International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 10 Issue: 11 | Nov - 2026 SJIF Rating: 8.659 ISSN: 2582-3930

Evaluating Critical Success Factors in Smart Construction Management Using the Relative Importance Index

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Abstract - This study ranks twelve critical success factor categories for smart construction management in high-rise projects using the Relative Importance Index (RII). The analysis uses aggregate responses from 50 construction professionals to a 47-statement, five-point questionnaire. The overall reliability coefficient was 0.921. Leadership ranked first (RII = 0.868), followed by technology infrastructure and interoperability (0.864), communication and collaboration (0.860), skills and training (0.848), and safety and risk management (0.840). All twelve categories exceeded 0.780. The technology group averaged 0.856, compared with 0.812 for the organisational group and 0.784 for finance. Frequency-based calculations reproduced the three leading indices. Discrepancies between frequency-derived dispersion and aggregate standard deviations, together with gaps in the available statistical outputs, limit conclusions about stakeholder differences, factor structure and effects on project performance. The ranking identifies where project teams can focus implementation planning, including leadership accountability, interoperable information systems, staff training and safety planning.

Key Words: Building Information Modelling, Critical Success Factors, High-Rise Buildings, Relative Importance Index, Smart Construction Management.

1. INTRODUCTION

Smart construction management integrates project information, digital coordination and site control to support decisions across design, procurement and execution. Building Information Modelling (BIM), connected sensors, digital dashboards and collaborative platforms create opportunities for faster information exchange. Their usefulness nevertheless depends on clear responsibilities, workforce competence, usable information and timely managerial decisions. Critical success factors (CSFs) provide a structured way to identify these enabling conditions and allocate managerial attention. Stakeholder-based prioritisation has established methodological value in sustainable construction management [1] and residential value management [2].

High-rise projects create a demanding setting for CSF evaluation. Multiple trades work on different floors while sharing cranes, hoists, storage areas and access routes. Design revisions can affect structural work, building services, façade installation and finishing sequences simultaneously. Delayed approvals or inconsistent information may therefore propagate across several activities. Research in Bangladesh demonstrates the relevance of finance, coordination and monitoring to construction management [3], while modular housing research extends the discussion to sustainable project delivery [4]. These studies support integrated evaluation while also showing that priorities depend on project and organisational context.

The present study addresses three technical questions: which of twelve CSF categories receives the highest perceived importance; how technology, organisation and finance compare under explicit grouping rules; and how far the available statistical outputs support conclusions beyond descriptive ranking. The objectives are to organise the 47 questionnaire statements, evaluate professional perceptions, calculate reproducible Relative Importance Index (RII) priorities, compare selected groups and translate the priorities into practical implementation measures. The analytical model uses aggregate survey results for 50 professionals. It evaluates perceived importance rather than direct changes in cost, duration, productivity or accident frequency.

2. RELATED WORK

2.1 Management sustainability and safety

Alawag et al. examined total quality management in industrialised building projects using 371 valid responses and PLS-SEM [5]. Their work connects quality implementation with enabling organisational conditions, whereas the present analysis concentrates on transparent priority scores. AlJaber et al. used stakeholder engagement and survey ranking to identify circular economy implementation priorities [6]. These findings support inclusion of leadership, resources, standards and sustainability, but their substantive objectives differ from smart construction readiness.

Buniya et al. combined exploratory factor analysis and structural modelling to study safety programme implementation in Iraq [7]. Chai et al. applied fuzzy DEMATEL to safety programmes in the regeneration of abandoned industrial buildings [8]. The latter study addresses interdependence between factors, which ordinary RII does not estimate. Alghuried evaluated sustainable construction management in Saudi Arabia through RII and AHP, identifying strategic planning, resource allocation, expertise and governance as contextually important [9]. Together, these studies justify treating safety, managerial commitment and regulatory support as substantive dimensions rather than optional additions to a technology-centred model.

2.2 Building information modelling and intelligent construction and information integration

Ottaviani et al. identified 18 BIM implementation factors across six dimensions and prioritised them using AHP with 31 construction professionals [10]. Their system-level approach emphasises strategy, processes, collaboration, training and technology integration. Dagou et al. examined emerging construction technologies using responses from 79 industry participants in Chad and exploratory factor analysis [11]. This empirical design differs from a purely conceptual technology review. Khan et al. used structural modelling to examine IoT adoption, safety monitoring, equipment management and efficiency on construction sites [12]. These studies reinforce

the need to consider implementation capability alongside technology availability.

Sun et al. reviewed integrated 5D BIM and grouped adoption factors through a technology–organisation–environment framework [13]. Demeke combined interviews and a survey of 135 professionals to rank success factors and discuss intelligent construction integration in Ethiopian road projects [14]. Wang and Chen examined BIM integration across the project lifecycle [15], while Parsamehr et al. reviewed BIM responses to schedule, cost, quality and safety challenges [16]. These contributions support information continuity and coordinated project control without implying that the same numerical rankings transfer to every construction market.

Xu et al. applied entropy weighting and TOPSIS to intelligent construction development across Chinese pilot cities [17]. Their unit of analysis is a city, whereas the current unit is professional perception. An et al. developed an intelligent construction management assessment system for prefabricated projects using AHP, entropy weights and cloud modelling [18]. Such maturity assessments can complement a priority ranking, but require additional indicators and calibration. The present study therefore retains RII as a simple ranking model and does not present it as a validated maturity index.

2.3 Recent evidence from 2025 and 2026

Nozari et al. synthesised 30 studies and identified recurring connections between digital strategy, coordination, innovation culture, enabling technologies and data analytics [19]. Their 2026 review also highlights limited attention to interoperability governance and long-term outcomes. Al-Ashmori et al. obtained 268 usable responses from Malaysian SMEs and found that early team participation, information availability and suitable tool selection support BIM implementation [20]. These findings suggest that firm size and resource conditions should shape the interpretation of digital construction priorities.

