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AI in Construction Budgeting: Review of Trends, Tools and Limitations

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ABSTRACT

Construction budgeting is an essential aspect of planning a project. The traditional methods of estimation come with a host of challenges, including inaccuracies, outdated manual procedures, and inability to adapt to shifting market conditions. This paper investigates the development and present state of Artificial Intelligence (AI) in construction budgeting, using empirical and review literature published from the year 2000 to 2023. Critical AI methodologies, including support vector machines (SVM), artificial neural networks (ANN), ensemble methods such as XGBoost, and natural language processing (NLP) alongside hybrid models, are discussed with regard to their AI-driven automation and adaptability capabilities as well as their predictive accuracy. Ensemble and hybrid models are increasingly used to enhance predictive accuracy in construction budgeting. The results show that modern ensemble and hybrid models, particularly XGBoost, outshine regression-based models in predictive accuracy and adaptability, with high R^2 coefficients (sometimes exceeding 0.95) and low mean absolute percentage errors around 9%. Moreover, NLP tools excel in parsing contract documents and cost item organization, while automated quantity takeoff is provided by computer-vision and BIM-integrated systems. However, data quality, lack of trust in AI algorithms (due to their opaque nature), prohibitive costs of implementation, and a lack of transparency in automated processes remains challenging. Practitioner feedback underscores that, while AI offers efficiency gains, it must function as a human-assisted "copilot" rather than a full substitute for expert judgment. The paper concludes with recommendations to promote data governance, hybrid workflows, pilot deployment, transparency, and stakeholder skills development—paving the way for responsible and scalable AI adoption in construction budgeting.

Keywords*: Artificial Intelligence, Construction Budgeting, Cost Estimation, Machine Learning, XGBoost, NLP, BIM, Ethics, AI Limitations.*

I. INTRODUCTION

Precision in construction cost estimation impacts financial clarity in budget allocation and helps in achieving project milestones. Relying on expert judgment and unit cost estimates from cost databases often causes errors in estimation automation templates, static systems, and automation workflows. Thus, construction firms globally experience cost overruns as a result of volatile material and labor costs and disruptions in the supply chain. The traditional estimation techniques gained popularity due to the emergence of powerful computers and abundant data. Traditional cost estimation techniques merged with AI algorithms, greatly enhancing the workflows budgeting accuracy, scalability, and adaptability. Just recently, integrating 39 construction sector specific case studies, a systematic review performed showed deep learning outperforming traditional regression methods scoring over 90% accurate cost predictions as opposed to 70-80% accuracy historically achieved with traditional methods. While the construction sector has historically not been quick to adopt technology, the results from this study may lead to a rapid shift in the industry's approach to cost estimation and budgeting driven by advanced technology and data predictive models.

Currently, AI-supported applications such as ProEst, Autodesk Construction Cloud, and Building Radar emphasize streamlining the automation of data extraction from BIM files, ERP systems, and even live market feeds to perform cost estimation, scenario analysis, and forecasting in near real-time (Building Radar, 2023; Wunderbuild, 2023). These systems not only preconstruction workflow automation, but also enable real-time agile estimation, ongoing breakdown analysis of

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labor and resource costs, deviation tracking of projected versus actual figures (Building Radar, 2023).

Recent advancements of AI in the construction industry, particularly in budgeting, face lack of momentum due to a handful of challenges. Redacted, inconsistent, outdated, incomplete, or obsolete historical data records create data-quality and availability challenges (MDPI review, 2023). In addition, the widespread adoption of AI technology is severely restricted for small and medium-sized contractors due to high costs associated with AI implementation, including licensing, training, and requisite hardware infrastructure (Conwize, 2023). There is also the growing concern of ethical and operational risks like algorithmic bias, decision-making transparency, and cybersecurity (Liang et al., 2023; MDPI review, 2023). Recent innovations like Automated Machine Learning (AutoML) focus on attempting to minimize the need for specialized data science skills by automating the entire process of model selection, training, and tuning. Zhao et al. (2023) conducted an empirical study which emphasized how AutoML is capable of constructing high-performing regression and classification models for construction datasets, even when there is insufficient technical team support. However, construction data complexity, long-document context challenges, and architectural plan parsing limitations still constrain real-world applicability (Reddit insights, r/estimators, 2024-25).

In this document, I focus on the construction budget management AI tools developed between 2000 and 2023 to critique their technological advancements. I analyze and document key trends and tools while noting their limitations. I also discuss the most prominent AI techniques applied, particularly focused on machine learning, deep learning, regression, and hybrid models, and examine their accuracy for cost estimation, risk evaluation, and automation of the budgeting processes. The discussion is centered on the barriers to implementation that are financial, technical, and ethical, which are critical to shaping perspective on AI integration.

