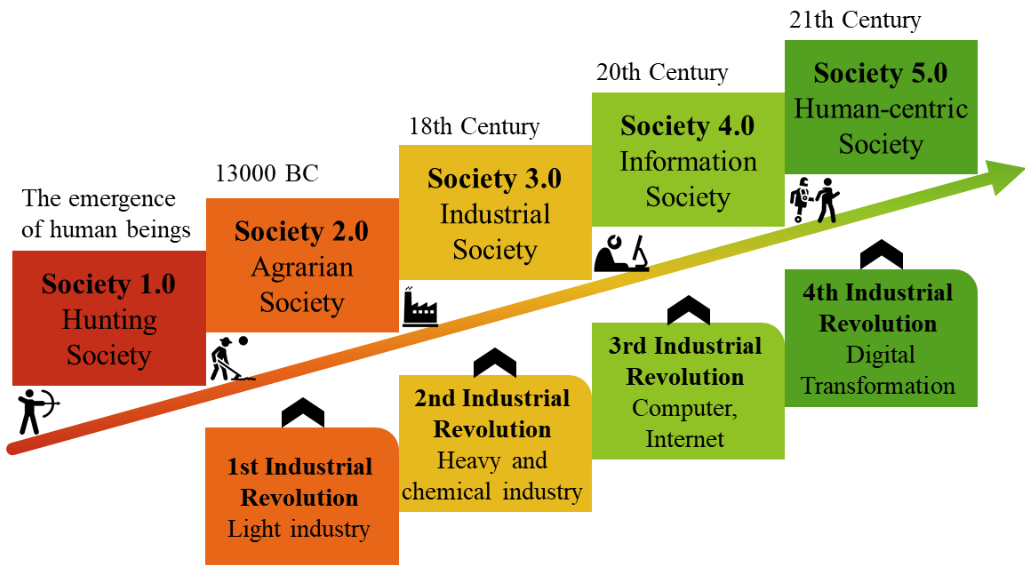

Figure 1. Schematic of the historical evolution of societies from the beginning of humankind to the present (Japan Society 5.0 Charter, 2018; Fukuyama, 2018).

Achieving Society 5.0 with these defining features enables the world to address critical social challenges while simultaneously realising economic development in an optimal manner (Metham et al. 2022). It also contributes to the achievement of the Smart Sustainable Development Goals (SDGs) established by the United Nations (Potocan et al., 2020). Japan aims to become the first country in the world to realise a human-centred society (Society 5.0), where everyone can enjoy a high-quality and vibrant life. To achieve this, the Japanese government intends to integrate advanced technologies into diverse industries and social activities while fostering innovation to create new value (Nair et al., 2021).

In the construction sector, Society 5.0 entails a high degree of convergence between the cyberspace (virtual space) and the physical space (real space). In the previous information society (Society 4.0), people accessed cloud services (databases) in cyberspace via the Internet to search, retrieve, and analyse information or data (Nair et al., 2021).

In Society 5.0, however, massive volumes of data from sensors embedded in the physical space are accumulated in cyberspace (Musarat et al. 2023). Within cyberspace, these data are analysed by AI, and the analytical results are fed back into the physical space in multiple forms (Deguchi et al., 2020). In the previous information society, the common approach was to collect information through networks and conduct analyses manually by humans. In contrast, in Society 5.0, people, objects, and systems are all interconnected in cyberspace, and the optimal results generated by AI, far exceeding human analytical capabilities, are fed back into the physical world (Potocan et al., 2020; Khazaei et al., 2026). This process generates new value for industry and society that was previously unattainable. Figure 2 illustrates the share of smart technologies across different industries worldwide, with a particular emphasis on applications in the construction sector.

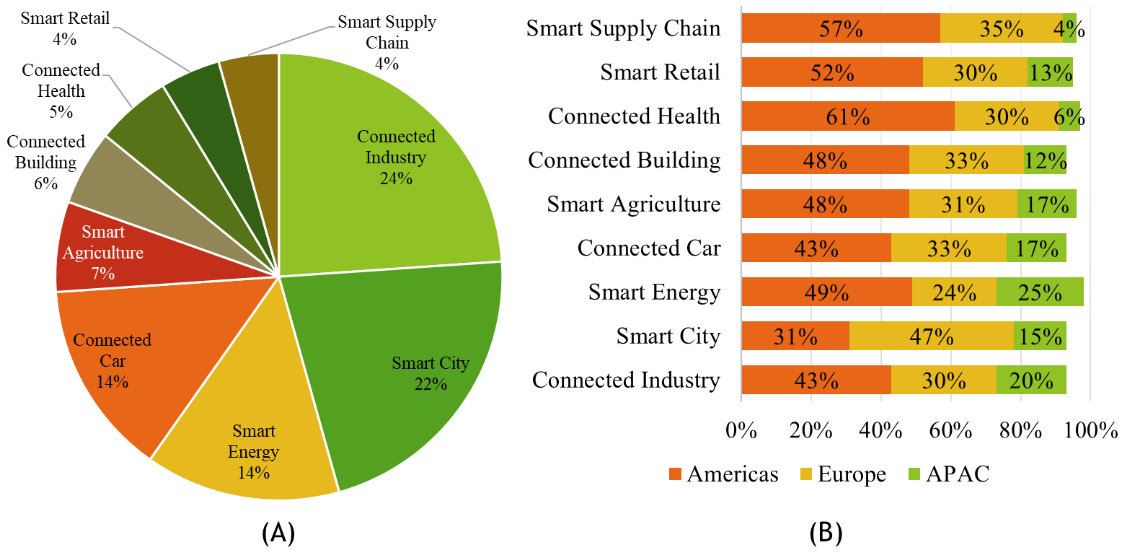

Figure 2. Global share of smart technology projects (A) and the adoption of Industry 4.0 (B) by region (Source: IoT Analytics, 2020).

Figure 2 illustrates the distribution of global smart technology projects across different sectors and their regional adoption levels. The results show that the Middle East and Africa, highlighted in grey, have an almost negligible share of this growth, indicating the importance of accelerating development in these regions. In these areas, the primary focus has traditionally been on social, economic, and organisational systems, which has created significant gaps in the products and services available to individuals due to differences in capabilities and other structural factors.

In contrast, advanced regions such as the United States and Europe have already achieved deep convergence between cyberspace and physical space, enabling AI, big data, and robotics to support tasks and adjustments previously carried out by humans (Deguchi et al., 2020).

In the construction sector, this highlights a major challenge of the information society (Society 4.0): knowledge sharing, collaboration across domains, and the use of information in large-scale built environments remain limited by human cognitive capacity to process vast datasets. As a result, information discovery and analysis are often insufficient and delayed. Another challenge lies in applying this information effectively in real-world contexts such as buildings and infrastructure projects.

With Society 5.0, however, these challenges can be addressed through three key aspects:

- Connecting all people and objects through the IoT to share diverse forms of knowledge and information.
- Providing and processing the necessary information in real time using AI.
- Applying this information in physical environments with advanced technologies such as robots and virtual/augmented reality (Luo et al., 2022).

Together, these elements aim to overcome demographic decline and population ageing, rural depopulation, and economic inequality, thereby creating a society in which people can enjoy greater comfort and well-being across generations and demographic groups.

This research seeks to examine the challenges of achieving Society 5.0 in the construction sector and to design a performance evaluation model tailored for construction projects. The model identifies and operationalises Society 5.0 indicators that construction professionals can apply to evaluate the performance of projects after completion. The next section reviews the relevant literature, with a particular emphasis on the construction industry, noting that no study on Society 5.0 has yet been conducted in Iran. The methodology section then outlines the implementation process and sequence of methods used. The findings section presents the qualitative and quantitative results, followed by managerial insights. Finally, the study concludes with a summary and provides research directions for future scholars.