Wuni reviewed critical success factors for artificial intelligence implementation through systematic review and social network analysis [21]. Liu et al. examined BIM, IoT and GIS integration for construction resource monitoring, identifying interoperability, security, dynamic monitoring and user convenience as research concerns [22]. Manzoor et al. reviewed digital twin implementation and highlighted technology integration, sustainability, human factors and policy gaps [23]. These works expand the technology dimension while reinforcing the importance of organisational and information interfaces.

Yang et al. used interviews with 13 senior managers to examine digital transformation barriers and leadership competencies [24]. Ghosh and Karmakar reviewed 105 articles to map information and communication technologies across construction management functions [25]. Mahpour examined BIM–IoT–blockchain integration through a critical review of 124 papers [26]. Their contributions support staged integration and capability development; none establishes the statistical stability of the present sample's rank differences.

Song et al. connected risk management practices, stakeholder engagement and sustainable project performance [27]. Rao et al. examined circular economy motivators using 199 responses from Indian academic and construction participants, placing education and training among the leading priorities [28]. Zamil et al. combined value management, life-cycle costing and weighted evaluation in a tunnelling case study [29]. Montoya Villanueva et al. developed a CSF framework for BIM, machine learning and digital twins in Peruvian public infrastructure [30]. These recent studies connect technical tools with competence, governance, engagement and value-based decisions.

2.4 Research gap and contribution

The literature supports multi-dimensional implementation models but provides limited grounds for transferring a universal priority order to high-rise construction. Three distinctions remain necessary: technology adoption differs from effective use; perceived importance differs from measured delivery performance; and descriptive rankings differ from tested causal relationships. The current contribution is a twelve-category RII evaluation with explicit score definitions, complete aggregate results and an audit of numerical consistency. The analysis also identifies the participant-level information required to evaluate rank stability and stakeholder differences. It does not claim a new BIM geometry model, digital twin, trained AI system or structural simulation.

3. RESEARCH METHODOLOGY

3.1 Research design and evidence boundary

A quantitative cross-sectional questionnaire framework was used to evaluate CSF importance in high-rise construction management. The source dissertation provides aggregate outputs for N = 50, including professional profiles, item counts, reliability coefficients, statistical summaries and RII rankings. The analysis in this paper checks arithmetic that can be reconstructed from those outputs. Participant-level responses, survey dates, invitation totals, project identifiers, group codes and original SPSS files are unavailable in the analytical evidence package. Consequently, the paper does not estimate a response rate, sampling error, population prevalence or causal project effects. No random sampling procedure is specified.

The professional-category and experience tables in the case-study section are adopted because their counts sum to 50 and the designation chart agrees with them. A later respondent table contains conflicting entries and is not used to redefine the sample. Safety and vertical-logistics priorities are taken consistently from the complete twelve-factor ranking: 0.840 and 0.808 respectively. The conceptual framework and all eight study figures are retained. The building image supplies project context; the available evidence does not establish a calibrated structural, BIM or simulation model for that building.

3.2 Instrument and construct specification

The questionnaire includes eleven categories with four statements each and sustainability with three statements, producing 47 statements overall. Ratings range from 1, very low importance, to 5, very high importance. A factor score should be defined as the participant's mean across its constituent statements. This preserves the five-point range despite unequal item counts. The precise rule used to generate the published frequency rows is unspecified; those rows are therefore presented as an arithmetic demonstration rather than a substitute for the complete item dataset. Table 1 defines the category structure and the intended measurement content.

Table -1: CSF categories and questionnaire structure

No.	Category	Items	Measurement focus
1	Top Management Support and Leadership	4	Management commitment and decisions
2	Organizational Strategy and Readiness	4	Strategy and process readiness
3	Financial Capability and Resource Availability	4	Funding and resource continuity
4	Technology Infrastructure and Interoperability	4	Digital systems and interoperability
5	Skills, Training and Technology Awareness	4	Competence training and awareness
6	Communication and Collaboration	4	Information sharing and coordination
7	Sustainability and Environmental Integration	3	Green practices and environmental monitoring
8	Policy, Standards and Regulatory Support	4	Institutional support and compliance
9	Vertical Logistics and Material Handling	4	Vertical movement and material flow
10	Structural and Design Complexity	4	Design interfaces and complexity
11	Safety and Risk Management	4	Safety planning and risk control
12	Site Constraints and Environment	4	Access space weather and site conditions

Total statements = 47. Ratings: 1 very low; 2 low; 3 moderate; 4 high; 5 very high.

Interpretation

Table 1 separates twelve CSF categories and shows how 47 statements cover the study's measurement framework. Eleven categories contain four statements, while sustainability contains three. This difference makes a category mean preferable to an unadjusted sum when categories are compared. Leadership, technology, communication and training describe enabling capabilities, whereas safety, logistics and site conditions connect those capabilities with execution requirements. Policy and organisational readiness address governance and process alignment. Finance concerns the resources needed to maintain implementation. The table defines measurement content; it does not establish discriminant validity or a latent factor structure. Four similarly worded statements may correlate strongly without capturing a distinct construct. Reliable scoring therefore requires item identifiers, response coding and an explicit aggregation rule. The category structure supports transparent RII calculation and helps future researchers reproduce the questionnaire. It also prevents technology adoption from being treated as a software purchase detached from people and management processes.

3.3 Conceptual model and study context

The conceptual model links management commitment, technology, communication, competence, safety, logistics, sustainability and project control. Its arrows express a management rationale rather than fitted paths or estimated causal effects. The analytical contribution is the RII calculation model and its ranking outputs. A high-rise context is useful because drawing coordination, floor sequencing, material handling and work at height require decisions across these dimensions.

