

A Structural-Relational Taxonomy for Integrating Safety and Quality Cost Components for Indonesian Public Apartment Construction: A Validation Study

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Keywords:

Cost Of Safety; Cost of Quality;
Domain Mapping Matrix;
Integrated Cost Breakdown
Structure; Public Apartment
Construction; Content Validity.

Abstract

Safety and quality costs are often managed separately in construction projects, although both domains involve shared resources related to planning, training, inspection, supervision, and documentation. This separation may result in duplicated budgeting, overlooked cost components, and limited expenditure traceability. This study aimed to develop and validate a structural-relational taxonomy for integrating safety and quality cost components in Indonesian public apartment construction. A qualitative, instrument-based, and artifact-oriented research design was employed. An initial inventory of 70 cost components was evaluated by six experts with 15–30 years of professional experience using the item-level content validity index. The retained components were paired and classified based on shared resources, outputs, and functions. The validation process retained 30 components, consisting of 20 safety-cost components and 10 quality-cost components, which generated 200 cross-domain relationships. The mapping identified 185 independent, 10 complementary, and five partial relationships, with no full relationships identified. The overlapping relationships were primarily concentrated in planning and documentation, inspection and appraisal, and training activities. These relationships were subsequently transformed into a 32-component cost breakdown structure. The findings demonstrate that integration should be implemented selectively rather than universally. Partial relationships should integrate only shared resources, complementary relationships should be coordinated while maintaining separate budgets, and independent components should remain separate to prevent double counting and maintain accountability.

INTRODUCTION

Safety and quality are often managed as separate responsibilities in construction projects. Safety is generally associated with accident prevention, occupational health, emergency response, and compliance with construction safety management requirements. Quality is generally associated with conformance to specifications, inspection, testing, documentation, and corrective actions. This separation is administratively convenient; however, it does not fully reflect actual project execution practices (Ajslev et al., 2022; Andreassen et al., 2015; Richards & Smith, 2016; Stål & Corvellec, 2022; Williams, 2021). At the field level, the same planning meetings, method statements, supervision routines, toolbox meetings, inspection activities, and document-control processes often support both safety and quality objectives.

The issue becomes more important when the 2 domains are translated into cost estimates. Cost of Safety (CoS) is the cost required to provide and implement safety resources, programs, and control measures in construction projects to prevent work accidents, reduce safety risks, and support the implementation of the construction safety management system (Fitriani et al., 2022). CoQ, by contrast, is usually embedded in specifications, overhead, work item unit prices, quality supervision activities or corrective allowances (Heravi & Jafari, 2014; Love & Li, 2000). This imbalance means that an integrated estimate cannot be developed by simply adding all CoS and CoQ items together. Without a clear relational rule, shared resources such as joint training sessions, inspection platforms and document-control activities may be counted twice, while hidden quality-related costs may remain unrecognised.

The literature already supports the conceptual relationship between safety and quality. Studies have reported that construction safety and quality performance are associated, and that defects, non-conformances and safety events may share common organizational and operational precursors (Love et al., 2015; Love et al., 2018; Wanberg et al., 2013; Das et al., 2008). ISO 9001:2015 defines requirements for quality management systems, while ISO 45001:2018 defines requirements for occupational health and safety management systems with guidance for use (International Organization for Standardization [ISO], 2015; International Organization for Standardization [ISO], 2018). These standards reinforce the need for controlled processes, documented information, performance evaluation and continuous improvement. However, standards and prior empirical studies do not specify how one safety cost item should be related to one quality cost item in an integrated construction budget.

This study addresses this gap by developing an expert-validated relational taxonomy and an integrated cost breakdown structure (CBS) for Indonesian public apartment construction. The contribution of this study is primarily structural. It does not aim to validate cost accuracy using completed project data; instead, it provides a validated classification framework that determines whether CoS–CoQ component pairs should be integrated, coordinated, or maintained separately. The proposed taxonomy is intended to serve as a foundation for future cost calibration, probabilistic estimation, and project-level validation.

The relationship between safety and quality becomes particularly important when organizational requirements are translated into project budgets. The Cost of Safety comprises expenditures for personnel, personal protective equipment, training, inspections, emergency arrangements, occupational health facilities, and other control measures intended to prevent accidents and support construction safety management systems. The Cost of Quality includes prevention, appraisal, internal failure, and external failure costs associated with achieving conformity and addressing defective outputs. Although both cost domains contribute to project reliability, they are commonly planned and recorded separately. Safety costs are often explicitly identified as regulatory or project-control expenditures, whereas quality costs may be distributed across technical specifications, unit prices, overhead, supervision, testing, documentation, and corrective work. This difference in cost visibility creates a risk that integrated budgeting may either overlook hidden quality costs or duplicate shared safety–quality resources.

