International Journal of Urban Management and Energy Sustainability (IJUMES)

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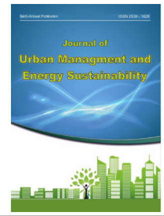

CASE STUDY RESEARCH PAPER

A Conceptual-Delphi Framework for Identifying and Prioritising Complexity-Generating Factors in Civil Projects Based on the Intrinsic Characteristics of Complex Systems and Aligned with the PMBOK 7 Performance Domains

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ARTICLE INFO

Article History:
Received 2026-05-19
Revised 2026-07-13
Accepted 2026-08-25

Keywords:
Complex systems; Conceptual Delphi; Complexity factors; PMBOK 7; project complexity

ABSTRACT

Delphi studies are widely used to identify the factors that generate complexity in civil projects; however, the extent to which the participating experts share a clear understanding of the concept of complexity and of the characteristics of complex systems is rarely reported. Building on the intrinsic characteristics of complex systems, this study introduces a "Conceptual Delphi" procedure applied before the Delphi rounds begin to create cognitive alignment among experts and thereby improve the validity and generalisability of the results. Twenty intrinsic characteristics of complex systems were extracted from sixteen complexity-science sources and presented to the experts in a structured form. A three-round Delphi panel was then conducted; the factors were organised within the eight performance domains of the PMBOK 7 standard, and consensus was evaluated using the median, inter-quartile ranges and agreement rate, complemented by Kendall's coefficient of concordance and the Wilcoxon signed-rank test. The preliminary list comprised 160 factors in the first round and was reduced to 55 factors in the second and third rounds. From the second to the third round, 17 of the 55 factors reached consensus, and only the "Development Approach and Life Cycle" performance domain achieved statistically significant. While the experts affirmed the importance of all factors, these results were used to derive a quantitative framework for prioritising project-complexity management. The resulting quantitative, PMBOK-7-aligned framework gives project managers a defensible basis for prioritising and managing the drivers of complexity in civil projects, particularly in unstable economic and administrative environments such as Iran.

DOI: 10.22034/ijumes.2025.2039678.1250

Running Title: Complexity-Generating Factors in Civil Projects

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
36	01	06

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INTRODUCTION

Complexity has come to occupy an independent place in the project-management body of knowledge (Project Management Institute, 2021), reflecting its wide-ranging effects on projects on performance and success (Baccarini, 1996; Bjorvatn & Wald, 2018; Carvalho et al., 2015; Floricel et al., 2016; Ghaleb et al., 2022; Ma & Fu, 2020; Nikolić & Čerić, 2022; Tatikonda & Rosenthal, 2000), on risk and uncertainty, on time and cost, on project delivery, on the team and its communication, and on megaprojects, together with simultaneous effects on planning, control, decision-making and the choice of organisational structure (San Cristóbal et al., 2018). The breadth of these effects reflects the wide range of views that exist about complexity in civil projects. Because of these effects, identifying the factors that generate complexity is of considerable importance; doing so also informs the methods used to measure and manage complexity. Although the literature has advanced the understanding, identification, measurement and management of complexity (Bakhshi et al., 2016; Vidal et al., 2013), no single agreed model for measuring complexity has emerged despite the various methods developed (Lu et al., 2015; Nguyen et al., 2015) and no consensus exists on a single standard (Vidal et al., 2011a). Consequently, the findings of different studies are difficult to reconcile and their practical use for managers is limited. Although the Project Management Institute has drawn attention to complexity (PMI, 2021), there is no direct link between the abstract concepts of complexity theory and the practical actions that managers can take to identify complexity-generating factors. Civil-project managers intuitively perceive that a project is complex, yet often do not recognise the generating factors and the characteristics of complex systems, and therefore cannot adopt the measures needed to reduce complexity's effects. Moreover, most research on complexity-generating factors has been conducted in developed countries within stable, well-structured settings; environments such as Iran affected by chronic economic, administrative and financial instability and by frequent regulatory change have received far less attention. Establishing complexity-generating factors as an independent section within project-management standards is itself an effort to give complexity greater weight (PMI, 2021). Most previous methods for identifying complexity-generating factors lacked a foundational study of the concepts and characteristics of complex systems and identified factors by emphasising individual viewpoints, rather than recognising that complexity is intrinsic to a system's characteristics (Boulton et al., 2015; Marle & Vidal, 2016). Re-identifying these factors in light of the emphasis of PMBOK 7 (PMI, 2021), together with building a shared conceptual understanding among experts of complex-system characteristics, is therefore a necessary new step. If the basic principles of complex systems are ignored, each expert's list reflects a different and possibly contradictory mindset, which weakens validity and makes a project's fate heavily dependent on the personal views of its managers (San Cristóbal et al., 2018). Building on the concepts of complexity and the characteristics of complex systems, this research carries out a process of identifying and prioritising these factors through a three-round Delphi survey. The study aims to provide a stable, convergent list of complexity-generating factors in civil projects that is independent of personal views and experience, thereby supporting the reduction and control of their effects and, ultimately, better management above all the control of negative effects and the prevention of the creation and intensification of complexity. Through these measures the likelihood of project success increases, since the relationship between controlling complexity and project success has repeatedly been confirmed (Antoniadis et al., 2011; Azmat & Siddiqui, 2023; Luo et al., 2017; Ma & Fu, 2020).