2. Research Background

The idea of integrating cyberspace with physical space (Figure 3) refers to a continuous cycle in which data flow from the physical world (reality) into cyberspace, are analysed, and then returned to the physical space as actionable solutions (Tunji-Olayeni et al. 2024). Traditionally, reliance has been placed on conventional systems such as energy supply or rail transportation, each operating within its own physical domain and controlled separately. (Yitmen et al., 2023). However, when these systems become interconnected through cyberspace, they enable more complex services and generate greater value in the real world.

2.1. Towards a Human-Centric Society

Through this mechanism, Society 5.0 evolves into a human-centric society. In the earlier analogy of an air-conditioning system, the goal was simply to maintain a comfortable room temperature. That problem was straightforward. However, when the goal becomes creating a human-centred society, the challenge becomes significantly more complex (Yitmen et al., 2023).

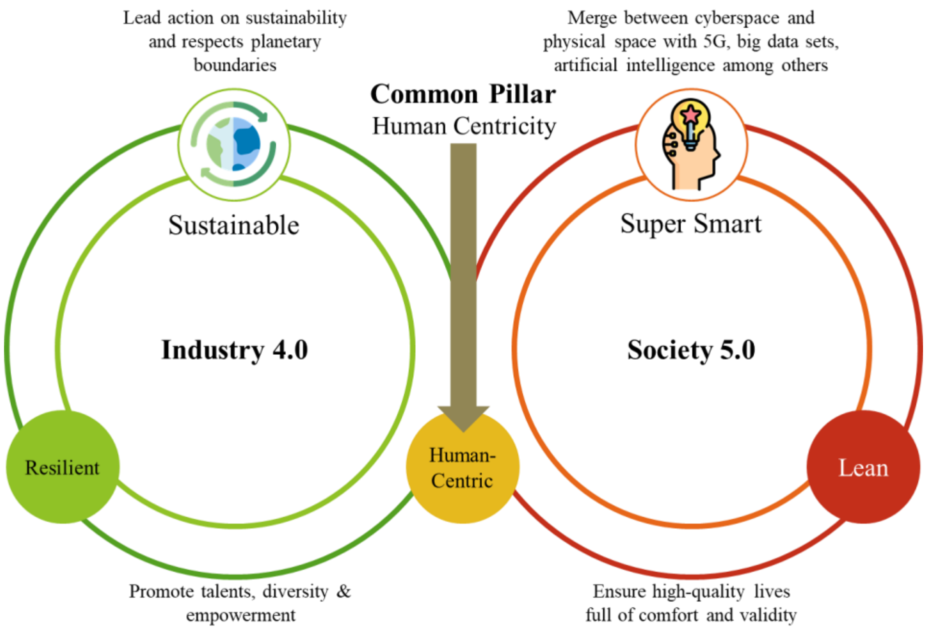

Figure 3. Conceptual framework of Society 5.0: balancing resilience, human-centricity, and lean efficiency.

Japan's comprehensive strategy (2017) defines Society 5.0 as a human-centric model that balances economic growth with addressing social issues to ensure that citizens enjoy a high quality of life (Yitmen et al., 2023). Achieving this balance is challenging because comfort, sustainability, and progress often conflict (Veshneva and Bolshakov 2022). For instance, air conditioning improves well-being but, when powered by fossil fuels, accelerates global warming. Overemphasising economic growth risks unsustainable mass production and consumption, while excessive energy minimisation reduces comfort and quality of life (Bungin et al., 2021). The central challenge is resolving social problems without undermining individual well-being; this requires technologies that mediate between personal needs and societal goals (Issa et al., 2020). In this context, cyberspace acts as a computational domain where real-world data are analysed, refined, and fed back into physical systems through IoT and AI, enabling continuous improvement and calibration (Rane, 2023; Izotov et al., 2018). Applied to construction, these principles help optimise energy consumption, enhance smart building systems, and mitigate environmental impacts such as greenhouse gas emissions, while offering scalable solutions across agriculture, industry, and energy.

2.2. Society 5.0 in Construction and Cities

Recent scholarship highlights Construction 5.0 as the next paradigm of industrial development, where human expertise is combined with cyber–physical systems to achieve resilient, sustainable, and human-centric outcomes (Wuni et al. 2022). Yitmen, Almusaed, and

Alizadehsalehi (2023) conceptualise Construction 5.0 as an integration of Operator 5.0 and Society 5.0, linking human-centricity, sustainability, and resilience through causal relationships tested via SEM. Their work emphasises collaboration between humans and machines, merging cyberspace and physical space, and balancing economic, environmental, and social pillars of sustainability. Pal et al. (2024) extend this debate by conducting a bibliometric review, noting that research on Construction 5.0 remains nascent but rapidly expanding, with opportunities in personalisation, sustainability alignment, and profitability, yet also facing challenges such as technological immaturity, lack of standardisation, and ethical concerns. Together, these studies establish a foundation for Construction 5.0 as an emergent framework where advanced digital tools, cyber-physical integration, and human-centric approaches are central to transforming the construction industry.

Parallel work in sustainability and smart cities further situates Construction 5.0 within broader socio-technical transitions. Kasinathan et al. (2022) and Adel and Alani (2024) argue that integrating Industry 5.0 and Society 5.0 into smart city and village contexts provides pathways to achieve Sustainable Development Goals, particularly those related to health, education, infrastructure, and sustainable urban development. Gurjanov et al. (2020) and Mishra et al. (2022) emphasise that the realisation of Society 5.0 requires embedding disruptive technologies such as IoT, AI, 5G, and blockchain into urban systems, thereby enabling super-intelligent cities that balance economic progress with social equity. Collectively, these studies show how the principles of Society 5.0 extend into Construction 5.0 by embedding disruptive technologies, human-centric design, and systemic resilience into construction practice, thereby creating a research frontier that links construction innovation with sustainable societal transformation.

2.3. A Review on Critical Systems Practice

The body of literature on Critical Systems Practice (CSP) reflects its evolution from a conceptual multimethodological framework into a versatile approach applied across sectors and contexts. Michael C. Jackson’s seminal four-part series (2020–2022) systematically articulates the EPIC cycle, Explore, Produce, Intervene, and Check, establishing CSP as a meta-methodology designed to tackle VUCA (volatile, uncertain, complex, ambiguous) environments. The Explore stage emphasises identifying systemic complexity through multiple perspectives, ensuring that interventions avoid oversimplification. The Produce stage advances to constructing a multimethodological strategy, structuring objectives, and selecting appropriate methodologies. The Intervene stage highlights pragmatic flexibility, iterative adjustment, and the integration of Eastern and Western systemic traditions through a philosophy of pragmatism. Finally, the Check stage underlines reflection, learning, and evaluation of outcomes to ensure that systemic goals are achieved while guiding future actions. Together, these contributions form the theoretical backbone of CSP and have been instrumental in broadening its application from systems theory to applied domains.

Recent empirical and applied studies demonstrate CSP's growing relevance in addressing real-world challenges. Zarghami and Zwikael (2025) applied CSP to project resilience, showing how multimethodology broadens the scope of resilience-building beyond traditional project management tools. Wilden et al. (2024) extended CSP to supply chain resilience, particularly under COVID-19 disruptions, highlighting its capacity to surface unresolved systemic issues such as inventory transparency. Elyasi and Teimoury (2023) pioneered CSP in agri-food systems, integrating soft, hard, and critical methodologies to address sustainability in Iran's rice supply chain. McKenna (2025) explored CSP in emergency relief evaluation, demonstrating complementarities between programme logic and critical systems heuristics. In project management, Zarghami (2024) linked CSP with von Bertalanffy's open systems theory to develop contingency planning models, while Norris et al. (2025) showcased CSP's Mode 2 application in high-stakes safety decisions in New Zealand's dairy industry, where reflective practice enhanced the "Check" stage. Collectively, these works reveal CSP's adaptability and strength: it bridges methodological pluralism with practical decision-making, enhancing resilience, sustainability, and systemic learning across diverse problem domains. This literature underscores CSP's dual contribution: deepening theoretical systems thinking and offering actionable frameworks for managing complex socio-technical challenges.