II. LITERATURE REVIEW

- *The chronological development of AI techniques and their application in construction cost estimation.*

Between 2000 and 2010, the use of AI in construction management focused on the deployment of support vector machines (SVMs), neural networks, and genetic algorithms to improve the accuracy of cost and effort estimation (Davahli et al., 2020). Early algorithm-based models provided estimation accuracy improvement over regression methods and manual estimation by leveraging learned past data. However, the real world use of these techniques was greatly hindered by the limited data and computational resources available at the time.

The 2010s saw the maturation of AI with its furthered application and the introduction of new hybrid systems incorporating advanced analytics and regression. It became industry standard for machine learning to be adopted, and for the most part, replace its position as an emerging piece of technology. The machine learning models became increasingly complex, and the flexibility of the models provided enhanced operational performance and strengthened adaptability to various datasets (Davahli et al., 2020).

- *Machine Learning, Predictive Analytics, and Real-Time Estimation*

In the domain of construction budgeting, powered AI technologies mark the use of ML and predictive analytics, emerging in the recent years. Analyzing datasets of past project costs, labor rates, site conditions, and weather, and even supplier pricing trends, ML systems create highly accurate cost projections (Keymakr, 2023). Furthermore, these systems enable dynamic forecasting and agile estimation, where, for example, material price surges or labor delays are simulated and their impact on construction budgets is modeled (Keymakr, 2023).

Predictive analytics also drives continuous cost monitoring. Managers can monitor costs in real time, and updates based on supply chain or project schedule changes provide the ability to adjust budgets proactively, thereby preventing project overruns (Crivva, 2023).

- *AI-Driven Quantity Takeoff and Computer Vision*

AI-driven quantity takeoff with computer vision on 2D drawings and BIM models is arguably the most advanced technique in budgeting. These systems can extract material quantities based on project instructions, and their calculations are far more accurate and much quicker than manual measurements. Although systematic descriptions of these methods will not be published until 2025, their origins can be traced to 2023 AI advancements, showing the growing influence of visual analytics on cost estimation.

- *BIM Integration for Automated Budgeting*

The implementation of Building Information Modeling (BIM) has revolutionized the budgeting process by incorporating relevant cost data into digital models. With the aid of artificial intelligence (AI), BIM can now perform real-time cost estimation and design changes as well as update cost estimates triggered by design shifts—automated quantity take-offs and unit cost reclusion updates (Keymakr, 2023); (BLDON, 2024). These approaches improve the productivity of the estimator and the accuracy of the process, enhancing the collaboration between cost estimator, designer, and procurement officer.

- *Industry Case Studies: Measurable Benefits*

Profitable returns on investment from AI budgeting tools are already evident. Skanska, for example, realized a significant gain in estimating accuracy, achieving a 10% increase in cost-estimation accuracy, and a 20% reduction in time spent per estimate (GloamingTech via Skanska case, date up to 2023). Another example is Mortenson Construction, who self-reported a 15% increase in productivity and a 25% increase in budget accuracy after the implementation of AI estimating workflows

(GloamingTech, 2023). These cases illustrate the impact of AI tools on enhanced operational performance efficiency.

- *Tools and Platforms: From AI Estimators to Integrated Suites*

The number of budget estimation workflows powered by AI technologies is growing. Companies such as Autodesk Construction Cloud and ProEst utilize AI technologies to automatically estimate costs and plan procurement by analyzing BIM data, ERP systems, and vendor pricing information (industry overviews 2023). These systems improve automation as well as efficiency in cost estimation, decision-making, and "bid versus actual" evaluations over multi-phase projects.

- *Risk Assessment and Cost Scenario Simulation*

AI tools extending beyond simple estimation to risk assessment, simulation, and preemptive contingency planning contain almost no boundaries. AI is well positioned to forecast cost exposure as well as budget buffers by modeling supply chain disruptions, regulatory shifts, redesign impacts, and other risks (BLDON, 2024). Predictive visualization helps in communicating to stakeholder's alternative budget scenarios ahead of times in actualization.

- *Challenges: Data Quality, Integration and Adoption Barriers*

The advantages of AI-powered estimating and budgeting are clear, but their adoption is fraught with challenges. Effectiveness, for instance, relies on adoption of cohesive, up-to-date, and complete data, and fragmented or stale cost records can destroy model accuracy (BLDON, 2024). This challenge is noted in integration with older systems as well (Keymakr, 2023). Furthermore, smaller companies are still held back by software licensing, infrastructure, and training expenses (BLDON, 2024).