MATERIALS AND METHODS

Complexity and complexity science

There is no single, universally accepted definition of complexity; the concept is studied across mathematics, physics, biology, the social sciences and engineering, and each discipline emphasises different features (Ladyman et al., 2013; Mitchell, 2009). Broadly, a complex system is one composed of many interacting components whose collective behaviour cannot be deduced simply by summing the behaviour of the parts, so that novel, system-level (emergent) properties arise from the interactions (Chu et al., 2003; Estrada, 2024). In project management, complexity is commonly distinguished from mere complicatedness: a complicated system can, in principle, be decomposed and fully predicted, whereas a complex system exhibits emergence, non-linearity and adaptive behaviour that limit prediction and control (Baccarini, 1996; Williams, 1999). Adopting a complexity-science lens therefore reframes a civil project as a complex adaptive system rather than a merely large or complicated one.

Characteristics of complex systems

To create a shared conceptual basis for the Delphi panel, twenty intrinsic characteristics of complex systems were extracted from sixteen complexity-science sources. These characteristics summarised in Table 1 were presented to the experts before the rounds began, so that the identification of complexity-generating factors would rest on the recognised properties of complex systems rather than on individual intuition (Estrada, 2024; Ladyman et al., 2013). (Tab. 1)

Table 1: Intrinsic characteristics of complex systems used as the conceptual basis of the study

No.	Characteristic	Brief description	Representative sources
1	Emergence	System-level properties arise from interactions and are not reducible to the parts.	Chu et al. (2003); Ladyman et al. (2013)
2	Non-linearity	Effects are not proportional to causes; small changes may have large effects.	Mitchell (2009); Estrada (2024)
3	Self-organization	Ordered structure forms without central control.	Ladyman et al. (2013)
4	Feedback loops	Outputs feed back as inputs, amplifying or damping behaviour.	Chu et al. (2003)
5	Adaptability	The system adjusts its behaviour in response to its environment.	Mitchell (2009)
6	Interconnectedness	Dense interdependencies link the components.	Ladyman et al. (2013)
7	Hierarchy / Nestedness	The system is organised in nested levels.	Estrada (2024)
8	Sensitivity to initial conditions	Small differences in starting states diverge over time.	Mitchell (2009)
9	Non-equilibrium	The system operates far from equilibrium.	Estrada (2024)
10	Resilience / robustness	The system maintains function under disturbance.	Ladyman et al. (2013)
11	Uncertainty / unpredictability	Future states cannot be fully predicted.	Cicmil et al. (2009)
12	Openness	The system exchanges matter, energy and information with its surroundings.	Chu et al. (2003)
13	Co-evolution	The system and its environment evolve together.	Mitchell (2009)
14	Path dependence	History constrains present and future states.	Estrada (2024)

