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A Cloud-Based Adaptive Dynamic Budgeting (CADB) Model: A Real-Time Cost-Updating Methodological Framework for Construction Project Budget Management in Peru

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Abstract

Budget management in Peruvian construction projects, particularly among small and medium-sized firms, still largely relies on periodic-update schemes that fail to continuously incorporate input price fluctuations, logistical constraints, and climatic conditions. This article presents and formalizes the Cloud-based Adaptive Dynamic Budgeting (CADB) model, a methodological framework built on four calculation principles—unit-cost updating, total dynamic budget recalculation, real-time cost-deviation index control, and indirect-cost updating—supported by a four-layer cloud-computing architecture that integrates Peruvian public data sources (INEI, SENAMHI, SUNAT) with on-site sensors and project-management platforms. The study follows a documentary and conceptual-modeling design, structured under the IMRaD format, systematizing the specialized literature on cloud computing applied to construction and deriving a set of verifiable formulas together with a qualitative comparative matrix against traditional static budgeting and periodic-update methods. Results show that the CADB model offers structural advantages in update speed, deviation traceability, and adaptability to scope changes, consistent with findings reported in prior studies on cloud-technology adoption in the construction sector. An illustrative, non-inferential scenario is discussed to exemplify the application of the formulas in a typical Peruvian project. The article concludes that the CADB model constitutes a replicable foundation for digitalizing cost management in the Peruvian context, identifying as its main limitation the current absence of longitudinal empirical validation with primary site data, which is proposed as a future research agenda.

Introduction

The construction sector is one of the main drivers of the Peruvian economy and, at the same time, one of the most exposed to budget deviations arising from input-price volatility, regional logistical constraints, and climatic events affecting site schedules. The prevailing practice among Peruvian construction firms—particularly small and medium-sized enterprises, which make up most of the sector—continues to rely on static budgets prepared at project inception, with periodic updates (monthly or quarterly) that do not continuously capture available information on prices, weather, or physical progress.

Cloud computing has been identified in the specialized literature as a relevant enabler for digitalizing cost-management processes in construction, allowing centralized storage, distributed processing, and near-real-time integration of heterogeneous data sources (Bello et al., 2021; Wang et al., 2024). Recent studies further show that adoption of these technologies improves cost traceability and reduces response times to deviations, although diffusion among small firms remains limited by cost, training, and connectivity barriers (Adekunle et al., 2025; Khattak et al., 2023; Oyetunji et al., 2022).

Research gap and contribution. Despite this growing body of international literature, no methodological framework has been identified that explicitly formalizes, through verifiable formulas, the dynamic updating of construction budgets using public data sources specific to the Peruvian context—price

indices from the National Institute of Statistics and Informatics (INEI), forecasts from the National Meteorology and Hydrology Service (SENAMHI), and foreign-trade records from the National Superintendency of Customs and Tax Administration (SUNAT). This article's contribution is to propose and formalize the CADB model (Cloud-based Adaptive Dynamic Budgeting), comprising four calculation principles and a four-layer architecture, as a replicable framework for Peruvian construction cost management, derived from a systematization of the specialized literature rather than from an experimental trial with primary data—a limitation explicitly declared and discussed in the conclusions.

Materials and Methods

Study design

A documentary, conceptual-modeling design was used, structured under the IMRaD format, aimed at systematizing the specialized literature on cloud computing applied to construction cost management and deriving from it a formal set of calculation principles and a technological architecture. The study does not involve the collection of personal data or intervention on human subjects, sensors, or identifiable real projects; therefore, approval from a research ethics committee was not required, which is explicitly declared in the Declarations section.

Sources and selection criteria

Publications indexed in databases such as Scopus, ScienceDirect, and institutional repositories were reviewed, prioritizing articles with a verifiable Digital Object Identifier (DOI), published between 2016 and 2025, focused on cloud computing, the Internet of Things (IoT), and cost management in the construction sector. Sources without a verifiable DOI or without peer review were excluded.

Formulation of the CADB model's calculation principles

Based on the synthesis of the reviewed literature, four calculation principles were formalized, numbered consecutively against the right margin, constituting the methodological core of the CADB model:

1) Unit-cost updating for input price fluctuation

$$CUA = CUB \times [1 + (IPC_I - IPC_B) / IPC_B] \times (1 + \Delta T) \quad (1)$$

Where CUA is the updated unit cost; CUB is the base unit cost; IPC_I and IPC_B are the input's price indices at the update period and base period, respectively (source: INEI); and ΔT is the logistic-climatic adjustment factor, fed in real time by SENAMHI data and road-authority records.