- *Ethical and Governance Considerations*

Examining ethical considerations when AI is incorporated into budgeting processes is no different than how other AI applications are treated within construction. Liang et al. (2023) have discussed critical considerations like algorithmic opacity, liability for AI predictions, data privacy, and bias within construction AI, which warrant special attention if AI is allowed to make financial decisions. Automation suggests systems to perform financial transactions or undertake other actions, which necessitates financial supervision interfaces and explanations to automate.

The commentary mentions that the late-stage evolution up to the year 2023 includes the AutoML segment focusing on model selection and tuning, thus widening the AI scope to teams without sophisticated data science skills. Natural Language Processing (NLP) is being researched to retrieve budget data from contracts, specifications, and RFPs (Crivva, 2023). There is emerging focus on the AI-enabled sustainability assessment (e.g. life-cycle costing on green materials) and using blockchain for budget supervision in multi stakeholder endeavors (Collab Management, 2023).

III. METHODOLOGY

The purpose of this article is to carry out a systematic literature review (SLR), documenting the technological evolution and application of artificial intelligence (AI) in construction budgeting, alongside its challenges, to analyze the evolution, application, and the challenges AI technologies present in construction budgeting. It sought to extract notable trends, tools, and barriers from primary literature published between the years 2000 to 2023.

- *Information Sources*

The search was performed in several academic databases including Science Direct, Emerald Insight, IEEE Xplore, Google Scholar, and arXiv. It was performed using the following phrases, "AI cost estimation in construction", "machine learning budgeting construction", "deep learning construction cost prediction", and "NLP budgeting construction". Coverage was also limited to Articles published in the English language between January 2000 and December 2023 to ensure relevance and capture historical evolution.

- *Inclusion and Exclusion Criteria*

- *The following are criteria for inclusion pertaining to the research:*

✓ Empirical or review articles that implemented AI through machine learning (ML), deep learning (DL), or natural language processing (NLP) for budgeting or cost estimation in construction.
✓ Articles focusing on measuring performance accuracy or mean absolute percentage error offer a quantitative assessment while critique on the efficacy of the AI tools presented is of a qualitative nature.
✓ Literature reviews on AI and budgeting.

The cited literature are articles lacking a defined methodology framework, self-published works, and any literature predating 2023 is excluded. literature was organized into categories.

- *The following criteria were compiled for each publication, encapsulating the most pertinent details.*

✓ Date and details of publication.
✓ AI technique applied in the study for analysis, for example, SVM, ANN, ensemble methods, and classifying through NLP.
✓ Domain or Sector of application, for example, conceptual cost estimation, takeoff automation, document classification.
✓ Outcomes of performance evaluation measuring benchmarks and metrics like MAPE, accuracy, and predictive power.

- ✓ Constraints recognized for the study, namely in data, lack of transparency, or barriers to adoption.

IV. FINDINGS

➢ *Accuracy and Performance of AI Techniques*

Findings of Kim et al. show that the application of both neural networks and case-based reasoning systems surpass the accuracy of basic multiple regression models in estimating construction costs. Neural networks are the most accurate, however, their interpretability is hindered by the "black box" problem. Additionally, in ASC review research on parametric modeling, it was found that one of the AI methods XGBoost outperformed the SVM, random forest, and fuzzy logic methods achieving an MAPE of about 9.09% and R^2 of 0.929. These results demonstrate that modern tree-based and ensemble AI models are more accurate and robust.

➢ *Machine Learning in Conceptual Costing*

SVM-based models have been noted to perform exceptionally well when estimating costs in the early stages of a project. The most recent is a report by Salahaldain et al. (2023) which demonstrates that trained SVM models, when given appropriate dataset, outperformed both traditional neural networks and nonlinear regression in conceptual cost estimation for construction projects. This illustrates that even simpler models which are well-designed and trained on appropriate data tend to perform well during the early stages of project feasibility.

➢ *AI-enabled Document Parsing and NLP Applications*

Specialized NLP technologies can now be utilized to analyze textual documents and extract pertinent information related to costs. Alberta University's 2021 test cases showed that NLP along with stochastic simulation performed within a given framework to create predictive models that autonomously extract reporting obligations and predict overhead costs with more than 95% accuracy. In a different study, convolutional and recurrent neural networks were trained on more than 50,000 cost descriptions to automatically classify them into taxonomy ICDs or BOQs with over 90% F1 score.

➢ *Integration of BIM and Computer Vision for Takeoffs*

The automation of quantity takeoffs becomes feasible when computer vision is integrated with BIM. Taghaddos et al. (2019), for example, in their comprehensive work focused on an API-based system that filters BIM elements for specific items to extract their corresponding quantities and successfully automated cost estimating workflows. Furthermore, more accurate predictions of cost in schematic design have been reported from the application of deep learning based on CNN and LSTM on features extracted from BIM.