15	Irreducibility	The whole cannot be understood by decomposition alone.	Ladyman et al. (2013)
16	Downward causation	System-level patterns constrain the parts.	Estrada (2024)
17	Diversity /Internal Inhomogeneity	Components differ in kind and behaviour.	Chu et al. (2003)
18	Radical openness	System boundaries are ambiguous and context-dependent.	Chu et al. (2003)
19	Contextuality	Behaviour depends on context and situation.	Estrada (2024)
20	Evolutionary teleonomy	Apparent goal-directedness emerges through evolution.	Mitchell (2009)

Table 1 gives a compact set of representative sources for each characteristic; the full source mapping (sixteen references) is provided in the Supplementary Material. Grounding the factor-identification process in these characteristics is the core of the “Conceptual Delphi” proposed here.

Project complexity and its frameworks

In construction, complexity has been characterised through successive frameworks. Baccarini (Baccarini, 1996) distinguished organisational and technological complexity, each with differentiation and interdependency; Williams (Williams, 1999) added structural complexity and uncertainty; and the TOE framework of Bosch-Rekveldt et al. (Bosch-Rekveldt et al., 2011) grouped drivers into technical, organisational and environmental dimensions. Later studies operationalised these dimensions through measurement models (Lu et al., 2015; Vidal et al., 2011a), multi-criteria methods (Jaber et al., 2021; Nguyen et al., 2015) and Delphi-based frameworks (Vidal et al., 2013). Recent reviews confirm both the proliferation of factors and the absence of a shared standard (Bakhshi et al., 2016; Lafhaj et al., 2024), which motivates the present focus on conceptual alignment before elicitation. The seventh edition of the PMBOK Standard organises project delivery into eight performance domains Stakeholders; Team; Development Approach and Life Cycle; Planning; Project Work; Delivery; Measurement; and Uncertainty (PMI, 2021). In this study these eight domains are used as the classification structure within which the complexity-generating factors are organised, ensuring that the identified factors map onto the recognised areas of project performance and can be acted upon by managers.

Methodology

The study follows a mixed, exploratory design centred on an expert panel. Its distinctive feature is a “Conceptual Delphi” step that precedes the conventional Delphi rounds: before eliciting judgements, the panel is given a structured briefing on the concept of complexity and on the intrinsic characteristics of complex systems (Tab. 1), so that the experts share a common conceptual frame of reference. This step is intended to reduce the dependence of the elicited factors on individual, and possibly contradictory, mental models and thereby to improve the validity and generalisability of the results (Vidal et al., 2013; von der Gracht, 2012). The overall process is summarised in Figure 1. (Fig. 1)

Expert panel

The panel was assembled by purposive sampling of specialists with substantial experience in the management of civil (construction) projects, complemented by academic expertise in project management and complex systems (Hallowell & Gambatese, 2010). Inclusion criteria were a relevant postgraduate qualification, significant professional or research experience in construction project management, and familiarity with the concepts of project complexity. Nineteen experts took part in the first round; sixteen and fourteen, respectively, completed the second and third rounds (participation of 84% and 74%), a size consistent with recommendations for Delphi panels in construction-management research (Sourani & Sohail, 2015). Table 2 summarises panel participation across the rounds. (Tab. 2)