This issue is particularly relevant to Indonesian public apartment construction because these projects involve high-rise building risks, repetitive work packages, extensive material testing, public accountability requirements, and strict standards for habitability and structural

performance. Indonesian construction projects are required to implement a Construction Safety Management System under the Regulation of the Minister of Public Works and Housing No. 10 of 2021, which includes construction safety plans, monitoring, inspections, competent personnel, and documented control measures. However, quality-management expenditures are not always represented through an equally visible and standardized cost structure. Activities such as joint field inspections, planning meetings, document control, toolbox meetings, worker training, site supervision, and audit preparation may simultaneously support safety and quality objectives. Without an explicit relationship-based classification, estimators may combine unrelated components, maintain duplicate budget items for shared resources, or exclude quality-related expenditures embedded within other work items.

Previous research has provided important evidence regarding the financial implications of construction quality. Heravi and Jafari (2014) examined quality-related activities and costs through 77 structured interviews involving 60 mass-housing projects and developed a model for estimating the optimum cost of quality. Their findings demonstrated that systematic Cost of Quality management could identify potential savings and improve resource allocation in mass-housing construction. Garg and Misra (2022) subsequently developed a framework for identifying Cost of Quality components in building projects and demonstrated relationships among prevention, appraisal, and nonconformance costs. Khadim et al. (2023), based on data from 25 building projects, further reported that failure costs exceeded 12% of total project costs, partly because construction organizations lacked comprehensive systems for capturing visible and hidden quality costs. These studies demonstrate that quality failures may create substantial financial burdens; however, they primarily evaluate quality costs without determining how individual quality-cost components relate to safety-cost components.

Research on construction safety costs has also developed approaches for identifying preventive resources and estimating the financial implications of safety controls. Gurcanli et al. (2015) proposed an activity-based risk assessment and safety-cost estimation approach for residential construction, while Ikpe et al. (2012) demonstrated the relevance of cost–benefit analysis for accident-prevention measures. In the Indonesian context, Ferakhim and Latief (2019) developed a work-breakdown-structure-based safety-cost model for architectural work in rental apartment projects. Fitriani et al. (2022) further established that security expenditures, including personnel, surveillance, access control, and asset protection, represent components of construction safety costs in apartment projects. Although these studies improved the identification and estimation of safety expenditures, they generally treated safety as an independent financial domain and did not establish component-level criteria for determining when safety and quality resources should be integrated, coordinated, or maintained separately.

Recent research has begun to establish a conceptual foundation for integrating these two domains. Friatmojo et al. (2025) concluded that integrating the Cost of Safety and Cost of Quality is feasible because safety incidents and quality failures share common precursors, can both be assessed through a risk-management perspective, and involve comparable cost-estimation processes. Nevertheless, the proposed framework remains conceptual and does not provide an empirically validated classification of relationships between individual safety- and quality-cost components. Existing studies have demonstrated that safety and quality are interrelated, and separate bodies of literature have identified their respective cost components; however, no operational taxonomy has sufficiently explained whether a specific component

pair shares common functions, resources, or outputs. Consequently, estimators still lack a defensible decision framework to prevent double counting while maintaining traceability and accountability for each domain.

Addressing this gap is important because simply combining all safety- and quality-cost items does not represent meaningful integration. Such an approach may incorrectly merge activities that serve different purposes or generate different contractual outputs. Conversely, maintaining complete separation may result in duplicated costs for shared personnel time, training facilities, inspection logistics, digital platforms, meeting administration, and document-control resources. Therefore, an integrated cost structure requires a selective mechanism that distinguishes independent relationships, complementary relationships requiring coordination, partial relationships involving shared resources, and full relationships representing identical resources, functions, and outputs. Establishing these distinctions before monetary calibration is essential because the reliability of an integrated estimate depends on the validity of its component structure. A transparent taxonomy may also support subsequent integration with work breakdown structures, risk registers, project schedules, and actual cost records.

The novelty of this research lies in developing an expert-validated structural-relational taxonomy and translating it into an integrated cost breakdown structure specifically for Indonesian public apartment construction. Unlike previous studies that separately identify safety or quality costs, propose broad conceptual integration, or directly estimate monetary values, this research evaluates each retained Cost of Safety and Cost of Quality component pair based on three explicit dimensions: shared resources, shared outputs, and shared functions. These dimensions are used to classify each pair as independent, complementary, partial, or full and to assign corresponding budgeting treatments, including separation, coordination, partial integration, or complete integration. The study also applies the item-level content validity index to screen relevant components before cross-domain mapping, ensuring that the proposed structure reflects evaluations from experienced contractor, regulatory, and academic experts rather than relying solely on literature-based assumptions.