➢ *AutoML for Accessible Model Generation*

The implementation of automated machine learning (AutoML) systems allows construction professionals with no or limited data science understanding to create high-quality regression or classification models to suit their needs. Zhao et al. (2023) provided proof of the concepts by showing how AutoML works with industrial construction datasets, thus resolving the intricacy of user-friendly implementation.

➢ *Practical Toolkits and Platforms*

Tools like Autodesk Construction Cloud and ProEst offer AI-based estimation features that fuse BIM, market pricing databases, and even forecasting algorithms. They have been shown to significantly shorten estimating cycles and improve the accuracy of forecasts. However, estimating performance metrics defined in academic literature remains scarce. Proprietary summaries of the platforms also indicate a reduction in manual work while improving inter-stakeholder transparency.

➢ *Budget, Risk Analytics, and Scenario Simulation*

Systems designed for estimating project budgets using AI also enable predictive risk assessment and scenario planning. For instance, design alteration, price changes, and regulatory changes can all be modeled by simulation tools to assess their impact on project cost, which aids in budget allocation.

➢ *Barriers, Ethical Concerns, and Adoption Challenges*

The specific benefits of AI in budgeting still face several obstacles to widespread use. Predicting accuracy issues always arise with incomplete historical data. Fragmented datasets pose a graphing challenge, especially for smaller businesses. The high cost of implementation, which includes licensing, infrastructure, and training, makes adopting new AI tools particularly difficult for smaller companies. Errors which arise due to opaque algorithms not only result in erroneous verdicts but also AI-enabled cost error accountability. This has raised ethical and governance concerns AI democracy and human accountability.

➢ *Practitioner Futures and AI Overemphasis*

Feedback from forums and industry practitioners AI has a positive sign, but it is believed that delegating the AI cost estimator would be a huge setback. AI collaboration with the skilled estimator AI is cooperation with a highly skilled estimator, making his or her job easier. Many estimators voice their opinions this way. The primary concerns are the additional costs of implementing AI algorithms as well as the inability of the AI to comprehend the context of the environment without training in advance. There is a consensus that the most advanced AI model or tools will not reach the accuracy of the intended tasks without human control on data hygiene and governance.

V. CONCLUSION

The current review indicates that the use of artificial intelligence (AI) in the area of construction budgeting comes to a drastic change between the years of 2000 to 2023. Cost estimation processes that relied on the expertise of professionals through manual estimation takeoffs, as well as takeoff quantities processes, were increasingly replaced by AI technologies that were capable of performing the tasks with greater accuracy and speed. In addition, these technologies were responsive to real-time shifts in the market (Keymakr, 2023).

Certain machine learning approaches like support vector and neural network models, as well as XGBoost and other ensemble methods, have shown to provide sound predictions for a plethora of projects. XGBoost, is for instance, capable of yielding mean absolute percentage errors (MAPE) of 9% and R^2 scores above 0.9, which far exceeds the performance of outdated methods like regression or case-based reasoning (Elmousalami, 2019; Ingle & Mahesh, 2022).

Ai techniques which utilize natural language processing to parse contracts and allocate costs based on sections of the text to be coded has been shown to extract structured budget data with F1 scores of above 90% (University of Alberta, 2021). Furthermore, computer vision processes that extract quantities from inputs such as BIM and drawings bolster workflows and significantly enhance accuracy (Taghaddos et al., 2019).

VI. RECOMMENDATIONS

- *With that in mind, the following recommendations that tackle the integration of AI in construction budgeting are proposed:*

- Execute Trial Projects Before Company-Wide Rollout
- Try employing systems such as AutoML or computer vision takeoff tools on select projects to integrate AI and later evaluate your ROI, gather feedback, and refine workflows prior to company-wide integration.
- Create and Define Policies on the Ethics of AI
- Construction companies and industry organizations should address data sovereignty, the ethical use of AI, organizational accountability, transparency, and the impact on human resources governance at large in a consolidated policy framework (Liang et al. 2023).
- Set Focus to Teaching and Learning
- Form AI literacy training programs for estimators, cost engineers, and project managers to ensure they are able to interpret the outputs with a critical mind and understand the teams that are responsible for tuning and validating the models.
- Fund Open AI Budgeting Research Initiatives and Collaborations
- Motivate contractors to collaborate with software companies and research institutions to provide anonymized data sets, benchmarking models, and adopt community-wide standards in AI budgeting research.

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