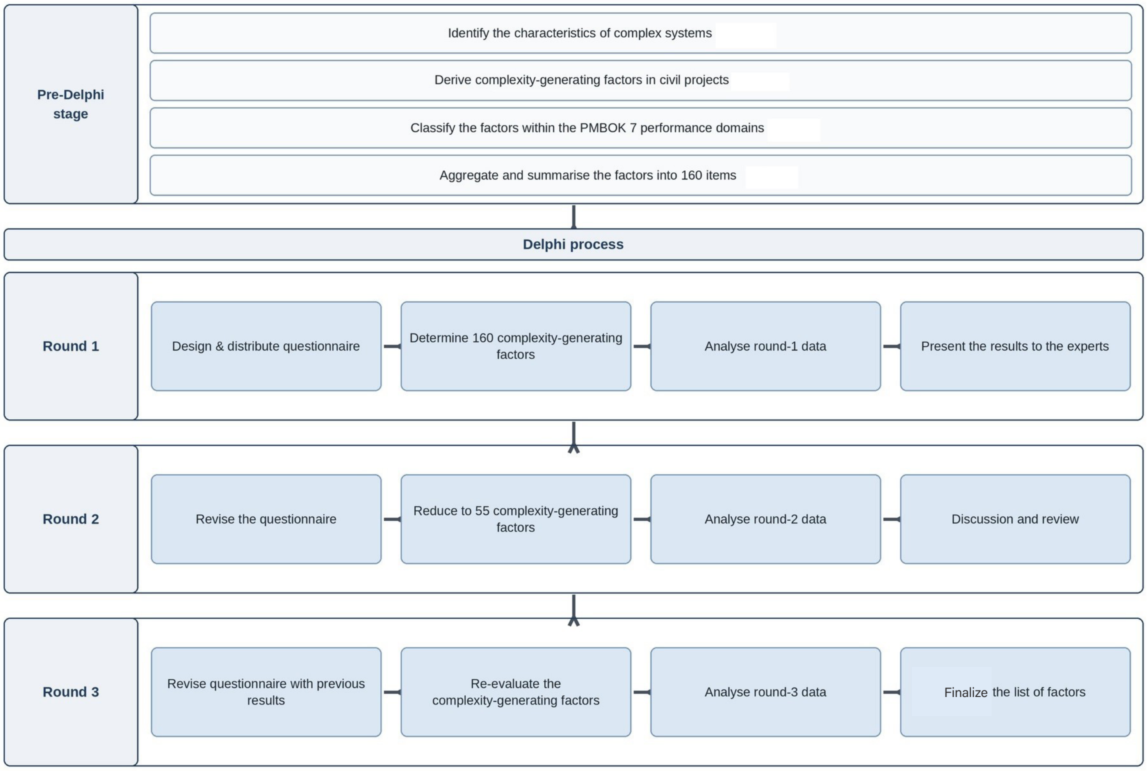

Figure 1: The Conceptual-Delphi research process, comprising the pre-Delphi conceptual-alignment stage and three Delphi rounds

Table 2: Expert-panel participation across the three Delphi rounds

Delphi round	Invited / continuing	Responses	Participation rate
Round 1 (open + rating)	19	19	–
Round 2 (rating, controlled feedback)	19	16	84%
Round 3 (re-rating, controlled feedback)	16	14	74%

Detailed demographic characteristics of the panel (role, sector, years of experience and highest qualification) are provided in the Supplementary Material; the panel combined site and project managers, design and consulting engineers, and academics, so that practical and theoretical perspectives were both represented.

Delphi procedure and instrument

The Delphi was conducted in three rounds with controlled feedback and preserved anonymity (Sourani & Sohail, 2015). In the first round, an initial pool of 160 complexity-generating factors compiled from the literature and organised within the eight PMBOK 7 performance domains was presented, and experts rated each factor's contribution to project complexity on a five-point Likert scale while proposing additions or revisions. In the second round, the consolidated results and the experts' comments were returned as controlled feedback, and a reduced list of 55 factors was re-rated. In the third round, the second-round statistics were again fed back and the 55 factors were re-rated to test the stability of the responses. A factor was deemed to have reached consensus when it simultaneously satisfied three descriptive criteria: a median of at least 4 (on the five-point scale), an inter-quartile range (IQR) of at most 1, and an agreement rate of at least 75% of experts rating the factor 4 or 5 (Diamond et al., 2014). In addition, the overall degree of agreement within each PMBOK 7 domain was assessed using Kendall's coefficient of concordance (W), and the stability of ratings between consecutive rounds was tested with the Wilcoxon signed-rank test; the absence of a statistically significant change between the second and third rounds was taken as evidence of stability and as the stopping rule for the panel (Schmidt, 1997; von der Gracht, 2012).