2) Total dynamic budget recalculation for scope variation

$PDT = PDT_0 + \Sigma(\Delta V \times CUA) + \Sigma(C \times R)$ (2)

Where PDT_0 is the initial base budget; ΔV_i is the quantity variation of item i; CUA_i is the updated unit cost of item i (Eq. 1); C_i is the change-order cost of item i; and R_i is a risk factor, updatable using site progress data and adverse-event forecasts.

3) Real-time cost-deviation index

$IDC = [(CRA - PPA) / PPA] \times 100$ (3)

Where CRA is the real accumulated cost as of the update date and PPA is the updated planned budget. Drawing on Peruvian professional-practice references, an indicative alert threshold of 5% is suggested, beyond which the system generates an automatic notification to the project manager; this threshold should be empirically calibrated by project type.

4) Indirect-cost updating for duration variation

$CIA = CIA_0 \times [1 + (T_R - T_P) / T_P] \times (1 + IPC_G)$ (4)

Where CIA_0 is the base indirect cost; T_R is the updated real duration according to site-progress data; T_P is the initially planned duration; and IPC_G is the general construction-sector price index reported by INEI.

Technological architecture of the CADB model

The model is structured into four interoperable layers, synthesized in Fig. 1: (1) data acquisition, integrating site sensors and public sources (INEI, SENAMHI, SUNAT); (2) cloud processing, where Equations 1 through 4 are executed and budget history is stored; (3) application, through web and mobile dashboards with IDC-derived alerts; and (4) integration, connecting the model with ERP project-management systems (e.g., SAP, Primavera P6) and with public-works accountability platforms.

Results

Qualitative comparative matrix of budget-management methods

Table 1

synthesizes, based on attributes reported in the reviewed literature for cloud-computing technologies applied to construction (Bello et al., 2021; Li, 2024; Xu et al., 2022), a qualitative comparison between the Traditional Static Budget Method (TSB), the Periodic Update Method (PUM), and the proposed CADB model. This is a qualitative assessment of the structural design attributes of each method—not inferential statistical results obtained from a sample—since the present study is documentary and conceptual in nature.

Criterion	**TSB (Traditional Static)**	**PUM (Periodic Update)**	**CADB (Proposed)**
Cost-update frequency	Project start (one-time)	Monthly / quarterly	Continuous (near real time)
Integration of public sources (INEI/SENAMHI/SUNAT)	No	Partial / manual	Yes, automated
Deviation traceability (CDI)	Not formalized	Manual, ex post	Automatic, with alerts
Adaptability to scope changes	Low	Medium	High
Infrastructure / IT requirements	Minimal	Low to medium	Connectivity and cloud platform
Documentary traceability for audit	Limited	Partial	Complete cloud-based history

Table 1. *Qualitative comparative matrix of construction budget-management methods. Source: author's own elaboration based on* Bello et al. (2021), Li (2024*), and* Xu et al. (2022).

Illustrative application scenario (for didactic purposes)

For strictly didactic purposes—and without claiming statistical generalization, since it is not derived from an empirical sample—the application of Eq. 1 is illustrated for a hypothetical social-housing project in the Peruvian highlands. If the base unit cost (CUB) of concrete is PEN 380 per m³, the cement price index increases by 8% between the base and update periods (IPC_I−IPC_B/IPC_B = 0.08) due to exchange-rate effects, and the logistic-climatic factor ΔT is 0.04 owing to a temporary access-road closure reported by SENAMHI, the resulting updated unit cost would be CUA = 380 × 1.08 × 1.04 ≈ PEN 426.9 per m³. This recalculation, executed in Layer 2 of the model within minutes, illustrates how the CADB model would allow a site manager to anticipate the budgetary effect of a logistic-climatic variable before it translates into a significant accumulated deviation.