Accordingly, this research aims to develop and validate a relational taxonomy for integrating safety- and quality-cost components in Indonesian public apartment construction and to convert the validated relationships into an operational integrated cost breakdown structure. Specifically, the study seeks to identify relevant safety- and quality-cost components, assess their content validity, map relationships among retained components, classify component pairs using shared-resource, shared-output, and shared-function criteria, and formulate appropriate budgeting rules. Academically, this study contributes a reproducible component-level framework that connects safety–quality relationship theory with construction cost management. Practically, it provides contractors, consultants, regulators, project owners, and estimators with a structured basis for identifying shared resources, preventing double counting, maintaining accountability for distinct outputs, and improving budget traceability. The resulting taxonomy is expected to serve as a foundation for future empirical calibration using completed project data and for broader applications across various project types and contractual contexts.

METHOD

A. Research design and component compilation

The study employed a qualitative, instrument-based, and artifact-oriented design. The objective was to validate the structure of Cost of Safety (CoS)–Cost of Quality (CoQ) relationships rather than estimate their monetary values. This design was selected because integrated cost estimation requires a reliable classification structure before numerical project data can be applied.

An initial inventory of 70 cost components was compiled from studies on safety costs, quality costs, risk management, and Indonesian construction practices. The components were categorized into seven groups: generic safety costs, specific safety costs, security costs, quality prevention costs, quality appraisal costs, internal failure costs, and external failure costs. Table I presents the component inventory used for expert screening. The table is presented at the category level to maintain conciseness while representing the content basis of the validation instrument.

Table I. CoS and CoQ component identification used for expert screening.

Cost type	Category	Cost components used for expert screening	Main literature basis
CoS	Generic safety cost (A)	Safety personnel; safety training, orientation and induction; Health and Safety Plan and work procedures; safety monitoring, inspection and audit; safety documentation and toolbox meeting; safety promotion media; insurance; site support facilities; safety budget management; heavy equipment and operator licenses; hygiene and health care; external safety consultation; HSE staff salaries; basic PPE.	Gurcanli et al. ; Fitriani et al. ; Friatmojo et al.
CoS	Specific safety cost (B)	Collective protective measures; fall protection; specific safety signs; hazard-control mitigation; equipment inspection, load testing, maintenance and safety devices; emergency response; site safety monitoring; fire-hazard control; crane and lifting operation safety; specific PPE.	Gurcanli et al. ; Ferakhim and Latief ; Fitriani et al.
CoS	Security cost (C)	Security personnel and patrol; CCTV/security camera; theft, vandalism and social-conflict control; material and equipment protection; access control.	Fitriani et al.
CoQ	Prevention cost (D)	Training, education and motivation; quality planning and QA/QC documentation; design review and verification; QMS implementation; quality staff salaries; supplier/contractor evaluation; procurement quality planning; calibration and maintenance; process control; continuous improvement; quality data planning; site layout and movement planning.	Crosby ; Schiffauerova and Thomson ; Garg and Misra
CoQ	Appraisal cost (E)	Site and process inspection/testing; material laboratory testing; site supervision and quality monitoring; internal and external audits; document review and control; quality record storage; incoming material evaluation; final inspection and commissioning; reinspection and retesting; data acquisition, analysis and	Garg and Misra ; Heravi and Jafari

		reporting; product/process performance evaluation.	
CoQ	Internal failure cost (F)	Rework, repair and corrective actions; scrap, demolition and material wastage; redesign due to quality failure; reassessment and retesting; variations and additional costs due to failures; productivity loss and downtime; failure analysis; waste generated due to rework; NCR handling.	Love and Li ; Barber et al.
CoQ	External failure cost (G)	Warranty and post-handover repair; complaints and claims; legal cost, arbitration and litigation; penalties due to non-conformance; revenue and reputational loss; delay due to quality failures; loss of future business; public image damage.	Desai ; Love and Li

Table I shows that the initial inventory covered both visible and hidden cost components. Safety components were primarily associated with regulatory and site-control requirements, whereas quality components included prevention, appraisal, and failure-related costs. This broad initial inventory was necessary to ensure that the validation process considered components beyond those commonly identified in conventional project budgets.

B. Expert panel and content validity procedure

6 experts were purposively selected from state-owned contractors, the Ministry of Public Works and academia. Their experience ranged from 15 to 30 years. The six-member panel is compatible with content-validity guidance, where an item-level content validity index (I-CVI) of 0.83 is commonly used as an acceptance threshold (Lynn, 1986; Polit & Beck, 2006; Polit et al., 2007).

The validation instrument used a binary relevance scale. Experts scored each component as 1 if it was relevant and essential for the proposed taxonomy, and 0 if it was not. Binary scoring is suitable for I-CVI analysis because it avoids post-hoc conversion of ordinal ratings (Yusoff, 2019). The I-CVI was calculated as the proportion of experts who approved an item. Components that reached the threshold were retained for mapping; components below the threshold were eliminated from the validated core.