FINDINGS AND DISCUSSION

The three-round process is summarised in Figure 1. From the systematic review of 37 studies, an exhaustive pool of 1,226 candidate factors was compiled; after removing items irrelevant to civil projects, merging duplicates and consolidating overlapping items on the judgement of three academic and practitioner experts and classifying the remainder within the eight PMBOK 7 performance domains, an initial list of 160 factors was prepared for the first Delphi round (Appendix; Supplementary Material). Following the first round, factors receiving the lowest ratings were removed and conceptually similar items were merged, yielding a refined list of 55 factors distributed across the eight domains, which were carried into the second and third rounds.

Second-round results (five-point scale)

In the second round, agreement at the level of each performance domain was assessed using Kendall's coefficient of concordance (W) with tie correction. As Table 3 shows, the coefficient was low in all eight domains and did not reach statistical significance (all $p > 0.05$), indicating that although some individual factors attracted highly convergent ratings the experts had not yet reached significant overall agreement on the relative ranking of factors within any domain (Schmidt, 1997). (Tab. 3)

Table 3: Domain-level concordance of expert ratings in the second Delphi round (Kendall's W)

PMBOK 7 performance domain	Kendall's W	p-value
Project Planning	0.040	0.697
Project Team	0.049	0.623
Project Stakeholders	0.018	0.943
Project Work	0.033	0.785
Project Delivery	0.011	0.953
Project Measurement	0.016	0.940
Project Uncertainty	0.031	0.841
Development Approach & Life Cycle	0.038	0.699

The descriptive indices confirmed that agreement varied markedly across individual factors. For factors on which the panel converged, the inter-quartile range (IQR) was very small and the agreement coefficient approached unity; for example, the factor "presence and introduction of undeclared stakeholders during project execution" had a median of 3, an IQR of 0.25 and an agreement coefficient of 0.94, reflecting a strong concentration of responses. In contrast, dispersed factors produced a large IQR and a low agreement coefficient; "incomplete and insufficient planning," for instance, had a median of 2.5, an IQR of 4 and an agreement coefficient of 0. This contrast shows that high agreement on some individual factors does not imply overall concordance within a domain: the agreement coefficient reflects the dispersion of responses for each factor separately, whereas Kendall's W evaluates agreement on the ranking of the whole set of factors in a domain.

Third-round results (nine-point reverse scale)

After controlled feedback of the second-round medians, the third round used a reverse nine-point scale (1 = very high impact, 9 = lowest impact, plus a "cannot determine" option) to sharpen the discrimination among factors; consensus was defined as Median ≤ 3, IQR ≤ 2 and agreement ≥ 75% of responses in the 1–3 band. The pattern of responses converged appreciably relative to the second round. Of the 55 factors, 4 reached strong consensus and 13 reached acceptable consensus 17 factors in total (30.9%) while 20 factors remained borderline and 18 did not reach consensus (Table 4). The distribution of outcomes is itself informative: rather than forcing artificial agreement, the process retained a defensible core of agreed factors while transparently flagging the remainder as context-dependent. (Tab. 4)

Table 4: Distribution of the 55 factors by consensus status in the third round.

Consensus status	No. of factors	Share of 55	Criterion
Strong consensus	4	7.3%	Median ≤ 3, IQR ≤ 2, agreement ≥ 80%
Acceptable consensus	13	23.6%	Median ≤ 3, IQR ≤ 2, agreement 75–79.99%
Consensus subtotal	17	30.9%	–
Borderline	20	36.4%	Favourable median but limited agreement
No consensus	18	32.7%	High dispersion / low agreement

The four factors that achieved strong consensus (Tab. 5) were, in order of agreement, the unavailability and volume of information circulating in the project; the number of structures, groups or teams that must be coordinated; the total number and difficulty of obtaining the legal permits required for the project works; and the importance of the project to the client. These factors span the Development Approach and Life Cycle, Planning and Stakeholders domains, and each attracted agreement of 85.7%.

Table 5: Factors reaching strong consensus in the third round.