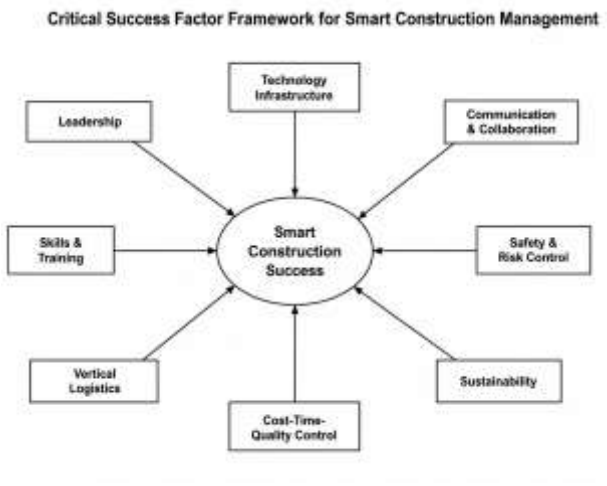


Fig -1: Conceptual CSF framework for smart construction management

Figure 1 presents the study's conceptual model of smart construction success. Leadership, technology infrastructure, communication, training, safety, logistics, sustainability and project control converge on a shared management outcome. The arrangement communicates that digital capability depends on complementary organisational and operational conditions. For high-rise projects, this integration is relevant because design approvals, material movement and safe access involve several teams simultaneously. The arrows indicate conceptual relationships and contain no estimated coefficients. They therefore support factor selection and interpretation rather than causal inference. The model also includes cost, time and quality as management objectives, although separate delivery measurements are unavailable for the current sample. Its practical use is to organise review responsibilities and identify missing implementation capabilities. The empirical component of the paper evaluates perceived category importance through RII, not the strength of each arrow. Later validation should define independent performance indicators and test whether the proposed relationships hold across different projects.



Fig -2: Research methodology flowchart

Figure 2 preserves the research sequence from problem identification to final recommendations. Literature screening and variable selection precede questionnaire design, ensuring that the survey addresses construction management issues rather than isolated technologies. Data collection is followed by reliability assessment, descriptive analysis and RII calculation. Ranking and interpretation then translate numerical scores into management priorities. The sequence is suitable for a descriptive cross-sectional study because all respondents evaluate the same importance scale. However, a flowchart describes intended analytical order and does not independently verify recruitment, item coding or statistical execution. For this paper, arithmetic checks were added to the interpretation stage to examine inconsistencies in the aggregate outputs. The figure should therefore be read alongside the explicit equations and evidence boundaries in the methodology. Reproducing the full workflow requires the completed response matrix, factor definitions, missing-data rules and original analysis settings. These materials would also support sensitivity checks and stronger validation.



Fig -3: High-rise building context included in the study dissertation

Figure 3 provides the high-rise building context used to motivate the construction management problem. Repeated floors, numerous façade interfaces and building service requirements create potential coordination demands across design and execution teams. Such conditions explain why leadership, information exchange, workforce competence and logistics were included in the questionnaire. The image is an architectural view and does not establish the building's height, structural system, location, completion status or actual use of smart construction technologies. It also does not demonstrate that the 50 respondents worked on this development. Consequently, the figure supports contextual explanation rather than project-level performance validation. No cost, schedule, safety or productivity outcome is calculated from the image. A fully specified case study would require project identification, drawings, execution records and details of technology deployment. Within the present paper, the analytical model remains the survey-based RII framework, while the building view provides visual context for discussing high-rise implementation challenges.

Figure provenance: Figures 1–8 are retained from the supplied Stage II dissertation. The original building image contains no verifiable project identifier or image credit; attribution and reuse rights require author verification before publication.

3.4 Analytical model and calculation procedure

For respondent i, category j and statement q, let x_{ijq} denote the importance rating and m_j denote the number of statements in that category. The category score z_{ij} is the arithmetic mean of its statements. Category means and RII are related directly: $RII_j = mean_j/5$. This relationship means that RII and mean rankings contain the same order information. For a single rating per respondent, frequency counts n_jr yield the same RII through a weighted sum. When category means contain fractional values, their underlying item scores must be used instead of forcing them into integer frequency bins.

The denominator is $A \times N = 5 \times 50 = 250$ for one effective five-point category score per respondent. For pooled item ratings, the corresponding denominator is $5 \times N \times m_j$. Mixing these denominators would bias comparisons when categories have unequal numbers of statements. RII lies between 0.2 and 1.0 for complete responses scored from 1 to 5; zero is outside this scale's attainable range. Factors are ordered by descending RII. For the selected group comparison, technology combines infrastructure and training; organisation combines readiness and policy; finance is a single category.

$$z_{ij} = \frac{\sum_{q=1}^{m_j} x_{ijq}}{m_j} \quad (1)$$

$$RII_j = \frac{\sum_{i=1}^{N} z_{ij}}{5N} = \frac{mean_j}{5} \quad (2)$$

$$RII_j = \frac{\sum_{r=1}^{5} r\, n_{jr}}{5N} \quad (3)$$

$$RII_g = \frac{\sum_{j \in g} RII_j}{|g|} \quad (4)$$

$$t_j = \frac{mean_j - 3}{\frac{s_j}{\sqrt{N}}};\ df = N - 1 \quad (5)$$

Here i identifies respondents; j identifies categories; q identifies statements; r is a scale value; n_jr is its frequency; s_j is a sample standard deviation; and $|g|$ is the number of categories in group g. Equations (1)–(4) define the scoring model, and (5) supports the aggregate t-test consistency check.

3.5 Statistical assessment and verification rules

Cronbach's alpha assesses internal consistency, while normality tests screen score distributions. Correlations describe associations between measured scores. ANOVA and one-sample t tests are retained as aggregate statistical outputs, with their interpretation restricted by missing variable definitions and participant data. Kaiser–Meyer–Olkin (KMO) and Bartlett statistics are presented without claiming a completed factor extraction. Values printed as 0.000 are expressed as $p < 0.001$. Arithmetic checks include frequency totals, weighted scores, mean-to-RII conversion, ANOVA sums and t values reconstructed from displayed means and standard deviations.

No bootstrap intervals, nonparametric sensitivity tests, missing-value corrections or post hoc contrasts are fabricated. With individual data, a defensible extension would compare stakeholder groups through appropriately specified robust or ordinal methods, evaluate correlations using rank-based sensitivity checks, and bootstrap factor ranks. The current ranking remains a descriptive assessment of professional perceptions.