Table 2. Expert panel profile

Expert	Affiliation type	Education	Experience (yr)
E1	State-owned contractor	Master	30
E2	State-owned contractor	Master	20
E3	Ministry of Public Works/regulator	Master	15
E4	Ministry of Public Works/regulator	Master	20
E5	Ministry of Public Works/regulator	Bachelor	30
E6	Academia	Doctorate	20

Table II indicates that the panel combined implementation, regulatory and academic perspectives. This composition is important because safety and quality cost components are not purely technical items; they are also shaped by contract administration, regulatory compliance and practical budgeting behaviour.

C. Relational taxonomy and mapping rules

After component validation, each retained CoS component was paired with each retained CoQ component. Because twenty CoS components and ten CoQ components were retained, the mapping produced 200 cross-domain pairs. Each pair was evaluated using three binary dimensions: shared resource, shared output and shared function. These dimensions were selected because cost integration is meaningful only when a pair has a traceable basis for sharing, coordination or separation.

The taxonomy contains four mutually exclusive classes. Independent pairs have no sufficient shared function and remain separate budget items. Complementary pairs share a function but do not share the same jointly usable resource or output, so they should be coordinated but budgeted separately. Partial pairs share a function and a jointly usable resource but do not produce an identical output, so the shared portion may be merged while the different outputs remain traceable. Full pairs would share resource, output and function, but no full pair was validated in this study.

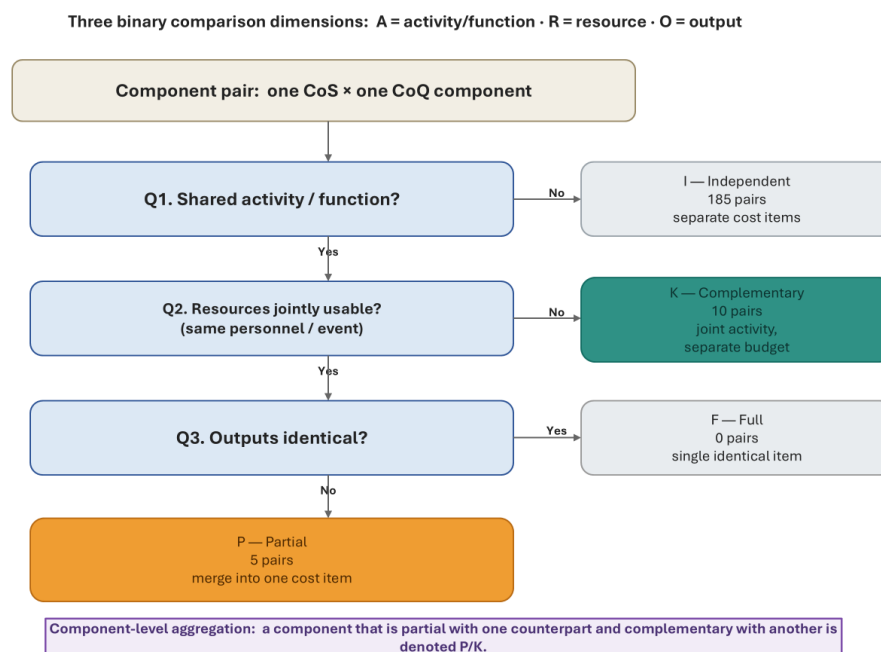


Figure 2. Relational taxonomy for classifying one CoS component and one CoQ component.

Figure 2 presents the decision logic used by the taxonomy. The first gate is the shared function test because a budget line should not be integrated merely because 2 items use similar words. The second gate is resource sharing because double counting occurs most directly when the same person, meeting, platform or field event is budgeted twice. The third gate is output identity, which distinguishes a true full overlap from a partial overlap.

D. Integrated CBS construction

The validated pairwise relationships were translated into an integrated CBS using the following treatment rules. Partial relationships were converted into merged or shared-resource cost positions. Complementary relationships were retained as separate cost positions but marked for joint coordination. Independent relationships remained stand-alone items. Corrective and failure positions that are normally contingent rather than planned as direct

budget lines were treated as literature-informed extensions and clearly distinguished from the expert-validated planned-cost core.

This approach preserves traceability. It does not collapse the safety and quality domains into one undifferentiated budget. Instead, it creates a relationship-aware CBS in which every component carries a budgeting instruction: merge, coordinate or separate.

RESULTS AND DISCUSSION

A. Component validation outcome

Of the 70 cost components, thirty met the retention threshold. The retained set consisted of twenty CoS components and ten CoQ components. The result indicates that experts were more likely to retain safety cost components than quality cost components. Appendix A reports the component-level I-CVI results for the full cost components pool, including the retained and eliminated items.

The elimination of most failure-cost components should not be interpreted as evidence that failure costs are theoretically unimportant. The expert comments clarified that these items were less suitable as planned components in the validated CBS core. Representative comments were: "failure cost is a consequence after non-conformance has occurred, not a planned resource to be budgeted at the beginning of the project" and "rework, productivity loss and accident consequences should be treated as contingency or corrective extensions, not as routine prevention or appraisal items." Therefore, failure costs remain relevant to the broader cost model, but most of them are positioned outside the expert-validated planned-cost core and should be estimated separately when project cost records become available.