2.4. Research Gaps and Novelty

Despite the growing literature on Society 5.0, Construction 5.0, and CSP, important gaps remain. Existing studies have largely stayed at conceptual, strategic, or bibliometric levels, clarifying principles such as human-centricity, sustainability, resilience, and cyber–physical integration, but offering limited guidance on how these ideas can be translated into operational performance indicators for construction projects. Although the literature recognises construction as a socio-technical system within broader smart city and sustainability transitions, it still does not sufficiently explain which Society 5.0 indicators should be measured, how they interact, or which factors function as key drivers for managerial decision-making. In addition,

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while CSP has proven valuable in other complex domains such as resilience, supply chains, agri-food systems, and project management, it has not yet been applied to the design of Society 5.0 indicators in construction. Likewise, DEMATEL and fuzzy decision-making methods are well established in evaluation and prioritisation research, but their use for analysing the causal relationships among Society 5.0 construction indicators remains underdeveloped. Accordingly, the novelty of this study lies not in introducing entirely new methods, but in integrating CSP and PF-DEMATEL to operationalise, structure, and prioritise Society 5.0 indicators for construction in a context where such an applied framework has been largely absent.

Based on these gaps, the novelty of this study is fourfold. First, it develops one of the earliest context-sensitive indicator frameworks for evaluating Society 5.0 in construction, thereby converting abstract principles into actionable project performance dimensions. Second, it introduces CSP, operationalised through the EPIC cycle, as a meta-methodological foundation for exploring, structuring, validating, and refining Society 5.0 indicators in a complex construction environment. Third, it combines CSP with Pythagorean Fuzzy DEMATEL to create a hybrid and methodologically integrated approach that both identifies indicators qualitatively and prioritises them quantitatively through causal analysis. While each method exists in the broader literature, their integration for this purpose, especially in the context of Iran's construction industry, constitutes a novel application. Fourth, the study contributes empirical insight from an underexplored national setting. Since Society 5.0 research has been dominated by discussions rooted in technologically advanced economies, examining the Iranian construction context adds value by showing how Society 5.0 can be interpreted and operationalised in an emerging economy facing distinctive institutional, governance, and digital maturity challenges.

3. Methodology

A systemic approach is essential when addressing complex socio-technical transitions (Yevu et al. 2021), where multiple interrelated factors evolve simultaneously within the construction industry (Sambo and Jackson, 2021; Khazaei et al., 2025). By integrating systems thinking with decision-making methods, it becomes possible to capture interdependencies, feedback structures, and causal mechanisms while still providing a structured and quantitative basis for analysis (Venter and Goede, 2018; Khazaei et al., 2026).

To achieve the objectives of this study, two methodologies were employed sequentially. First, CSP was used to identify the relevant Society 5.0 indicators for the construction industry.

Second, the outputs were transferred into a quantitative framework, where the identified indicators were structured and prioritised using the Pythagorean Fuzzy DEMATEL multi-criteria decision-making technique. The selection of Pythagorean Fuzzy DEMATEL was motivated by the nature of the problem, which involves complex causal relationships among indicators as well as a high degree of uncertainty and subjectivity in expert judgments. Unlike classical DEMATEL, which requires precise evaluations, the Pythagorean fuzzy extension allows experts to express hesitation and ambiguity more flexibly through independent membership and non-membership degrees, thereby capturing uncertainty more effectively. Compared with other fuzzy variants, this approach provides greater representational freedom in situations where judgments are imprecise, while still preserving the core strength of DEMATEL in revealing cause–effect relationships and the relative prominence of factors. For this reason, Pythagorean Fuzzy DEMATEL was considered more appropriate for analysing Society 5.0 indicators in construction, where interdependencies are strong and expert assessments are inherently uncertain.

3.1. CSP through the EPIC Process

CSP is a multimethodological framework developed to address complex and uncertain problem situations by integrating diverse systems methodologies (Sambo and Jackson, 2021; Venter and Goede, 2018). Designed to respond to today's VUCA environments (Jackson, 2020), CSP emphasises examining the system as a whole rather than analysing isolated parts (Jackson, 2006). Since its introduction, CSP has been applied across healthcare, supply chain management, information systems, and project scheduling, offering a flexible yet structured approach for engaging with systemic challenges (Sambo and Jackson, 2021; Basta et al., 2023; Venter and Goede, 2018; Zarghami, 2024).

The framework rests on five systemic perspectives: machine, organism, cultural/political, societal/environmental, and interrelationships (Jackson, 2023), which help to expose different facets of complex problems. Building on these perspectives, CSP unfolds through four iterative stages: Explore, Produce, Intervene, and Check. Each stage is designed to guide practitioners through an ongoing cycle of inquiry, action, and reflection.

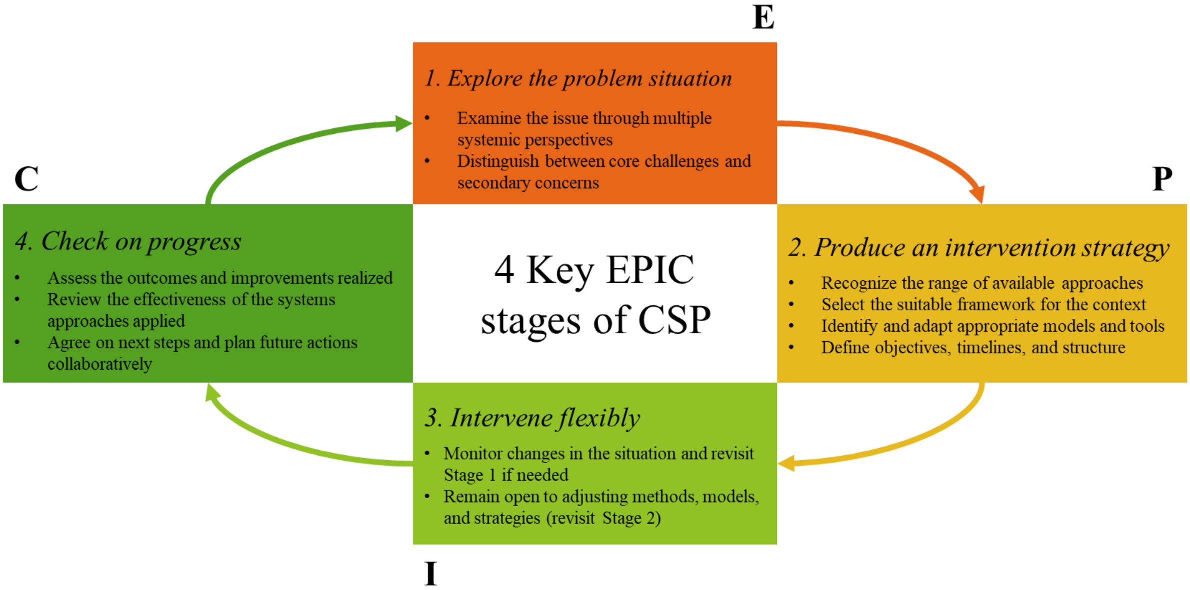

Figure 4. The four key stages of CSP through EPIC.

The first stage, Explore the problem situation, focuses on untangling the complexity of the problem by examining it through multiple systemic perspectives. At this stage, analysts distinguish between core challenges and secondary concerns, thereby clarifying the issues that must be prioritised. In this research, the Explore stage was used to analyse systemic behaviours in the construction industry and to identify candidate indicators of Society 5.0 relevant to construction projects.