PMBOK 7 domain	Complexity factor	Median	IQR	Agree. %
Development Approach & Life Cycle	Unavailability and volume of information circulating in the project	2	1.75	85.7
Planning	Number of structures/groups/teams that must be coordinated	2	2	85.7
Development Approach & Life Cycle	Total number and difficulty of obtaining the legal permits required for project works	3	1	85.7
Stakeholders	Importance of the project to the client	3	1.75	85.7

A further 13 factors reached acceptable consensus (Tab. 6), including the lack of stakeholder awareness of project problems (Team); weak or absent support and site-infrastructure deficiencies (Project Work); ambiguity in handling delays or funding problems, contingent contract terms and contractual ambiguity, and responses to unpredictable emergent conditions (Uncertainty); interdependence among project plans (Planning); unfamiliarity with, or contradiction between, project-related standards, and ambiguity in acceptance and hand-over criteria (Delivery); deficiencies in feedback methods for unmet requirements (Measurement); and a lack of team experience with the technologies used (Team).

Table 6: Factors reaching acceptable consensus in the third round.

No.	PMBOK 7 domain	Complexity factor	Med.	IQR	Agree. %
16	Team	Lack of stakeholder awareness of project problems	2	1	78.6
24	Project Work	Weak/absent support or deficiencies in existing site infrastructure	2	1	78.6
42	Uncertainty	Ambiguity in handling delays or problems in project funding	2	1	78.6
43	Uncertainty	Contingent contract terms and ambiguity in contractual concepts	2	1	76.9
25	Project Work	Ambiguity in the project-governance approach	2	1.75	78.6
7	Planning	Interdependence among the plans within the project	2.5	1	78.6
31	Delivery	Unfamiliarity with, or contradiction between, project standards	2.5	1	78.6
45	Uncertainty	Responses to unpredictable emergent states, actions and events	3	0	76.9
52	Dev. Approach & Life Cycle	Obtaining permits from bodies outside the project to continue works	3	0	78.6
46	Uncertainty	Uncertainty/ambiguity in project paths, processes or final outcomes	3	0.5	75.0
34	Delivery	Absence/ambiguity or late notification of acceptance criteria (quality, HSE)	3	0.75	78.6
41	Measurement	Absence/deficiency in feedback methods for unmet requirements	3	1	76.9
10	Team	Lack of team experience with the technologies used in the project	3	2	78.6

The 20 borderline factors retained a favourable median but did not fully meet the agreement threshold, and the 18 factors without consensus combined high dispersion with low agreement. In line with the analysis plan, these were not discarded on the basis of a single statistic: factors with an acceptable median and limited dispersion were retained as cases of “borderline consensus” for interpretation, whereas the absence of consensus was treated not as a defect of the Delphi process but as a possible reflection of genuine heterogeneity in expert views complexity factors whose importance shifts with the type, scale and context of the project (von der Gracht, 2012).

Domain-level agreement, convergence and stability

Analysing the consensus outcomes across the eight PMBOK 7 domains showed that agreement was not evenly distributed. The Uncertainty domain contained the largest share of agreed factors (four of its eight factors reached acceptable or strong consensus), whereas the Stakeholders domain contained the fewest (two of eight). The greater agreement in the Uncertainty domain may reflect a shared recognition of factors linked directly to unpredictability and changing project conditions, while the wider dispersion in the Stakeholders domain may mirror differences in the experts' experience and the context-dependence of social and governance factors. At the domain level in the third round, only the Development Approach and Life Cycle domain reached statistically significant concordance (Kendall's $W = 0.37$, $p < 0.01$); the increase in W relative to the second round, accompanied by stable factor-level indices, was interpreted as evidence of genuine convergence rather than of forced agreement (Schmidt, 1997; von der Gracht, 2012). The stability of the panel's judgements between the second and third rounds was tested for each of the 55 factors using the Wilcoxon signed-rank test on the fourteen experts who participated in both rounds, with a false-discovery-rate correction for the 55 simultaneous tests (Schmidt, 1997). Because the two rounds used scales of different length and direction, the third-round scores were first re-aligned to the second-round orientation and the "cannot determine" responses were excluded from the paired analysis. The test revealed no systematic, statistically significant change in the ratings between the two rounds; combined with the stability of the medians, IQRs and consensus status, this confirmed that the panel's judgements had stabilised and justified terminating the Delphi after the third round. Finally, the agreed factors were prioritised using the median as the primary criterion and the IQR as a secondary criterion for factors sharing the same median (a smaller IQR indicating a tighter concentration of expert judgement around the median). On this basis, and given that the experts affirmed the importance of all retained factors, a quantitative, domain-organised prioritisation of the complexity-generating factors was derived to support project-complexity management; the complete per-factor statistics for all 55 factors and the full prioritisation are provided in the Supplementary Material.