Table 3. Validation outcome by cost type and category.

Category	Cost components	Retained	Eliminated	Mean I-CVI
Safety - Generic	14	9	5	0.81
Safety - Specific	10	8	2	0.83
Safety - Security	5	3	2	0.70
Quality - Prevention	12	4	8	0.50
Quality - Appraisal	12	5	7	0.57
Quality - Internal failure	9	0	9	0.33
Quality - External failure	8	1	7	0.31
All safety	29	20	9	0.79
All quality	41	10	31	0.45
Total	70	30	40	0.59

Table 3 explains why the final mapping was based on thirty components rather than the full list of seventy. The higher retention of safety components reflects their stronger visibility in project safety cost structures, while the lower retention of quality components reflects the fact that many quality costs are indirect, hidden or contingent. This screening stage protected the mapping matrix from being overloaded by items that experts did not consider sufficiently relevant for the target project context.

B. Distribution of relational classes

The validated thirty components produced 200 CoS-CoQ pairs. The classification results showed 185 independent relationships, 10 complementary relationships, 5 partial relationships and no full relationship. At first glance, the dominance of independent relationships may appear

to weaken the integration argument. In fact, it strengthens it. The taxonomy is not designed to maximize overlap; it is designed to identify defensible overlap and prevent artificial merging.

The overlap was concentrated in three zones: planning/documentation, inspection/appraisal and training. These zones are operationally plausible because they represent routine project processes where safety and quality teams interact, share documents, attend the same meetings, use related checklists or perform field verification in the same work areas.

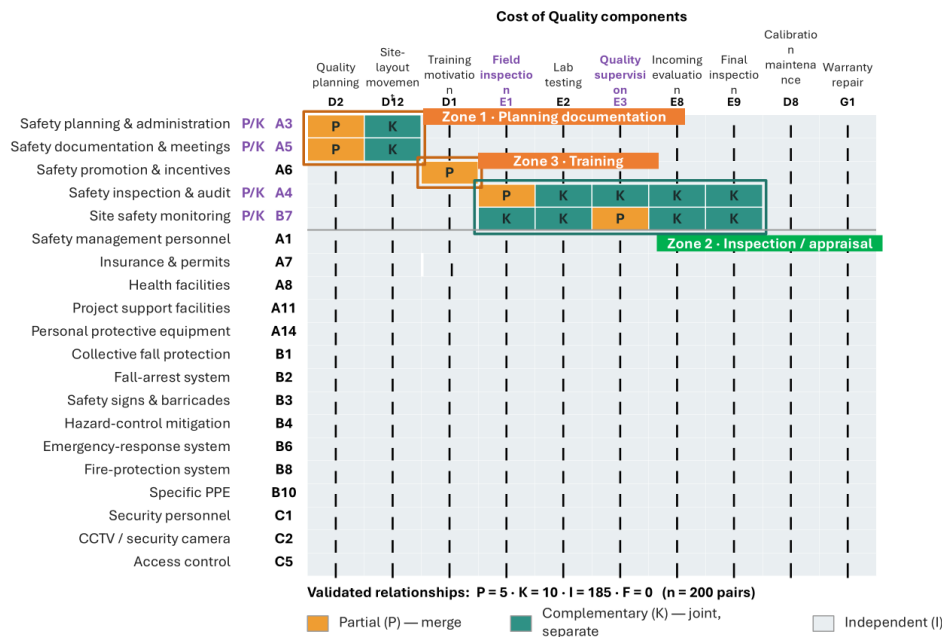


Figure 3. Domain mapping matrix showing validated partial and complementary relationships

Figure 3 displays the mapping matrix after independent relationships are visually de-emphasised. The orange cells indicate partial relationships that may justify a merged/shared-resource cost treatment. The green cells indicate complementary relationships that should be coordinated but budgeted separately. The matrix shows that integration is concentrated rather than universal.

Table 4. Distribution of the 200 validated pairwise classifications

Relationship class	n	Share	Budgetary treatment	Meaning in integrated estimation
Independent (I)	185	92.5%	Separate stand-alone item	No sufficient shared function; forced integration would be artificial.
Complementary (K)	10	5.0%	Jointly coordinated, separately budgeted	Activities interact, but resources or outputs remain distinct.
Partial (P)	5	2.5%	Merged into one cost position	Shared activity and resource justify a merged/shared cost basis.
Full (F)	0	0.0%	Single identical item	No pair was identical across activity, resource and output.
Total	200	100%	-	-

Table 4 converts the visual pattern in Fig. 3 into numerical evidence. Only 7.5% of pairs were classified as partial or complementary, which confirms that most CoS and CoQ

components should remain independent. The value of the taxonomy is therefore selective: it isolates the limited set of relationships that matter for integrated budgeting.