The second stage, Produce an intervention strategy, is concerned with designing systemic responses. This involves recognising the range of available approaches, selecting the most suitable framework for the context, and identifying appropriate models and tools. The stage concludes with the definition of objectives, timelines, and structures for implementation. For this study, the Produce stage led to the formulation of intervention strategies that connected Society 5.0 principles, such as the integration of cyberspace and physical space, to construction sector needs.

The third stage, Intervene flexibly, involves the implementation of intervention strategies in practice. This stage emphasises the importance of monitoring changes in the situation and remaining open to iterative adjustments. Practitioners are encouraged to revisit earlier stages, adjusting models, methods, and strategies to reflect evolving conditions. In this study, Intervene was conceptualised as the application of the identified Society 5.0 indicators to construction project scenarios, while tracking how the problem situation evolved in practice.

Finally, the fourth stage, Check on progress, provides a reflective evaluation of the interventions. This includes assessing the outcomes achieved, reviewing the effectiveness of the approaches applied, and agreeing on future actions collaboratively. In the context of this research, the Check stage involved reflecting on how effectively the CSP-derived indicators captured the priorities of Society 5.0 in construction, and preparing them for quantitative structuring and prioritisation using the Pythagorean Fuzzy DEMATEL technique.

Together, these four EPIC stages form an iterative cycle of learning and adaptation. The EPIC cycle ensures that interventions are context-sensitive, flexible, and systemically grounded. By applying CSP through the EPIC framework, this study was able to explore the complexity of construction projects from multiple perspectives, identify Society 5.0 indicators, and prepare them for rigorous quantitative analysis.

3.2. Pythagorean Fuzzy DEMATEL

The DEMATEL method is a well-established approach for constructing structural models to analyse complex cause-and-effect relationships among factors in real-world systems. Compared with traditional methods such as the Analytic Hierarchy Process, DEMATEL provides superior capability by explicitly considering mutual dependencies among factors through causal diagrams, an aspect typically overlooked in conventional techniques. The fuzzy DEMATEL approach extends this methodology by analysing relationships between criteria and sub-criteria within a fuzzy environment. Using a fuzzy direct-relation matrix, the method identifies causal (influential) and effect (influenced) criteria based on expert evaluations.

The Pythagorean fuzzy DEMATEL procedure used in this study followed a structured process in which evaluation variables were defined on a linguistic scale, pairwise comparisons from domain experts were used to build the fuzzy direct-relation matrix, and fuzzy logic was applied to assess influence relationships among criteria. This allowed causal relationships to be derived and the Society 5.0 indicators for construction projects to be prioritised. In this way, the qualitative insights obtained through CSP were systematically transformed into quantitative results, enabling both the structuring and ranking of the indicators.

$$\tilde{Z}_{ij} = (z_{ij}^{l}, z_{ij}^{m}, z_{ij}^{u})_{n\times n} = \begin{bmatrix} 0 & \tilde{z}_{12} & \cdots & \tilde{z}_{12} \\ \tilde{z}_{21} & 0 & \cdots & \tilde{z}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{z}_{n1} & \tilde{z}_{n2} & \cdots & 0 \end{bmatrix}_{n\times n} \quad (1)$$

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Formation of the normalised fuzzy direct-relation matrix: In this step, the initial direct influence values provided by experts are normalised so that they are all comparable within the same scale. This process ensures that the relative strength of influence between factors is expressed consistently.

$$\tilde{H}_{ij} = \frac{\tilde{Z}_{ij}}{r} = \left(\frac{z_{ij}^{l}}{r}, \frac{z_{ij}^{m}}{r}, \frac{z_{ij}^{u}}{r}\right) \tag{2}$$

$$r = \max_{1 \le i \le n}\left(\sum_{j=1}^{n} z_{ij}^{u}\right) \tag{3}$$

Formation of the total fuzzy relation matrix: Here, the normalised direct influences are extended to capture both direct and indirect effects among factors. The result is a comprehensive matrix that shows how each factor affects, and is affected by, others throughout the system.

$$T = \lim_{k \to \infty}(\tilde{H}^{1} \oplus \tilde{H}^{2} \oplus \ldots \oplus \tilde{H}^{k}) \tag{4}$$

$$[t_{ij}^{l}] = H_{l} \times (1 - H_{l})^{-1} \tag{5}$$

$$[t_{ij}^{m}] = H_{m} \times (1 - H_{m})^{-1} \tag{6}$$

$$[t_{ij}^{u}] = H_{u} \times (1 - H_{u})^{-1} \tag{7}$$

Defuzzification of the total relation matrix: Since the values in the total relation matrix are fuzzy (expressed with uncertainty), they must be converted into crisp, interpretable numbers. Defuzzification provides precise values that can be used for further analysis.

$$Defuzzy(t_{ij}) = \frac{t_{ij}^{l} + 4t_{ij}^{m} + t_{ij}^{u}}{6} \tag{8}$$

$$r = [r_i]_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} \tag{9}$$

$$d = [d_j]_{n\times 1} = \left[\sum_{i=1}^{n} t_{ij}\right]'_{n\times 1} \tag{10}$$

Evaluation of the relationships among criteria: At this stage, the sums of the rows and columns of the total relation matrix are calculated. The r vector represents the row sums, which show the extent to which each factor influences other factors (degree of driving power). The d vector represents the column sums, which show the extent to which each factor is influenced by others (degree of dependence). In other words, *r* reflects the influencing strength of a factor, while *d* reflects its receiving strength. This provides a clear picture of causal and dependent relationships within the system.

4. Results

By applying CSP through the EPIC cycle, this study identified and validated a comprehensive set of indicators relevant to Society 5.0 in the construction industry. The process engaged 11 domain experts through structured interviews and feedback loops. These experts were selected purposively based on their demonstrated knowledge and professional experience in fields directly related to the study, including construction management, digital technologies in construction, sustainability, systems thinking, and policy or strategic planning relevant to Society 5.0. The selection criteria emphasised both academic and practical expertise to ensure that the panel could capture the technical, managerial, and socio-systemic dimensions of the problem. This expert involvement helped ensure that the findings were both theoretically grounded and practically relevant. The stages of CSP provided a systematic pathway for moving from exploratory insights to validated, measurable indicators.

1- To illustrate the EPIC process, Table 1 summarises the main objectives and outputs of each stage, while Table 2 presents the role of expert input across the stages. Table 3 then reports the final set of 29 indicators, classified by their primary managerial criteria.

Table 1. EPIC stages of CSP and their objectives in this study.

CSP stage	Objective in this study	Key Output
Explore	Untangle the complexity of construction project challenges through systemic perspectives	Identification of core and secondary challenges
Produce	Translate challenges into systemic responses and measurable criteria	Draft list of Society 5.0 candidate indicators
Intervene	Validate and refine indicators through expert workshops	Consolidated and practically applicable indicator set
Check	Reflect on completeness and prepare for quantitative analysis	Final confirmation of 29 Society 5.0 indicators

In the Explore stage, the complexity of construction project challenges was untangled by applying the five systemic perspectives of CSP (machine, organism, cultural/political, societal/environmental, and interrelationships). Experts were asked to highlight the main obstacles and opportunities that Society 5.0 principles could address within construction. This process helped distinguish between core challenges (such as cost overruns, inefficient energy use, and weak stakeholder communication) and secondary concerns (such as localised delays or minor compliance issues).

During the Produce stage, these challenges were translated into systemic responses. Experts, together with the research team, mapped specific strategies and designed candidate indicators aligned with Society 5.0. At this point, abstract notions such as "smart construction" or "sustainability" were broken down into measurable items, for example, the use of IoT in projects, integration of cyber–physical systems, or water and energy consumption measures.

Table 2. Role of expert engagement in the EPIC process.