RESULTS AND CONCLUSION

The findings support the central argument of the study: that the value of a Delphi-based identification of complexity factors depends heavily on whether the experts share a common understanding of what complexity is. By inserting a conceptual-alignment stage grounded in the intrinsic characteristics of complex systems (Table 1), the present approach reduces the risk that the resulting list merely aggregates divergent individual mental models (Marle & Vidal, 2016; San Cristóbal et al., 2018). This is consistent with earlier Delphi-based complexity frameworks, which likewise stressed the need for a structured, theory-informed elicitation (Vidal et al., 2013), but it goes further by making the characteristics of complex systems an explicit input to the panel. The result that only the "Development Approach and Life Cycle" domain achieved significant concordance is itself informative. It suggests that experts most readily agree on complexity drivers associated with the chosen delivery approach and life-cycle strategy where the link between decisions and complexity is relatively tangible while their views diverge more widely on domains such as stakeholders, uncertainty or measurement, in which complexity is more context-dependent. This pattern is coherent with the broader literature, which reports persistent disagreement on the relative weight of complexity factors across studies and settings (Bakhshi et al., 2016; Lafhaj et al., 2024), and it reinforces the argument that national and sectoral context here, the unstable economic and administrative environment of Iranian construction must be considered when interpreting complexity (Ghaleb et al., 2022). Practically, the confirmed relationship between managing complexity and project success (Luo et al., 2017; Ma & Fu, 2020) means that a stable, PMBOK-7-aligned list of prioritised complexity factors gives managers a concrete tool for anticipating and mitigating complexity: it can inform risk registers, the selection of delivery approach, planning and control, and the alignment of project teams around a shared understanding of the project's complexity profile. This study proposed and applied a Conceptual-Delphi framework for identifying and prioritising the factors that generate complexity in civil projects, grounding the elicitation in the intrinsic characteristics of complex systems and organising the factors within the eight PMBOK 7 performance domains. A three-round panel reduced an initial pool of 160 factors to 55, of which 15 (27%) reached consensus; only the Development Approach and Life Cycle domain achieved significant concordance (Kendall's $W = 0.37$, $p < 0.01$), and the ratings were stable between the final two rounds. The main contribution is methodological: establishing a shared conceptual understanding before the Delphi rounds improves the validity and generalisability of the identified factors, and yields a quantitative, standard-aligned basis for prioritising complexity management. The study has limitations. The panel was drawn from a single national context (Iran), so the specific ranking of factors should be generalised with caution; the domain-level concordance was significant for only one domain, reflecting genuine diversity of expert opinion; and the quantitative prioritisation rests on expert judgement rather than on measured project outcomes. Future research could apply the framework in other countries and sectors to test its transferability, link the prioritised factors to measured project performance through longitudinal or case-based studies, and combine the Conceptual-Delphi list with multi-criteria or structural-modelling methods to quantify the interactions among the factors.

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HOW TO CITE THIS ARTICLE

Sajjadi, A., Jani, R., Fard Moradnia, S., Ghorbani.,M & Salami, E. (2026). A Conceptual-Delphi Framework for Identifying and Prioritising Complexity-Generating Factors in Civil Projects Based on the Intrinsic Characteristics of Complex Systems and Aligned with the PMBOK 7 Performance Domains. (e727077). International Journal of Urban Management and Energy Sustainability, ( ), e727077

DOI:10.22034/ijumes.2025.2039678.1250