C. Example of integration based on cross-mapping results

To make the taxonomy operational, selected validated pairs from the cross-mapping sheet were translated into budgeting examples. The examples in Table V follow the same logic as the full matrix: D1 indicates shared resource, D2 indicates shared output and D3 indicates shared function. A partial pair is not interpreted as a total merger of safety and quality obligations. It means that the shared resource portion may be costed once, while separate outputs remain traceable. A complementary pair means that coordination is required, but the budget should remain separate because the resources or outputs are not the same.

This distinction is important for estimators. For example, safety inspection and quality field inspection can share a site walk, attendance time and checklist platform, but their findings, sign-offs and compliance consequences remain different. By contrast, laboratory material testing may be coordinated with safety inspection schedules, but it uses different resources and produces different outputs, so it should not be merged.

Table 5. Examples of CoS-CoQ integration based on the cross-mapping logic

CoS-CoQ pair	D1 resource	D2 output	D3 function	Class	Budget implication
A3 Safety planning and administration x D2 Quality planning	Yes	No	Yes	P	Shared coordination, template preparation and document-control resources may be costed once, while the safety plan and QA/QC plan remain separately traceable.
A3 Safety planning and administration x D12 Site layout planning	No	No	Yes	K	Both influence site arrangement, but safety planning and movement/layout planning produce different outputs; they should be coordinated but not merged.
A4 Safety inspection and audit x E1 Field inspection/testing	Yes	No	Yes	P	A joint field inspection can share personnel time, checklist platform and visit logistics; the safety and quality findings remain separate records.
A4 Safety inspection and audit x E2 Laboratory material testing	No	No	Yes	K	Safety inspection may coordinate with material testing schedules, but laboratory resources and test outputs remain distinct.
A6 Safety promotion and incentives x D1 Training, education and motivation	Yes	No	Yes	P	Induction or toolbox sessions may jointly deliver safety and quality messages; shared trainer time and attendance administration should not be double counted.
B7 Site safety monitoring x E3 Quality supervision and monitoring	Yes	No	Yes	P	Daily field observation may share site observation resources; safety observations and quality

					non-conformance records should still be coded separately.
A4 Safety inspection and audit x D12 Ease of movement and project site layout planning	No	No	No	I	This component does not have sufficiently strong similarities in resources, outputs, or functions; therefore, it is more appropriately treated as an independent component

Table 5 demonstrates that the taxonomy can be used as an estimation rule rather than only as a classification label. The practical question is not merely whether 2 components are related, but how the relationship should change the budget. The table shows that partial pairs control double counting by merging only shared resources, while complementary pairs maintain separate budget accountability while requiring planning coordination.

D. Hypothetical application in cost estimation

A hypothetical estimation case was added to demonstrate how the taxonomy can be used by an estimator. Assume that a public apartment project prepares an early QHSE budget and identifies four overlapping CoS-CoQ pairs from the validated matrix. If the estimator budgets each safety and quality item independently, several shared resources may be counted twice. The taxonomy changes the treatment by merging only the shared-resource portion for partial pairs, while complementary pairs remain separately budgeted but coordinated.

Table 6. Hypothetical application of the taxonomy in early cost estimation

Pair	Class	Taxonomy-based treatment
A6 x D1: safety promotion and quality training	P	Merge shared trainer time, room, attendance administration and learning media; keep separate safety and quality outputs.
A4 x E1: safety inspection and field quality inspection	P	Cost one joint walkdown platform and shared inspection logistics once; keep safety findings and quality findings separately coded.
A3 x D2: safety planning and QA/QC planning	P	Merge shared document-control resources and coordination meeting time; maintain safety plan and quality plan as separate deliverables.
A4 x E2: safety inspection and laboratory material testing	K	Coordinate schedule and site access, but do not merge because laboratory testing uses different resources and outputs.
Total illustrative estimate	-	Potential double-counted shared resources are removed only where a partial relationship is validated.

Table 6 is not intended to provide a universal percentage or a validated project price. It only illustrates the budgeting consequence of the taxonomy. Partial pairs reduce potential double counting because shared resources are costed once, whereas complementary pairs protect accountability because related but different resources are not merged.

E. Integrated CBS

The validated relationships were converted into a 32-component integrated CBS. The CBS is organized into preventive, appraisal/detection and corrective/failure categories. The first 2 categories mainly represent planned cost positions that were derived from the expert-validated component set. The corrective/failure category includes warranty and post-handover

repair as a retained item and 2 literature-informed extensions: internal quality failure cost and occupational accident cost.

The extensions are intentionally separated from the validated core. This avoids the misleading claim that accident cost and internal failure cost were fully expert-validated as planned budget items. They are included because the literature consistently recognizes failure and accident consequences as relevant cost positions, but they should be calibrated separately when actual project data become available.