Stage	Expert activity	Contribution to results
Explore	Semi-structured interviews with 11 experts	Identification of broad challenge areas and key concerns
Produce	Mapping of challenges into measurable indicators	Draft indicator list co-designed with experts
Intervene	Feedback sessions and workshops	Validation, consolidation, and refinement of draft indicators
Check	Reflective review and consensus	Agreement on the final 29 indicators for Society 5.0 in construction

In the Intervene stage, the draft indicators were validated through expert workshops. This phase emphasised flexibility: experts were invited to refine, reject, or merge indicators to ensure practical applicability. As a result, several criteria were consolidated into clearer categories (e.g., "energy efficiency" and "adoption of energy-saving technologies" were combined under energy management).

Table 3. Final Society 5.0 indicators identified through CSP (EPIC).

Main Criterion	Indicator / Measure	Code	Type
Cost management	Initial project cost	I1	Negative
	Time delays and deviations from baseline plan	I2	Negative
	Duration of project tasks and activities	I3	Negative
Quality management	Application of quality standards and procedures	I4	Positive
	Compliance of project outcomes with technical standards	I5	Positive
Water consumption	Daily average water consumption in construction	I6	Negative
Eco-friendly materials	Use of environmentally friendly materials	I7	Positive
	Sustainable procurement of raw materials	I8	Positive
Energy management	Energy consumption in construction processes	O1	Positive
	Energy efficiency and adoption of energy-saving technologies	O2	Positive
Virtual–Physical integration	Connectivity between physical and digital systems	O3	Positive
	Use of virtual platforms for project activities	O4	Positive
Smart construction	Application of automated systems and smart controls	O5	Positive
	Use of IoT in projects	O6	Positive

Main Criterion	Indicator / Measure	Code	Type
Indoor smartness	Smart management of internal building environments	O7	Positive
	Optimisation of energy and resource use within buildings	O8	Positive
Innovation	Implementation of advanced technologies	O9	Positive
	Process improvements through innovative methods	O10	Positive
Smart sustainable design	Use of recyclable and eco-friendly materials	O11	Positive
Pollution control	Air, water, and soil pollution control on construction sites	O12	Positive
	Adoption of pollution reduction technologies	O13	Positive
Team collaboration	Level of collaboration and coordination among project members	R1	Positive
	Quality of communication within teams	R2	Positive
Stakeholder engagement	Communication quality with clients, suppliers, and stakeholders	R3	Positive
	Effective use of technology for transparent reporting	R4	Positive
Project management	Clarity in project planning	N1	Positive
	Monitoring and reporting project progress	N2	Positive
Construction pollution	Use of technologies to reduce construction-related emissions	N3	Positive
	Compliance with environmental and health regulations	N4	Positive

Finally, the Check stage provided an evaluation of the intervention outcomes. Experts reflected on the completeness and clarity of the 29 identified indicators, confirming their alignment with the goals of Society 5.0 in construction. At this stage, the qualitative outputs generated through interviews, workshops, and iterative expert discussions were consolidated into a finalised list of indicators and a clarified understanding of their meanings and boundaries. This step was essential for preparing the indicators for transfer into the next methodological phase, namely quantitative prioritisation through Pythagorean Fuzzy DEMATEL. More specifically, once the indicators were validated in the CSP process, they were translated into a structured pairwise influence assessment format, in which experts evaluated the degree to which one indicator affects another using predefined linguistic scales. These linguistic judgements were then converted into Pythagorean fuzzy numbers to construct the initial direct-relation matrix required by DEMATEL. In this way, CSP generated the qualitative content and conceptual structure of the indicators, while PF-DEMATEL provided the quantitative mechanism for modelling their interdependencies and causal prominence.

In this process, the study also drew on Instrumental Stakeholder Theory, which emphasises that both internal and external actors play crucial roles in shaping systemic outcomes. By integrating this perspective into the CSP framework, the analysis ensured that the identified indicators addressed not only technical and managerial dimensions but also the expectations and influences of diverse stakeholders. This enriched the EPIC cycle by adding a clear stakeholder lens during the Explore and Produce stages, and by validating the social legitimacy of the results during the Intervene and Check stages.

Through this combined approach, the study demonstrated how CSP, operationalised via the EPIC cycle, can move from complex and ambiguous problem situations to a structured and validated set of indicators. By iteratively engaging experts and stakeholders, the process ensured that the final outputs were not only academically rigorous but also practically meaningful for managers, decision-makers, and policymakers in the construction industry.

4.1. Results of PF-DEMATEL

Based on the findings of this study and considering the Society 5.0 perspective in the construction industry, a sample response table derived from the responses of 11 experts is presented in Appendix 1. This sample response was analysed using the Pythagorean Fuzzy DEMATEL (PF-DEMATEL) method to process the decision matrices for each factor and to calculate the corresponding weights for each criterion. In this approach, the various criteria, each carrying different levels of importance, are aggregated through their associated weights. These weights are determined through the multi-criteria decision-making process. To illustrate this process, the decision matrix for each factor was examined, and through the calculation of weights, the final value for each factor was obtained. In PF-DEMATEL , fuzzy logic is applied in multi-criteria decision-making. The method employs the Pythagorean fuzzy set concept to combine criteria under different weights, providing more flexibility than traditional fuzzy sets.

The results of the Pythagorean fuzzy DEMATEL analysis, including the D+R (Prominence) values, the D–R (Relation) values, and their corresponding weights for the coded factors, are summarised in Table 4. By accounting for fuzziness, this approach accommodates real-world conditions and incorporates uncertainty into the evaluation. Therefore, the outcomes of the Pythagorean fuzzy DEMATEL analysis (Table 4) demonstrate that this multi-criteria decision-making method can provide robust estimates in situations where the available data involve ambiguity or imprecision.

Table 4. Results obtained from Pythagorean Fuzzy DEMATEL.

Code	D+R (Prominence)	D–R (Relation)	Weight
I1	0.677	0.677	0
I2	1.182	-0.129	0.024
I3	2.631	0.033	0.048
I4	2.391	0.262	0.039
I5	-1.620	1.620	-0.060
I6	1.821	0.281	0.029
I7	2.619	-0.530	0.058
I8	1.742	-0.201	0.036
O1	1.368	1.368	0
O2	-0.462	0.462	-0.017
O3	1.031	0.304	0.013
O4	2.868	-1.513	0.081
O5	0.891	0.110	0.014
O6	2.890	1.116	0.033
O7	2.850	-0.173	0.056
O8	2.435	0.484	0.036
O9	2.128	-0.234	0.044
O10	1.757	-0.567	0.043
O11	2.698	0.014	0.050
O12	2.561	-1.107	0.068
O13	2.707	-0.695	0.063
R1	2.070	0.334	0.032
R2	2.927	0.285	0.049
R3	2.349	-1.572	0.073
R4	1.368	0.042	0.025
N1	1.613	0.956	0.012
N2	2.829	-0.868	0.068
N3	0.568	0.568	0
N4	3.108	-1.328	0.082

Figure 5, adapted from the four-quadrant framework of the DEMATEL method, classifies factors according to their importance and systemic interconnections. Quadrant I contains core or complex drivers that are both highly important and strongly interconnected, making them critical levers for systemic improvement. Quadrant II includes autonomous drivers that exert influence on other factors despite having lower direct importance. Quadrant III represents passive receivers with low importance and weak interconnections, contributing little to overall system dynamics. Quadrant IV highlights dependent factors that are highly important but weakly connected, meaning they are strongly influenced by others and cannot be improved in isolation. In this study, both environmental and project management factors were mapped within these quadrants, offering a clear visualisation of their roles. The results guide decision-making by identifying which factors should be prioritised for direct intervention and which require indirect strategies due to their dependency on stronger systemic drivers.