4. RESULTS AND DISCUSSION

4.1 Respondent profile

Table -2: Professional and experience profile of the analytical sample

Panel	Category	Frequency	Percentage
Professional category	Project Managers / Planning Managers	8	16%
Professional category	Site Engineers / Planning Engineers	18	36%
Professional category	Contractors / Sub-contractors	10	20%
Professional category	Consultants / Architects / Designers	7	14%
Professional category	Safety, Quality and MEP Personnel	7	14%
Experience	0-5 years	12	24%
Experience	6-10 years	17	34%
Experience	11-15 years	11	22%
Experience	Above 15 years	10	20%

Each panel totals N = 50 and 100%; the panels describe the same participants.

Table 2 describes the professional and experience composition of the 50-person analytical sample. Engineers form the largest professional group at 36%, followed by contractors at 20% and managers at 16%. Consulting and specialist personnel each contribute 14%. The profile includes both decision-making and execution perspectives, but equal stakeholder representation is absent. Experience is concentrated in the six-to-ten-year category at 34%, while 42% have more than ten years. This composition suggests substantial practical exposure alongside early-career input. Nevertheless, the distribution does not establish statistical representativeness because the recruitment frame and selection probabilities are unspecified. Each respondent contributes two classifications, so the professional and experience panels describe the same participants rather than separate samples. The later contradictory respondent table is excluded in favour of these internally consistent counts. Further analysis should retain participant-level role and experience codes to assess whether priorities differ systematically between categories without attributing untested preferences to particular groups.

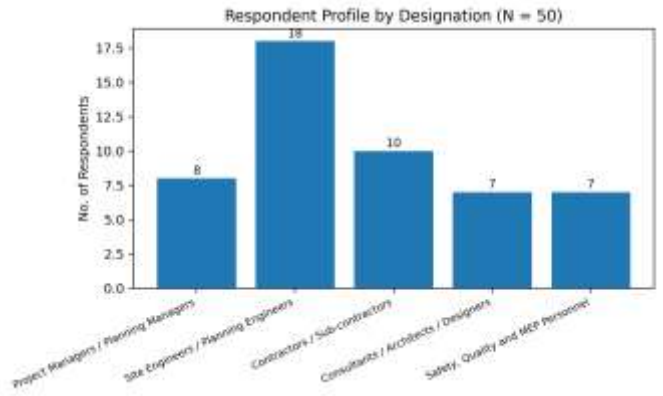


Fig -4: Respondent profile by designation for N = 50

Figure 4 visualises the designation counts summarised in Table 2. The tallest bar corresponds to engineers, with 18 participants, making their perspective influential in the pooled ranking. Contractors contribute ten responses, managers eight, and the consulting and specialist categories seven each. Because every participant receives equal weight in the RII calculation, categories with more respondents contribute more observations to the overall score. The chart therefore helps readers understand the composition behind the priorities. It does not show importance ratings, within-group variability or agreement between professions. Differences in bar height reflect sample counts rather than professional influence on project outcomes. The chart also confirms that the analysis uses several professional categories, resolving the inconsistent later description of all respondents as managers. Role-specific rankings would require separate response summaries or participant data. Until those are available, the pooled results should be interpreted as priorities of this combined sample rather than profession-specific conclusions.

4.2 Reliability and distribution screening

Table -3: Reliability statistics

Scale	No. of Items	Cronbach's Alpha
Overall CSF Questionnaire	47	0.921
Technology-related CSFs	8	0.887
Leadership and Collaboration CSFs	8	0.902
Organizational and Financial CSFs	8	0.864

Broad interpretation guides: $\alpha \geq 0.70$ acceptable; $\alpha \geq 0.80$ good; $\alpha \geq 0.90$ excellent. These guides do not establish construct validity.

Table 3 presents the internal consistency coefficients available for the overall instrument and three selected dimensions. The overall alpha of 0.921 indicates strong covariance among the 47 statements. Leadership and collaboration achieve 0.902, technology achieves 0.887, and organisation with finance achieves 0.864. These values support further examination of the questionnaire's measurement behaviour, but they do not establish that all categories measure one construct or that each category is valid. Alpha is influenced by item number and similarity of wording, so a high coefficient may partly reflect repeated content. The three subgroup scales contain eight statements each and do not exhaust the full instrument. Their item membership should accompany any reproducible analysis. Conventional thresholds of 0.70, 0.80 and 0.90 describe acceptable, good and excellent consistency only as broad guides. The current coefficients remain aggregate outputs because item-level covariance matrices are unavailable. Future validation should examine category reliability and construct structure separately.

Table -4: Normality screening probabilities

Variable / CSF Group	Kolmogorov-Smirnov Sig.	Shapiro-Wilk Sig.
Leadership and Management Support	0.041	0.032
Technology and BIM Readiness	0.052	0.046
Communication and Collaboration	0.063	0.057
Safety and Risk Management	0.038	0.029
Overall CSF Score	0.071	0.064

Only probabilities are available; the corresponding test statistics and score definitions are absent.

Table 4 shows mixed distribution screening results for the five score groups. Leadership, technology and safety have Shapiro–Wilk probabilities below 0.05, whereas

communication and the overall score exceed that threshold. These outcomes indicate that a single normality description would oversimplify the available evidence. They do not establish that scores with larger probabilities follow an normal distribution. Likert ratings are bounded and may cluster toward high importance, which can influence such tests. The descriptive RII ranking does not require normality because it follows directly from weighted ratings. Inferential tests need additional attention to score definitions, independence and residual behaviour. The table lacks test statistics and detailed score construction, preventing a full assessment of distribution shape. Histograms, quantile plots and participant-level sensitivity checks would strengthen interpretation. For this paper, normality screening informs caution around supplementary tests without changing the transparent arithmetic of the factor means or their associated RII values and rankings.

4.3 Associations and factorability diagnostics

Table -5: Pearson correlations between major score groups

Variable	Leadership	Technology	Communication	Safety	Overall success
Leadership	1.000	0.612	0.684	0.571	0.701
Technology	0.612	1.000	0.646	0.538	0.693
Communication	0.684	0.646	1.000	0.552	0.721
Safety	0.571	0.538	0.552	1.000	0.628
Overall Project Success	0.701	0.693	0.721	0.628	1.000

Source annotation: all off-diagonal coefficients significant at the 0.01 level. The separate overall-success scale is unspecified.