Discussion

The results of this systematization are consistent with international literature identifying cloud computing as a key enabler for traceability and response speed in construction cost management (Bello et al., 2021; Oesterreich & Teuteberg, 2016; Wang et al., 2024). They also align with studies warning that the main adoption barrier in small projects is organizational and training-related rather than technological (Adekunle et al., 2025; Khattak et al., 2023), which is relevant to the Peruvian context given

the weight of SMEs in the sector. Unlike generic cloud-computing models applied to construction, the CADB model explicitly incorporates Peruvian public data sources (INEI, SENAMHI, SUNAT), which constitutes its main differential contribution relative to the reviewed literature.

A central limitation of this study is its documentary and conceptual nature: the proposed formulas and architecture have not yet been empirically validated with primary data from real Peruvian projects, so the results presented—including the comparative matrix and the illustrative scenario—should be interpreted as a verifiable and replicable methodological proposal, not as inferential statistical evidence. A quasi-experimental validation with a representative sample of projects, under prior approval from a research ethics committee, is recommended as a future research agenda.

Conclusions

The CADB model formalizes, through four verifiable equations and a four-layer architecture, a methodological framework for dynamically updating construction budgets in Peru, grounded in the integration of national public data sources with cloud-computing technologies. Its main contribution is to offer a replicable and technically verifiable foundation—not a conclusive empirical validation—so that researchers and project managers can operationalize, and subsequently empirically test, dynamic budget management in contexts similar to Peru's. Future studies are recommended to implement the model in pilot projects, under a quasi-experimental design with corresponding ethical approval, to quantify its performance relative to traditional methods.

Declarations

Ethical approval:

Not applicable. The study is documentary and conceptual-modeling in nature; it did not involve the collection of data from human subjects, animals, or identifiable projects, and therefore did not require approval from a research ethics committee.

Conflict of interest:

The author declares no conflicts of interest related to this work.

Authorship contribution

Paul Ricardo Prudencio Gálvez is solely responsible for the conceptualization, literature review, methodological development, and drafting of this article.

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Data availability:

All sources used are publicly available and cited in the References section; the study did not generate primary datasets.

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Figures

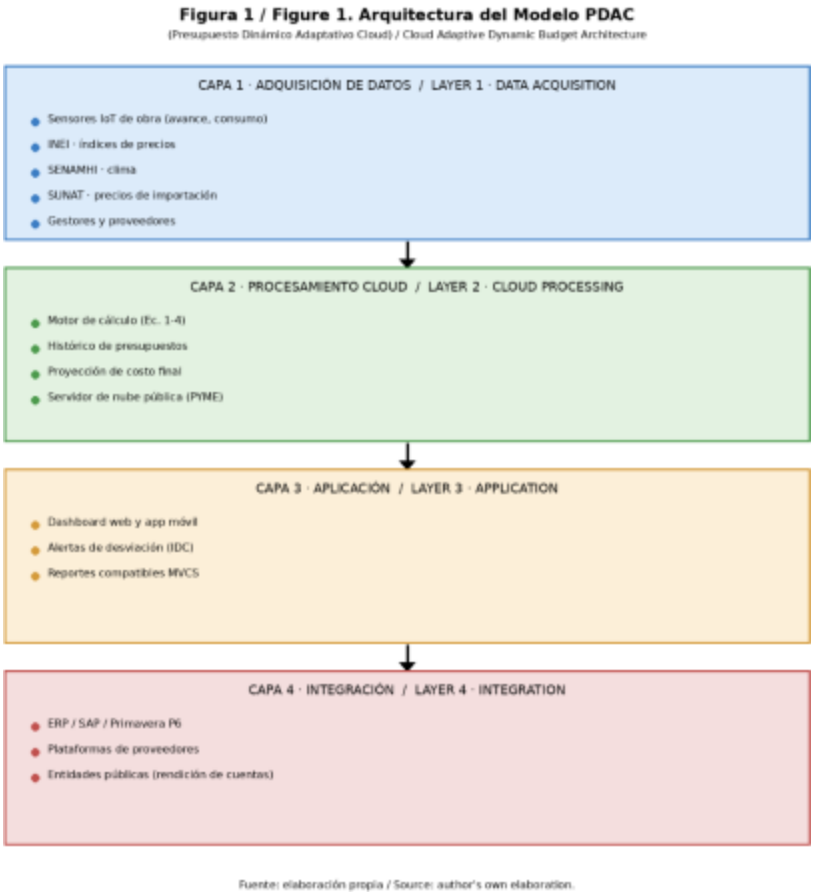


Figure 1

Four-layer architecture of the CADB model. Source: author's own elaboration.