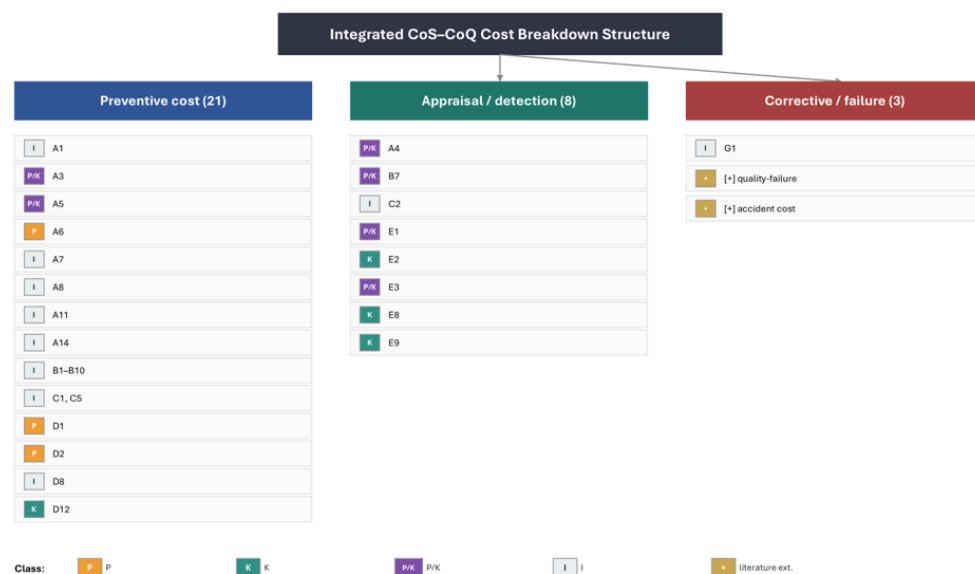


Figure 4. Integrated CoS-CoQ cost breakdown structure derived from the validated taxonomy

Figure 4 shows the final structure of the integrated CBS. The figure does not combine all safety and quality components into a single list without logic. Instead, each component retains a relationship class. The class label functions as a budgeting instruction: I means stand-alone, K means jointly coordinated but separately budgeted, P means merge the shared-resource portion, and P/K means the component has different relationships with different counterparts.

Table 7. Integrated CoS-CoQ CBS and budget treatment rules

Code	Integrated CBS component	Domain	Class	Budget rule
A1	Safety management personnel	CoS	I	Stand-alone safety cost
A3	Safety planning and administration	CoS	P/K	Merge shared planning resources only; coordinate separate outputs
A5	Safety documentation and meetings	CoS	P/K	Coordinate with QA/QC documentation and layout records
A6	Safety promotion and incentives	CoS	P	Merge shared training/promotion event resources where applicable
A7	Insurance and permits	CoS	I	Stand-alone contractual/regulatory cost
A8	Health facilities	CoS	I	Stand-alone welfare and health provision
A11	Project support facilities	CoS	I	Stand-alone project facility provision
A14	Personal protective equipment	CoS	I	Stand-alone PPE line item

B1-B10	Specific safety provisions: collective protection, fall arrest, signage, hazard mitigation, emergency response, fire protection and specific PPE	CoS	I	Stand-alone activity-specific controls
C1, C5	Security personnel and access control	CoS	I	Stand-alone security cost
D1	Training, education and motivation	CoQ	P	Merge shared training resources with A6 when the event is joint
D2	Quality planning and QA/QC documentation	CoQ	P	Merge shared document-control resources with A3 where overlapping
D8	Calibration and maintenance	CoQ	I	Stand-alone quality prevention item
D12	Site layout and movement planning	CoQ	K	Coordinate with safety planning but budget separately
A4	Safety inspection and audit	CoS	P/K	Merge field inspection resources where shared; coordinate specialized audits
B7	Site safety monitoring	CoS	P/K	Merge monitoring resources with E3 where jointly usable
C2	CCTV/security camera	CoS	I	Stand-alone monitoring/security equipment
E1	Field inspection and testing	CoQ	P/K	Merge or coordinate depending on shared inspection resource and output
E2	Laboratory material testing	CoQ	K	Coordinate timing with safety inspection but budget separately
E3	Quality supervision and monitoring	CoQ	P/K	Merge site monitoring resources with B7 when jointly usable
E8	Incoming material evaluation	CoQ	K	Coordinate with safety inspection of material handling/storage
E9	Final inspection and commissioning	CoQ	K	Coordinate with safety acceptance checks but retain quality outputs
G1	Warranty and post-handover repair	CoQ	I	Stand-alone post-handover cost

Table 7 provides the operational CBS. The table is deliberately rule-based: the same component is not treated the same way in every relationship. A3, A4, A5, B7, E1 and E3 are marked as P/K because each may be partial with one counterpart and complementary with another. This prevents overgeneralisation and keeps the CBS traceable at the component-pair level.