Interpretation

Table 5 contains positive correlations among leadership, technology, communication, safety and the score labelled overall project success. Communication has the largest association with that outcome, at 0.721, followed by leadership at 0.701 and technology at 0.693. Leadership and communication also correlate at 0.684. These patterns are compatible with interconnected management capabilities, but they do not demonstrate causal effects or independent contributions. Shared respondents and similarly framed questionnaire items may increase associations. The outcome scale is not separately defined, so overlap with predictor items cannot be evaluated. The original significance markings are retained as aggregate annotations rather than reproduced tests. Ordinal sensitivity analysis and confidence intervals require the underlying responses. A future model should specify outcome items, examine construct overlap and use objective delivery indicators where possible. The current matrix supports a descriptive discussion of association only, while the RII results remain the principal basis for prioritising the twelve CSF categories.

Table -6: KMO and Bartlett factorability diagnostics

Test	Value
Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.704
Bartlett's Test of Sphericity - Approx. Chi-Square	568.420
df	276
Sig.	< 0.001

Bartlett df = 276 corresponds to 24 variables, using df = p(p − 1)/2; this does not match 47 items or twelve category scores.

Table 6 retains the factorability statistics while identifying a key dimensional inconsistency. The KMO value of 0.704 suggests some shared variance, and the Bartlett probability is below 0.001. However, Bartlett's degrees of freedom equal p times p minus one divided by two. A value of 276 therefore corresponds to 24 analysed variables, which differs from both the 47 statements and twelve categories described in the instrument. The variable set used for this output is unspecified. Consequently, the statistics do not validate factor extraction for the questionnaire. The table also lacks communalities, extraction criteria, eigenvalues, rotated loadings and a factor solution. With 50 participants, the adequacy of any proposed solution would depend strongly on these missing details. The appropriate interpretation is a preliminary aggregate diagnostic with unresolved variable mapping. Further work should identify the analysed variables and evaluate sampling adequacy before making claims about the instrument's underlying dimensional structure or validity.

4.4 Relative Importance Index calculation and complete factor ranking

Table -7: Frequency-based RII arithmetic and dispersion check

Factor	1	2	3	4	5	ΣW	RII	SD from frequencies
Leadership	1	2	5	13	29	217	0.868	0.961
Technology	1	2	6	12	29	216	0.864	0.978
Communication	1	2	6	13	28	215	0.860	0.974

Each frequency row totals 50. SD values are recalculated from the displayed frequencies and do not replace the aggregate ranking SD values.

Table 7 reconstructs the leading RII calculations from the available rating frequencies. Each row contains 50 responses, and the weighted sums of 217, 216 and 215 produce indices of 0.868, 0.864 and 0.860. Their means also agree with the complete ranking table. Dispersion provides a different finding: frequency-derived sample standard deviations are approximately 0.961, 0.978 and 0.974, exceeding the corresponding aggregate standard deviations of 0.610, 0.660 and 0.640. The difference may arise from distinct scoring units, such as category averages compared with single ratings, but the available evidence does not specify that distinction. These rows therefore validate weighted-score arithmetic while leaving the source of dispersion unresolved. The calculation should not be extended into reconstructed participant data. To reproduce uncertainty estimates, researchers need the actual category scores and item aggregation rules. The audit preserves the ranking evidence while preventing incompatible frequency and dispersion summaries from being treated as one verified dataset.

Table -8: Complete descriptive statistics and RII ranking

Rank	Critical Success Factor	Mean	SD	RII
1	Top Management Support and Leadership	4.340	0.610	0.868
2	Technology Infrastructure and Interoperability	4.320	0.660	0.864
3	Communication and Collaboration	4.300	0.640	0.860
4	Skills, Training and Technology Awareness	4.240	0.680	0.848
5	Safety and Risk Management	4.200	0.700	0.840
6	Structural and Design Complexity	4.140	0.730	0.828
7	Policy, Standards and Regulatory Support	4.100	0.750	0.820

Rank	Critical Success Factor	Mean	SD	RII
8	Vertical Logistics and Material Handling	4.040	0.770	0.808
9	Organizational Strategy and Readiness	4.020	0.780	0.804
10	Site Constraints and Environment	3.980	0.810	0.796
11	Sustainability and Environmental Integration	3.960	0.820	0.792
12	Financial Capability and Resource Availability	3.920	0.840	0.784

Safety RII = 0.840 and vertical logistics RII = 0.808 are used consistently from this complete ranking.

Interpretation

Table 8 provides the complete ordering of the twelve critical success factor categories. Leadership leads at 0.868, closely followed by technology at 0.864 and communication at 0.860. Training and safety complete the leading five. Finance ranks last at 0.784, although its mean of 3.920 remains above the neutral rating of three. Every category mean equals five times its RII, confirming internal consistency between these two columns. The total RII spread is only 0.084, indicating broadly favourable importance ratings rather than sharply separated priorities. Differences of 0.004 among the top three equal one weighted-score point when the denominator is 250. Their exact ordering may therefore be sensitive to small response changes. Standard deviations are retained from the aggregate ranking and should not be conflated with those reconstructed from example frequencies. The table supports descriptive prioritisation, while rank confidence and stakeholder-specific differences require participant-level analysis before stronger comparative conclusions can be established.