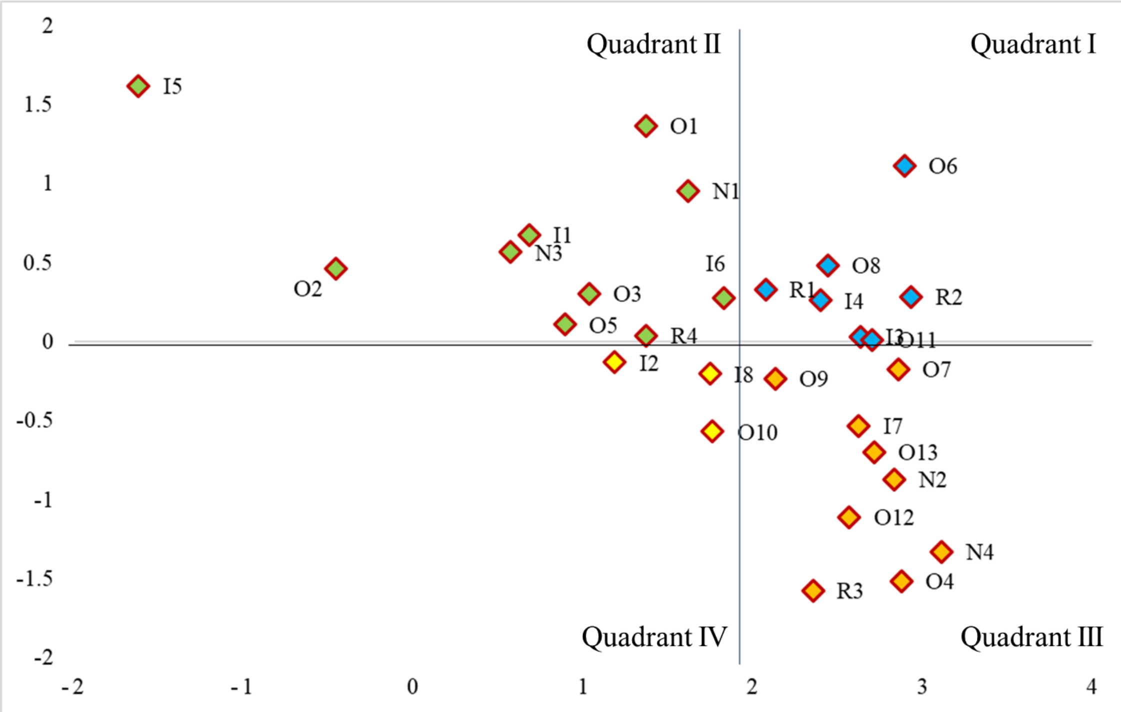

Figure 5. DEMATEL results mapped into the four-quadrant framework.

As shown in Figure 5, in Quadrant I, known as the zone of core or complex factors, elements such as the use of automated systems and smart controls in construction (O5) and optimisation of energy and resource use within buildings (O8) are identified as highly important and strongly interconnected. Managerial aspects such as the level of collaboration and coordination among project team members (R1) and the quality of communication and teamwork (R2) also fall within this quadrant. Quadrant II, representing driving or autonomous factors, includes elements such as compliance of project outcomes with required standards and technical specifications (I5) and energy efficiency and the adoption of energy-saving technologies (O2). These factors have relatively lower importance but strong interconnections with other elements.

In Quadrant III, factors such as procurement of raw materials through sustainable methods and processes (I8) and implementation of innovation in projects (O10) are placed. With both low importance and weak interconnections, these are recognised as independent or passive receivers. In Quadrant IV, known as the zone of influenced or dependent factors, elements such as implementation of advanced technologies in construction projects (O9) and the use of eco-friendly and recyclable materials in construction (O11) are identified. These factors are of high importance but exhibit weaker interconnections, making them highly dependent on other drivers and less amenable to direct improvement.

5. Discussion and Managerial Insights

The findings of this study highlight the transformative role of the Society 5.0 paradigm in shaping the future of Iran's construction industry. By integrating AI, IoT, digital platforms, and advanced automation, Society 5.0 creates opportunities to improve cost efficiency, time performance, quality assurance, and sustainable resource use, while also strengthening communication and coordination among stakeholders through real-time digital integration. However, the practical value of these findings lies not only in identifying relevant dimensions, but also in linking managerial actions to the prioritised indicators revealed by the analysis. In particular, the indicators associated with project management performance, such as cost management (I1), time management (I2, I3), and quality management (I4, I5), emerged as key areas requiring immediate managerial attention, suggesting that organisations should first strengthen transparent budgeting systems, dynamic scheduling mechanisms, and quality-control procedures. Likewise, the prioritised environmental and resource-related indicators, including resource management (I6, I7), energy efficiency (O1, O2), and pollution control (O11, O12), indicate the need for targeted interventions such as reducing water consumption, adopting sustainable materials, improving energy-saving technologies, and enforcing environmental compliance measures. At the same time, the indicators related to digital and technological transformation, namely the integration of physical and digital spaces (O3, O4), smart construction systems (O5, O6), indoor smartness solutions (O7, O8), and innovation-oriented practices (O9, O10), show that investments in digital coordination platforms, intelligent monitoring systems, and innovation capacity are critical for advancing Society 5.0 in construction. From this perspective, the recommendations are directly grounded in the indicator structure produced by the study: managerial priorities should first address the most influential and foundational groups of indicators, and then extend toward complementary technological and sustainability-oriented improvements. In this regard, CSP offers a practical meta-framework for interpreting these priorities in a context-sensitive and participatory way. By following the EPIC cycle, managers can explore interdependencies among indicator groups, design interventions aligned with stakeholder needs, implement them flexibly, and evaluate outcomes iteratively. This makes the discussion more coherent by connecting strategic recommendations to the validated and prioritised indicator set, while also ensuring that technological transformation remains human-centred, resilient, and systemically integrated.

6. Conclusion

It is demonstrated in this study that a CSP-guided EPIC cycle can translate the broad, human-centred vision of Society 5.0 into a concrete, decision-ready indicator set for the construction sector. Through iterative Explore–Produce–Intervene–Check cycles conducted with 11 domain experts, 29 indicators were distilled to reflect not only technical and environmental priorities (e.g., energy efficiency, cyber-physical integration, pollution control) but also socio-organisational levers (e.g., collaboration, stakeholder communication, transparent reporting).but also socio-organisational levers (e.g., collaboration, stakeholder communication, transparent reporting). The subsequent Pythagorean fuzzy DEMATEL analysis clarified causal structure: core/complex drivers such as automated systems and smart controls (O5), optimisation of resources within buildings (O8), and team coordination/communication (R1–R2) exert disproportionate influence on system performance, while dependent yet critical outcomes (e.g., eco-materials and advanced technologies, O11–O9) require indirect improvement through their upstream drivers. Taken together, the results offer a practicable roadmap for Iranian construction: start with data-rich, high-leverage enablers (IoT/AI deployment, collaborative workflows, energy optimisation), sequence complementary initiatives (standards compliance and energy-saving technologies), and measure progress against a balanced set of Society 5.0 indicators. At the managerial level, CSP's meta-method ensures technology adoption remains context-sensitive, pluralistic, and reflexive, helping leaders surface hidden constraints, negotiate trade-offs, and institutionalise learning loops so that digital transformation advances efficiency, sustainability, and inclusivity in tandem.