The findings refine the safety-quality integration argument. Integration is not a general instruction to combine 2 cost domains. It is a selective budgeting rule that applies only where a validated relationship exists. The predominance of independent relationships shows that most safety and quality cost components should remain separate. This is a useful result because it prevents the integrated CBS from becoming a broad and ambiguous cost pool.

The planning/documentation zone is meaningful because safety planning and administration, quality planning and QA/QC documentation rely on related project information and document-control routines. The inspection/appraisal zone is meaningful because safety inspection, site monitoring, quality inspection and quality supervision often occur in the same

work areas and may use overlapping field observation resources. The training zone is meaningful because safety induction and quality awareness can be delivered through shared sessions, communication media and attendance administration.

The taxonomy also clarifies the difference between coordination and merger. Complementary relationships are important because they show that 2 components can be related without being financially identical. A laboratory test may be coordinated with inspection schedules, but it should not be merged with safety inspection. This distinction protects both cost accuracy and accountability.

The Indonesian context strengthens the practical value of the taxonomy. Because safety cost is more explicitly itemised through construction safety management requirements [8], [9], while quality cost is more often embedded in work items, supervision routines or organisational quality-management practices [23], [28], integrated estimation could create either double counting or omission if it is not governed by a clear rule. The proposed taxonomy gives estimators a defensible basis for deciding which resources can be shared, which outputs must remain separate and which components should not be integrated at all.

A. Empirically testable propositions

Although this study is structural rather than predictive, the taxonomy can be converted into propositions for future empirical testing. These propositions do not introduce a new grand theory; they simply translate the validated decision logic into testable statements that can be examined using future project data, expert surveys or experimental estimating tasks.

Table 8. Propositions derived from the validated relational taxonomy

Proposition	Statement	Operational implication
P1	CoS-CoQ pairs with a shared activity/function are more likely to require integration treatment than pairs without a shared activity/function.	The shared-function test should be the first screening gate in future empirical replications.
P2	Pairs with shared activity and jointly usable resources should be treated as partial relationships and should be merged only at the shared-resource level.	Merging should be limited to trainer time, joint inspection time, shared checklist platforms or shared document-control resources.
P3	Pairs with shared activity but different resources or outputs should be treated as complementary rather than merged.	Complementary components need coordination rules, not a single budget line.
P4	An integrated CBS that distinguishes independent, complementary and partial relationships will produce higher traceability than a CBS that lists CoS and CoQ items without relationship labels.	Future studies can compare auditability, double-counting detection and expert usability between labeled and unlabeled CBS structures.

Table 8 addresses the need for empirical follow-up without overstating the present findings. The propositions are directly derived from the classification rules and can be tested using future project data. For instance, future researchers can compare whether partial pairs are more frequently associated with shared personnel time or shared digital inspection platforms than independent pairs.

B. Limitations and future research

Several limitations must be acknowledged. First, the study validates structure rather than monetary magnitude. It does not use completed project bills of quantities, actual safety-cost

reports or actual quality-cost ledgers. Therefore, the output should be read as an expert-validated CBS foundation, not as a fully calibrated estimation model. Second, although Appendix A improves transparency by reporting the I-CVI for each cost component, the values represent content validity judgements rather than empirical cost magnitudes.

Second, the expert panel is appropriate for content validity but remains limited to the Indonesian public apartment context. Revalidation is needed before the taxonomy is applied to infrastructure projects, private developments, design-build contracts or other national regulatory systems. Third, the 2 literature-informed corrective/failure extensions should be estimated separately using actual project data. Future work should connect the integrated CBS with WBS, risk registers, project schedules and actual cost records so that the structural rule can be tested quantitatively.

CONCLUSION

This study developed an expert-validated relational taxonomy for integrating Cost of Safety (CoS) and Cost of Quality (CoQ) components in Indonesian public apartment construction. Seventy cost components were screened by six experts using the item-level content validity index (I-CVI), resulting in 30 retained components. These components were subsequently mapped into 200 CoS–CoQ pairs and classified using three binary dimensions: shared resources, shared outputs, and shared functions.

The results identified 185 independent relationships, 10 complementary relationships, and five partial relationships, with no full relationships identified. The overlapping relationships were concentrated in planning and documentation, inspection and appraisal, and training activities. The validated relationship classes were then converted into a 32-component integrated cost breakdown structure (CBS), in which partial relationships were integrated at the shared-resource level, complementary relationships were coordinated but maintained as separate budget items, and independent components remained stand-alone.

The contribution of this study is a transparent and reproducible component-level structure for integrated safety–quality cost estimation. The proposed taxonomy does not replace project-specific cost calibration; instead, it provides a systematic framework for preventing double counting, maintaining accountability, and improving cost traceability when CoS and CoQ are planned together.

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