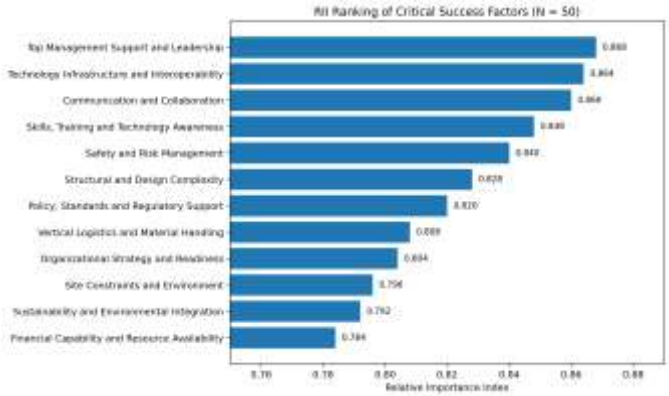


Fig -5: Complete RII ranking of twelve CSF categories for N = 50

Figure 5 displays the full ranking in descending order, allowing the CSF pattern to be assessed. Leadership, technology and communication form a closely spaced leading cluster, while training and safety follow with lower values. The lower portion includes organisational readiness, site conditions, sustainability and finance. Their positions indicate relative ordering within the selected list and do not imply that these requirements can be neglected. The horizontal layout makes long category names readable and connects directly with Table 8. The plotted axis begins above zero, which visually enlarges the modest numerical differences. Readers should therefore use the RII labels when comparing priorities. Error bars are absent because the individual responses needed for uncertainty estimation are unavailable. The figure communicates point estimates rather than statistically separated groups. Its practical value is to identify categories for management review, with the first three treated as a priority cluster rather than different levels of importance.

4.5 Group comparisons and leading priorities

Table -9: Explicit technology organisational and financial group comparison

CSF Group	Included Factors	Mean RII	Rank
Technology-related CSFs	Technology Infrastructure; Skills, Training and Technology Awareness	0.856	1
Organizational CSFs	Organizational Strategy and Readiness; Policy and Standards	0.812	2
Financial CSFs	Financial Capability and Resource Availability	0.784	3

RIIg is an unweighted mean of category indices: technology = (0.864 + 0.848)/2; organisation = (0.804 + 0.820)/2; finance = 0.784.

Table 9 compares three explicitly defined category groups. Technology combines infrastructure with training, yielding an average RII of 0.856. Organisation combines readiness with policy and standards, yielding 0.812. Finance consists of one category at 0.784. The technology–organisation difference is 0.044, while technology exceeds finance by 0.072. These are descriptive contrasts between group definitions, not outcomes of a statistical comparison. The groups also differ in the number and content of their constituent categories. Training contributes to the technology average even though it contains human capability content, illustrating why the grouping rule must remain visible. Other classifications may produce different group summaries. Equal category weighting is used here; neither item weighting nor respondent-level group variability is available. The results suggest prioritising digital capability together with workforce preparation while maintaining organisational and financial support. They do not establish that technology investment produces greater delivery benefits or requires a larger budget than other capabilities.

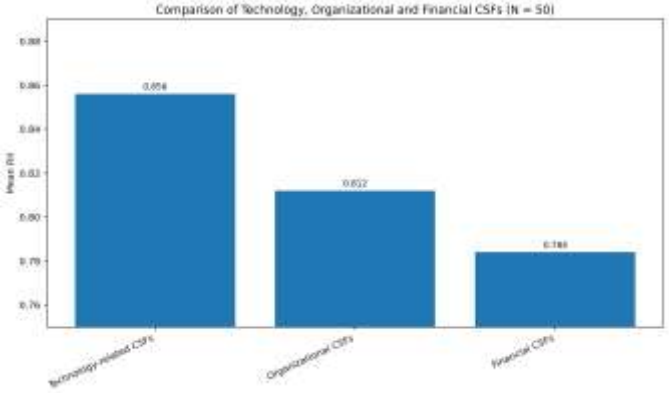


Fig -6: Technology organisational and financial group RII comparison

Figure 6 visualises the three-group comparison calculated in Table 9. Technology-related categories have the highest mean RII at 0.856, followed by organisation at 0.812 and finance at 0.784. The plot makes the direction of these descriptive contrasts easy to inspect. Technology includes training as well as infrastructure, so its bar represents a combined implementation capability rather than hardware or software alone. Organisational readiness and policy comprise the second bar, while finance represents a single category. Because group composition differs, the display should not be interpreted as a balanced experimental comparison. The vertical axis is truncated, which accentuates the apparent separation; the numerical labels provide the appropriate basis

for comparison. No confidence intervals or paired significance tests accompany the bars. Their purpose is managerial communication of sample priorities. Future analysis should specify mutually interpretable group definitions, calculate participant-level composite scores and assess how alternative weighting rules affect the resulting group order.

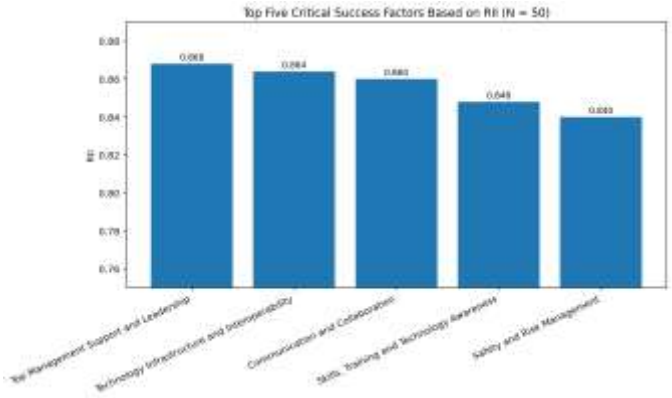


Fig -7: Five highest-ranked critical success factors

Figure 7 isolates the five leading categories to show the integrated capability package suggested by the ranking. Leadership scores 0.868, technology 0.864, communication 0.860, training 0.848 and safety 0.840. Their proximity indicates that successful implementation planning should consider them together. A management sponsor can authorise resources, interoperable systems can support information exchange, collaboration can resolve interfaces, training can enable use and safety controls can guide execution. These operational mechanisms are interpretations of the categories rather than measured effect sizes. The chart does not establish that improving any one category will produce a specified schedule or cost benefit. Its truncated axis also magnifies the small differences between bars. The figure is therefore best used to organise a coordinated review agenda instead of assigning rigid investment percentages. The remaining seven categories retain substantial importance and should remain within the implementation plan, particularly where local resource, regulatory or logistical deficiencies create immediate constraints.