Future work should deepen and scale this research programme on three fronts: method, implementation, and governance. Methodologically, the indicator system and DEMATEL causal map warrant triangulation through longitudinal pilots and richer analytics, such as linking PF-DEMATEL to system dynamics or Bayesian learning for dynamic causal updating, integrating Quality 4.0 metrics, and conducting cross-project benchmarking to test external validity beyond the initial expert panel and the Iranian context. In particular, given that the present framework was validated through a relatively small expert panel, future studies should broaden the validation base by engaging larger, more diverse, and international samples of experts and practitioners to enhance generalisability across different regulatory, cultural, and technological settings. Implementation priorities include establishing EPIC as a standing practice, for example through a cross-stakeholder steering group that cycles quarterly through the EPIC process from Explore through Check, deploying digital twins to operationalise cyber–

physical integration, and investing in capacity-building for site engineers and planners on IoT data governance, interoperability, and AI-assisted decision support. Governance efforts should codify ethical, privacy, and cybersecurity safeguards; align incentives and procurement with Society 5.0 outcomes, such as performance-based contracts tied to the 29 indicators; and synchronise sectoral standards so that upstream drivers in Quadrants I–II can reliably improve dependent outcomes in Quadrant IV. Extending this agenda across infrastructure, housing, and urban services, while connecting it to SDG targets, can help transform the study's indicator framework into a broader roadmap for resilient, low-carbon, and human-centric construction.

Moreover, the present study is grounded in the Iranian construction sector, and this context-specific focus may limit the transferability of the findings to economies with different governance structures, institutional arrangements, and levels of digital maturity. Although the proposed framework is conceptually robust, it has not yet been tested using large-scale empirical datasets or real-life project case studies, and therefore its practical performance across varied construction environments remains to be demonstrated. In addition, the methodological design prioritises causal structuring and prioritisation through PF-DEMATEL rather than statistical validation; accordingly, conventional robustness assessments such as reliability testing, factor analysis, or large-sample measurement validation were beyond the scope of the present study. Future research should therefore complement the current systems-based approach with broader empirical testing, project-level applications, and psychometric or multivariate validation techniques to strengthen the reliability, transferability, and statistical robustness of the proposed indicator framework.

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References

Adel, A. and Alani, N.H.S., 2024. Human-centric collaboration and Industry 5.0 framework in smart cities and communities: Fostering Sustainable Development Goals 3, 4, 9, and 11 in Society 5.0. Smart Cities, 7(4), pp.1723–1775. https://doi.org/10.3390/smartcities7040068

Basta, M., Lapalme, J. and Paquet, M., 2023. The systemic tenets of the key supply chain social responsibility approaches. International Journal of Engineering Business Management, 15, p.18479790231202420. https://doi.org/10.1177/18479790231202420

Bonakdari, H., Khazaei, M., Gholian-Jouybari, F. and Hajiaghaei-Keshteli, M., 2026. Sustainable wastewater-to-hydrogen systems in Canada: A scenario-based decision support analysis. Renewable Energy, 256, p.124308. https://doi.org/10.1016/j.renene.2025.124308

Bungin, B., Wono, H.Y. and Shwari, E.J.A., 2021. Communication media technology and social harmony construction in the era of Society 5.0: A critical view. International Journal of Computer and Information System (IJCIS), 2(4), pp.125–130. https://doi.org/10.29040/ijcis.v2i4.40

Deguchi, A., Hirai, C., Matsuoka, H., Nakano, T., Oshima, K., Tai, M. and Tani, S., 2020. What is Society 5.0? In: Society 5.0. Singapore: Springer, pp.1–23. https://doi.org/10.1007/978-981-15-2989-4_1

Elyasi, A. and Teimoury, E., 2023. Applying Critical Systems Practice meta-methodology to improve sustainability in the rice supply chain of Iran. Sustainable Production and Consumption, 35, pp.453–468. https://doi.org/10.1016/j.spc.2022.11.024

Fukuda, K., 2020. Science, technology and innovation ecosystem transformation toward Society 5.0. International Journal of Production Economics, 220, p.107460. https://doi.org/10.1016/j.ijpe.2019.07.033

Fukuyama, M., 2018. Society 5.0: Aiming for a new human-centered society. Japan Spotlight, 27(5), pp.47–50.

Gholian-Jouybari, F., Khazaei, M., Farzipoor Saen, R., Kia, R., Bonakdari, H., Hajiaghaei-Keshteli, M. and Ramezani, M., 2024. Developing environmental, social and governance (ESG) strategies on evaluation of municipal waste disposal centers: A case of Mexico. Chemosphere, 364, p.142961. https://doi.org/10.1016/j.chemosphere.2024.142961

Gurjanov, A.V., Zakoldaev, D.A., Shukalov, A.V. and Zharinov, I.O., 2020. The smart city technology in the super-intellectual Society 5.0. Journal of Physics: Conference Series, 1679(3), p.032029. https://doi.org/10.1088/1742-6596/1679/3/032029

Issa, U.H., Mosaad, S.A. and Hassan, M.S., 2020. Evaluation and selection of construction projects based on risk analysis. Structures, 27, pp.361–370. https://doi.org/10.1016/j.istruc.2020.05.049

Izotov, A., Rostova, O. and Dubgorn, A., 2018. The application of the real options method for the evaluation of high-rise construction projects. E3S Web of Conferences, 33, p.03008. https://doi.org/10.1051/e3sconf/20183303008

Jackson, M.C., 2006. Creative holism: A critical systems approach to complex problem situations. Systems Research and Behavioral Science, 23(5), pp.647–657. https://doi.org/10.1002/sres.799

Jackson, M.C., 2020. Critical systems practice 1: Explore, starting a multimethodological intervention. Systems Research and Behavioral Science, 37(5), pp.839–858. https://doi.org/10.1002/sres.2746

Jackson, M.C., 2021. Critical systems practice 2: Produce, constructing a multimethodological intervention strategy. Systems Research and Behavioral Science, 38(5), pp.594–609. https://doi.org/10.1002/sres.2809

Jackson, M.C., 2022. Critical systems practice 3: Intervene, flexibly executing a multimethodological intervention. Systems Research and Behavioral Science, 39(6), pp.1014–1023. https://doi.org/10.1002/sres.2909

Jackson, M.C., 2023. Critical systems practice 4: Check, evaluating and reflecting on a multimethodological intervention. Systems Research and Behavioral Science, 40(4), pp.617–632. https://doi.org/10.1002/sres.2912

Kasinathan, P., Pugazhendhi, R., Elavarasan, R.M., Ramachandaramurthy, V.K., Ramanathan, V., Subramanian, S., Kumar, S., Nandhagopal, K., Vijaya Raghavan, R.R., Rangasamy, S., Devendiran, R. and Alsharif, M.H., 2022. Realization of Sustainable Development Goals with disruptive technologies by integrating Industry 5.0, Society 5.0, smart cities and villages. Sustainability, 14(22), p.15258. https://doi.org/10.3390/su142215258

Keidanren, 2018. Society 5.0: Co-creating the future. Tokyo: Japan Business Federation. Available at: https://www.keidanren.or.jp/en/policy/2018/095.html (Accessed: 29 August 2026).