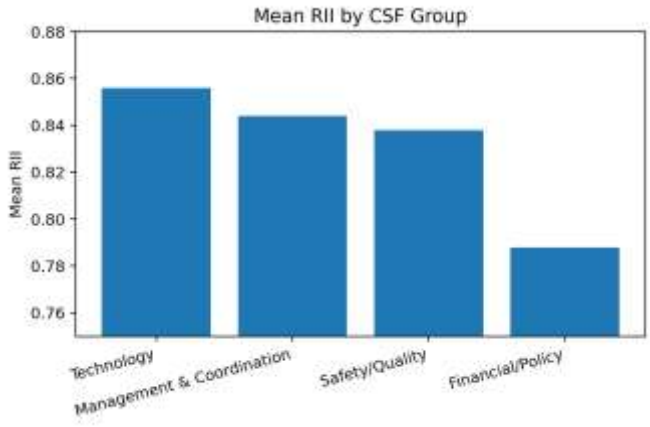


Fig -8: Alternative grouped RII display with unspecified membership rules

Figure 8 preserves an alternative grouped summary from the source dissertation. It displays technology, management and coordination, safety and quality, and finance and policy as labels. Technology is visually highest, with the remaining bars lower. Unlike Table 9, the source does not supply complete membership rules or calculations for these four groups. Several labels also combine concepts measured in different categories. The displayed values therefore lack a reproducible mapping to the twelve-factor ranking. This figure is retained to preserve the study's visual results, but it is not used to test group differences or validate a latent structure. The auditable three-group calculation remains Table 9 and Fig. 6. Future analysis should define each composite, specify equal or differential weights and provide participant-level group scores. Only then would a direct comparison with these bars be meaningful. The visual reinforces integration across capabilities while leaving the numerical interpretation of this alternative grouping unresolved.

4.6 Stakeholder comparison

Table -10: Aggregate one-way ANOVA output

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.275	3	1.425	3.502	0.023
Within Groups	18.722	46	0.407		
Total	22.997	49			

F(3,46) = 3.502 implies four groups; the respondent profile contains five professional categories. Group mapping and the dependent score need verification.

Table 10 retains the one-way ANOVA summary and checks its internal arithmetic. The between-group mean square is 4.275 divided by three, giving 1.425. The within-group mean square is 18.722 divided by 46, approximately 0.407. Their ratio agrees with F = 3.502 after rounding, and the probability is approximately 0.023. The unresolved issue concerns group definition: between-group degrees of freedom equal three, implying four groups, while the professional profile contains five categories. No mapping explains a merger or exclusion. The dependent score is also insufficiently specified. Consequently, the table supports the numerical consistency of this four-group output but not an unqualified conclusion about all five professions. It cannot establish which groups differ because group means and post hoc contrasts are absent. The result should remain provisional until participant codes and the original analysis specification are available. Any profession-specific management recommendation needs additional evidence rather than interpretation of the omnibus probability alone.

4.7 Evaluation of study propositions

Table -11: Evidence status of the three study propositions

Code	Proposition	Available evidence	Interpretation status
P1	Stakeholder groups differ	F = 3.502; p = 0.023	Provisional; four-group coding unresolved
P2	Technology group scores higher	0.856 > 0.812 > 0.784	Descriptive ordering supported; no significance test
P3	Leadership and collaboration are leading priorities	Leadership 0.868 rank 1; communication 0.860 rank 3	Ranking supported; causal influence untested

P1–P3 identify propositions; causal wording is not treated as an established finding.

Table 11 separates the statistical status of the study propositions. The stakeholder-difference proposition has an aggregate ANOVA probability below 0.05, but its group structure remains unresolved. The technology-priority proposition agrees descriptively with the three defined averages, without a participant-level significance test.

Leadership and collaboration occupy first and third positions, supporting their placement among the leading priorities. Their ranking does not demonstrate that they positively cause project success or change other CSF scores. This distinction prevents acceptance language from overstating the available evidence. A proposition about ordering is different from a proposition about association or causal influence. For testing, researchers should define outcomes, specify stakeholder codes and retain the covariance structure of repeated ratings. The table also preserves the leadership and communication scores previously shown in a separate comparison. Overall, descriptive support is strongest for the priority ordering, whereas inferential and causal propositions require additional data and a reproducible analytical specification.

4.8 One-sample testing consistency check

Table -12: One-sample t values against the neutral value of three

Score group	Mean	SD	Source t	Recalculated t	df	Two-sided p
Leadership and Management Support	4.34	0.610	15.54	15.53	49	< 0.001
Technology and BIM Readiness	4.32	0.660	14.12	14.14	49	< 0.001
Communication and Collaboration	4.30	0.640	14.36	14.36	49	< 0.001
Safety and Risk Management	4.20	0.700	12.97	12.12	49	< 0.001
Financial Capability and Resources	3.92	0.840	9.48	7.74	49	< 0.001

Recalculated statistics use the displayed mean, ranking SD and N = 50. The source output also prints p = 0.000 for every row; this means p < 0.001.

Table 12 compares the one-sample t values in the aggregate output with values reconstructed from the displayed means and standard deviations. Using N = 50 and a neutral value of three, the calculation is the mean difference divided by its standard error. Leadership reproduces 15.53, closely matching 15.54 after rounding. Technology gives 14.14 compared with 14.12, and communication gives 14.36 in both calculations. Safety gives 12.12 rather than 12.97, while finance gives 7.74 rather than 9.48. These differences require clarification of the scores or dispersion values used. All reconstructed statistics nevertheless exceed the neutral benchmark under the stated parametric model, with two-sided probabilities below 0.001. That result concerns perceived importance relative to three and does not demonstrate real project benefits. The calculations are consistency checks on aggregate summaries, not a replacement for analysis of individual responses. Distributional sensitivity and score construction remain necessary before presenting inferential conclusions from these comparisons.

4.9 Overall verification of the analytical outputs

Table -13: Consolidated reproducibility and verification summary

Output	Numerical evidence	Status
RII calculation	Leading frequencies total 50; weighted sums and indices agree	Arithmetic verified
Complete ranking	Mean = 5 × RII for all twelve categories	Arithmetic verified
Group means	Technology 0.856; organisation 0.812; finance 0.784	Arithmetic verified
Reliability	Overall α = 0.921; selected subscales 0.864–0.902	Aggregate output; covariance unavailable
Normality	Mixed probabilities around 0.05	Aggregate output; score definitions incomplete
Correlation	Positive coefficients from 0.538 to 0.721	Aggregate output; outcome definition incomplete
Factorability	KMO 0.704; Bartlett χ^2 568.420; df 276; $p < 0.001$	24-variable mapping unresolved
ANOVA	$F(3,46) = 3.502$; $p = 0.023$	Arithmetic consistent; group coding unresolved
One-sample testing	All recalculated $p < 0.001$; selected t values differ	Dispersion and scoring need verification

Interpretation

Table 13 consolidates what the available evidence verifies and what remains unresolved. Frequency totals, leading weighted scores, mean-to-RII conversions and selected group averages are arithmetically reproducible. Reliability coefficients, distribution tests and correlations are retained as aggregate outputs because their underlying responses are unavailable. The factorability statistics require clarification of the 24-variable analysis implied by Bartlett's degrees of freedom. ANOVA arithmetic is consistent, while stakeholder group coding remains uncertain. One-sample testing contains differences between selected published statistics and calculations from the ranking summaries. The table therefore prevents distinct checks from being combined into a blanket claim of statistical validation. Its purpose is to establish a reproducibility boundary for the technical paper. The ranking can inform management discussion within the sample, but generalisation, measurement validation and causal attribution require further evidence. Providing anonymised participant scores, item identifiers, analysis syntax and original output would resolve these issues and support an independent technical assessment.

4.10 Integrated technical discussion

The five leading categories combine organisational authority with usable information and competent execution. Leadership can establish decision rights and resources; interoperability can improve exchange between design and construction systems; communication can support timely issue resolution; training can enable practical use; and safety planning can control high-risk activities. These mechanisms are consistent with the BIM implementation framework of Ottaviani et al. [10], the leadership evidence of Yang et al. [24] and the resource-monitoring review of Liu et al. [22]. Their plausibility does not establish that the present RII scores predict actual delivery performance.

The narrow leading margins require particular care. Leadership exceeds technology by 0.004, and technology exceeds communication by the same amount. A single one-point change in one effective category rating changes RII by 1/250 = 0.004. Thus, the first three positions should be treated as a close priority cluster rather than a precisely separated hierarchy. The aggregate data permit this sensitivity calculation but do not permit confidence intervals or probabilities of each rank.

Finance has the lowest RII, 0.784, yet its mean of 3.920 remains above the neutral scale value. A lower relative position does not establish that funding is sufficient, unimportant or readily replaceable. Gunduz and Almuajebh [1] and Datta et al. [3] place substantial emphasis on financial and managerial issues in their settings. Differences across studies may arise from participants, project conditions, instruments and economic context. Cross-study consistency should therefore be assessed at the level of mechanisms rather than identical numerical rank positions.

4.11 Practical implementation model

A practical application sequence begins with a named senior sponsor and a responsibility matrix for design approvals, resource decisions and unresolved coordination issues. The second stage establishes a common information environment, revision control and clear exchange requirements between participating teams. The third stage links role-specific training to the actual digital tasks expected on site. The fourth stage integrates lifting plans, work-at-height controls, logistics sequencing and risk reviews with short-term work planning. The final stage reviews whether these changes improve defined indicators such as approval turnaround, unresolved design issues, rework, equipment waiting time and inspection closure. These indicators are proposed for future field evaluation; no numerical improvements are claimed here.

The ranking can guide the order of managerial review, but budget allocation requires evidence of current capability gaps, implementation cost and risk exposure. High importance combined with strong existing capability may need less immediate spending than a lower-ranked category with a serious deficiency. The RII scores therefore support structured discussion and baseline diagnostics. They should be combined with contractual obligations, minimum safety controls and project-specific constraints before investment decisions are made.

4.12 Limitations and reproducibility

The principal limitation is the absence of the participant-level dataset. Internal consistency, correlations and inferential tests cannot be independently reproduced from aggregate tables alone. The five-category respondent profile conflicts with the four-group ANOVA degrees of freedom. The Bartlett degrees of freedom correspond to 24 variables, while the instrument contains 47 statements and twelve categories. Several displayed t values disagree with direct reconstruction from the ranking table's standard deviations. These issues restrict inferential interpretation and require the original variable map and statistical output.

Additional limitations include the small sample, an unspecified recruitment procedure, unavailable survey dates and geographical boundaries, and possible common-method response effects. The project image does not establish building geometry, construction progress or technology deployment. The outcome labelled overall project success lacks a separate scale definition. The evidence therefore supports prioritisation within this analytical sample, with broader transfer requiring independent surveys and project performance measures. Ethical approval, participant consent and data-sharing arrangements must be supplied by the study team before journal submission if required by the chosen venue.

5. CONCLUSIONS

This study prioritised twelve critical success factor categories for smart construction management using aggregate outputs for 50 professionals and a 47-statement instrument. Leadership ranked first at 0.868, followed by technology infrastructure at 0.864, communication at 0.860, training at 0.848 and safety at 0.840. Finance ranked twelfth at 0.784, indicating lower relative priority while retaining a mean above the neutral point. The selected technology grouping averaged 0.856, organisation averaged 0.812 and finance remained 0.784. The overall internal consistency coefficient was 0.921. The RII arithmetic and group averages are reproducible from the available summaries. However, the small differences between the leading categories, conflicting group definitions and inconsistent dispersion statistics limit stronger claims. Stakeholder differences, latent factor structure and causal project benefits remain unresolved. The practical contribution is a transparent ranking model that connects leadership accountability, interoperable information, training, communication and safety with project review. Future validation should retain individual responses, specify composite scoring and stakeholder codes, test rank stability and link implementation capability to independently measured cost, schedule, quality and safety outcomes.

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