Khazaei, M., Ebrahimi, S., Samarghandi, H., Boloorchian, M. and Abbasabadarabi, S., 2026. Critical examination and assessment of government policies on green hydrogen: Entrepreneurial challenges in renewable energy sector. Systemic Practice and Action Research, 39(3), p.26. https://doi.org/10.1007/s11213-026-09776-z

Khazaei, M., Elmi, E., Gholian-Jouybari, F. and Hajiaghaei-Keshteli, M., 2026. Environment-system conflict (ENSY) in policy making and strategic analysis: A case study of hydrogen energy. Environment Systems and Decisions, 46(1), p.6. https://doi.org/10.1007/s10669-025-10067-6

Khazaei, M., Gholian-Jouybari, F., Davari Dolatabadi, M., Pourebrahimi Alamdari, A., Eskandari, H. and Hajiaghaei-Keshteli, M., 2025. Renewable energy portfolio in Mexico for Industry 5.0 and SDGs: Hydrogen, wind, or solar? Renewable and Sustainable Energy Reviews, 213, p.115420. https://doi.org/10.1016/j.rser.2025.115420

Khazaei, M., Gholian-Jouybari, F., Ramezani, M. and Hajiaghaei-Keshteli, M., 2025. Environmental, social, and governance enablers of the hydrogen supply chain: Application of community operational research using STRIDES framework. Journal of Environmental Management, 389, p.126092. https://doi.org/10.1016/j.jenvman.2025.126092

Khazaei, M., Mehrparvar, M., Govindan, K., Barazandeh, S., Mostofi, A. and Mohemmi, Z., 2026. Circular supply chain design for biohydrogen recovery from perishable agri-food waste. International Journal of Hydrogen Energy, 217, p.153731. https://doi.org/10.1016/j.ijhydene.2026.153731

Luo, L., Chen, H., Yang, Y., Wu, G. and Chen, L., 2022. A three-stage network DEA approach for performance evaluation of BIM application in construction projects. Technology in Society, 71, p.102105. https://doi.org/10.1016/j.techsoc.2022.102105

Marinelli, M., 2023. From Industry 4.0 to Construction 5.0: Exploring the path towards human–robot collaboration in construction. Systems, 11(3), p.152. https://doi.org/10.3390/systems11030152

McKenna, P., 2025. The complementarity of programme logic and critical systems heuristics: Critical systems practice for the evaluation of emergency relief in Australia. Systems Research and Behavioral Science, 42(1), pp.111–122. https://doi.org/10.1002/sres.3114

Metham, M., Benjaoran, V. and Sedthamanop, A., 2022. An evaluation of Green Road Incentive Procurement in road construction projects by using the AHP. International Journal of Construction Management, 22(3), pp.501–513. https://doi.org/10.1080/15623599.2019.1635757

Mishra, P., Thakur, P. and Singh, G., 2022. Sustainable smart city to Society 5.0: State-of-the-art and research challenges. SAIEE Africa Research Journal, 113(4), pp.152–164. https://doi.org/10.23919/SAIEE.2022.9945865

Mortazavi, S., Kheyroddin, A. and Naderpour, H., 2020. Risk evaluation and prioritization in bridge construction projects using system dynamics approach. Practice Periodical on Structural Design and Construction, 25(3), p.04020015. https://doi.org/10.1061/(ASCE)SC.1943-5576.0000493

Musarat, M.A., Irfan, M., Alaloul, W.S., Maqsoom, A. and Ghufran, M., 2023. A review on the way forward in construction through Industrial Revolution 5.0. Sustainability, 15(18), p.13862. https://doi.org/10.3390/su151813862

Nair, M.M., Tyagi, A.K. and Sreenath, N., 2021. The future with Industry 4.0 at the core of Society 5.0: Open issues, future opportunities and challenges. In: 2021 International Conference on Computer Communication and Informatics (ICCCI). IEEE, pp.1–7. https://doi.org/10.1109/ICCCI50826.2021.9402498

Noorizadeh, A., Peltokorpi, A. and Avkiran, N.K., 2019. Supplier performance evaluation in construction projects: Challenges and possible solutions. Journal of Construction Engineering and Management, 145(4), p.04019007. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001616

Norris, D., Foote, J. and Greatbanks, R., 2025. Mode 2 critical systems practice for complex safety decisions: Reflections from New Zealand's dairy industry. Systems Research and Behavioral Science, 42(1), pp.189–205. https://doi.org/10.1002/sres.3083

Pal, U.K., Zhang, C., Haupt, T.C., Li, H. and Su, L., 2024. The evolution of Construction 5.0: Challenges and opportunities for the construction industry. Buildings, 14(12), p.4010. https://doi.org/10.3390/buildings14124010

Potočan, V., Mulej, M. and Nedelko, Z., 2021. Society 5.0: Balancing of Industry 4.0, economic advancement and social problems. Kybernetes, 50(3), pp.794–811. https://doi.org/10.1108/K-12-2019-0858

Rane, N., 2023. ChatGPT and similar generative artificial intelligence (AI) for building and construction industry: Contribution, opportunities and challenges of large language models for Industry 4.0, Industry 5.0, and Society 5.0. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.4603221

Salgues, B., 2018. Society 5.0, its logic and its construction. In: Society 5.0: Industry of the Future, Technologies, Methods and Tools. Hoboken, NJ: Wiley, pp.1–21. https://doi.org/10.1002/9781119507314.ch1

Sambo, L.G. and Jackson, M.C., 2021. Empowering health systems research to engage with technical, organizational, social and economic forces: Lessons from the 2014 Ebola epidemic. Systems Research and Behavioral Science, 38(3), pp.307–320. https://doi.org/10.1002/sres.2784

Tunji-Olayeni, P., Aigbavboa, C., Oke, A. and Chukwu, N., 2024. Research trends in Industry 5.0 and its application in the construction industry. Technological Sustainability, 3(1), pp.1–23. https://doi.org/10.1108/TECHS-07-2023-0029

Venter, C. and Goede, R., 2018. A report and reflection on an application of Critical Systems Practice to improve a business intelligence system's business requirements. Systems Research and Behavioral Science, 35(5), pp.548–563. https://doi.org/10.1002/sres.2565

Veshneva, I. and Bolshakov, A.A., 2022. Construction of digital twins of socio-economic systems using mathematical models based on status functions. In: Kravets, A.G., Bolshakov, A.A. and Shcherbakov, M. (eds.), Society 5.0: Human-Centered Society Challenges and Solutions. Cham: Springer, pp.129–

141. https://doi.org/10.1007/978-3-030-95112-2_11

Wilden, D., Hopkins, J. and Sadler, I., 2025. The utility of critical systems practice: A supply chain practitioner perspective. Systems Research and Behavioral Science, 42(1), pp.206–218. https://doi.org/10.1002/sres.3117

Wopata, M., 2020. Industry 4.0 adoption 2020: Who is ahead? IoT Analytics, 4 February. Available at: https://iot-analytics.com/industry-4-0-adoption-2020-who-is-ahead/ (Accessed: 29 August 2026).

Wuni, I.Y., Shen, G.Q. and Osei-Kyei, R., 2022. Quantitative evaluation and ranking of the critical success factors for modular integrated construction projects. International Journal of Construction Management, 22(11), pp.2108–2120. https://doi.org/10.1080/15623599.2020.1766190

Yevu, S.K., Yu, A.T.W., Darko, A. and Addy, M.N., 2021. Evaluation model for influences of driving forces for electronic procurement systems application in Ghanaian construction projects. Journal of Construction Engineering and Management, 147(8), p.04021076. https://doi.org/10.1061/(ASCE)CO.1943-7862.0002107

Yitmen, I., Almusaed, A. and Alizadehsalehi, S., 2023. Investigating the causal relationships among enablers of the Construction 5.0 paradigm: Integration of Operator 5.0 and Society 5.0 with human-centricity, sustainability, and resilience. Sustainability, 15(11), p.9105. https://doi.org/10.3390/su15119105

Zarghami, S.A., 2024. Project schedule contingency planning: Building on von Bertalanffy's open systems theory and critical systems practice. Systems Research and Behavioral Science, 41(2), pp.247–261. https://doi.org/10.1002/sres.2965

Zarghami, S.A. and Zwikael, O., 2025. Building project resilience: A critical systems practice approach. Systems Research and Behavioral Science, 42(3), pp.916–929. https://doi.org/10.1002/sres.3010

Zeraati Foukolaei, P., Ghaedi, M., Hajiaghaei-Keshteli, M. and Khazaei, M., 2026. Feedstock reliability optimization model for a biogas supply chain with climate, land, energy, and water nexus approach. Process Integration and Optimization for Sustainability, advance online publication. https://doi.org/10.1007/s41660-026-00708-x