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A Conceptual Framework for Building Cost Estimate using Artificial Intelligence: Convolution Neural Network (CNN) and Wolf Pack Algorithm

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Abstract

The accuracy of cost estimates often depends on the availability of information from the development of building drawings. As a result, this leads to limited information for producing accurate cost estimates for building. Typically, the conceptual cost estimates have a wide accuracy range, which means estimated costs can deviate from actual between -50% to +100% When budgeted costs are inaccurate, the construction costs of a project can be severely impacted. Traditional cost estimation methods in construction projects often rely on expert judgment, historical data, and basic mathematical models, which can be subjective, time-consuming, and prone to errors. Therefore, leveraging on Artificial Intelligence (AI) technologies offers potential to improve the efficiency of cost estimation for construction projects. The aim of the research is to develop an innovative conceptual method for estimating building costs using artificial intelligence. This research adopts a subfield of AI, which are Convolutional Neural Network (CNN) and the Wolfpack Algorithm. The research objective of this paper is to propose a conceptual research framework on AI based cost estimation for construction project and to show that convolutional neural networks are not only suitable for image processing but also for dealing with large amounts of data in quantity surveying accuracy. The research methodology adopted uses an experimental approach where simulation modeling is generated to determine optimal cost estimation for a low-rise building project. A total of 29 residential building cost data such as estimated and actual costs are input in the model. 20 of the data are used for simulation modelling whereas another 9 data are used for testing the model. The results of this research are expected to break the long-standing perception that convolutional neural networks are only suitable for processing images, and the results show that convolutional neural networks combine Wolfpack Algorithm can reduce the error value of construction cost estimation.

1. Introduction

Cost estimation for building projects is an important step as it plays a role in project planning, budgeting, and overall project success (F.H. Abanda, 2017). Accurate and reliable preliminary cost estimates are important to make informed decisions and allocate resources effectively. Traditional cost estimation methods often rely on

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expert judgment (Mirarchi, 2017), historical data, and basic mathematical models which can be subjective, time-consuming, and prone to errors (Fitzgerald, 2010). Artificial Intelligence (AI) has been proposed to have the ability to enhance the accuracy of cost estimation in construction by minimizing the margin of error. According to a study conducted by (Mirarchi, 2017), the use of Artificial Intelligence in estimating the cost of building projects significantly decreases errors to less than 10%. A deviation of less than 10% suggests that the difference between the actual and estimated costs can be either greater than 10% or less than 10%.

There are other studies whom have attempted to use AI in estimating cost for building projects such as In 2017, Jindong Sun used an AI network to predict the price trend of concrete and determined that the use of artificial neural networks could keep the price forecast generally at 3%.Then in 2021, Ximei Li discussed the development of artificial intelligence in the field of preliminary cost estimation of buildings and confirmed the need for development.

The aforementioned studies indicate that there is a significant potential for AI to improve accuracy level in estimating costs for building projects. Despite prior studies that have demonstrated that AI enhances the accurateness of cost estimation, more empirical research is necessary to gain a comprehensive understanding of the range of accuracy it can provide to accommodate the varying dynamics of construction projects. The combination of convolutional neural networks and building initial costs is built upon the study by Xue (2020) where the methodology was applied for preliminary cost estimates for the highway.

2. Literature Review

2.1 Traditional Cost Estimation methods

The Royal Institution of Chartered Surveyors (RICS) describes construction cost control as the process of achieving breakeven in a certain context. (Pal *et al*., 2022b). There are six common traditional cost estimate methods which are.

- Unit area method
- Cube method
- Superficial method
- Elemental cost estimation
- Approximately quantity
- Bill of quantities

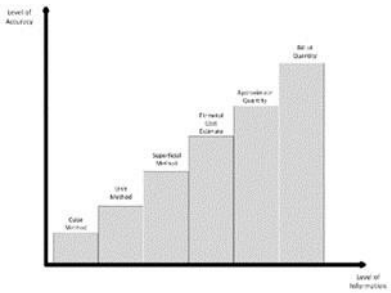

Fig. 1 Accuracy level of estimates

The traditional cost methods are known to have weaknesses in their capacity to deliver the most accurate cost estimation for building projects (Fitzgerald, 2010). The inaccuracy of the cost estimates using the traditional cost methods are such as the lack of hands-on knowledge of the construction process on the part of the personnel responsible for the estimation function (Mirarchi, 2017), lack of sufficient time to prepare the cost estimate, inadequate bidding documents (F.H. Abanda, 2017) and fluctuating prices of subcontractors.Table1 below describes how each method provides a variation between the actual costs and the estimated building costs

Table 1: Each method of a table

Cost estimation methods	Variation between estimated cost and actual costs	(F.H. Abanda, 2017)
Traditional cost estimation method	-50% to +100%	(Fitzgera ld, 2010)

Unit area method	+8%	(Savas ,2 016)
Bill of quantities	+13%	(Wen-der Yu wenderyu and Mirosław J. Skibniewski, 2009)

According to research by Savas (2016) who analysed 316 sample projects found that the actual cost exceeds by 8% more when applied unit area method. Wenderyu et a. (2009), who analysed 200 sample projects, found that the actual cost exceeds by +13% more when used bill of quantities. And then Fitzgerald (2010) found that the actual cost exceeds by -50% to +100% more when used traditional cost estimation method.

2.2 Technologies that facilitate traditional cost estimate.

Traditional cost methods such as bill of quantities are known to be time consuming where 50% to 80% of time is spent on preparing quantities (Pengalex *et al*., 2014). Traditional cost method is now facilitated with the use of software such as BIM related software such as Cost X, Revit and Glodon (Adanda, 2017; Wang qiong, 2021). This software enables quantities and the cost of the construction material to be automated (Zhuwei, 2019). Subsequently, the time for preparing cost budget is 45% less than the manual method (Mirarchi, 2017). Other research has also agreed on the findings by Abanda (2017) such as (F.H. Abanda, 2017) However, the studies did not mention specifically how much less.

Although the availability of these technologies has resulted in quicker cost estimates, there is still evidence of issues with their application. For example, measurements for excavation for different depths were done manually because they were not familiar with the operational tools of the software (Fitzgerald, 2010)

2.3 Application of Artificial Intelligence in construction cost estimate.

The issues presented by prior studies above (Zhang, 2022) indicate that there is an opportunity for further improvement in the methods for estimating costs for building projects. In Artificial Intelligence, there are several sub-fields which are ANN, BP-Neural Network, CNN. The combination of subfields in AI have been suggested that it can yield higher accuracy in estimation and minimize margin of error (Xue,2020). Thus, this research builds upon the work of Xue (2020) and Wang (2021) to further explore the accuracy level of cost estimation for building projects using AI.

2.3.1 Neural network

According to Dou 2023 said “Neural network is a computer system consisting of a number of very simple processing units connected to each other in a certain way, which processes information by the dynamics of its state in response to the input from the outside” (Dou, 2023) Its principles are from the biological thinking process of the human brain ((Ngo *et al*., 2024))

The component under Neural Network includes Recurrent Neural Network (RNN), Convolutional Neural Network (CNN) and BPNeural Network are as shown in Figure 2. (Tao Qian, 2021)

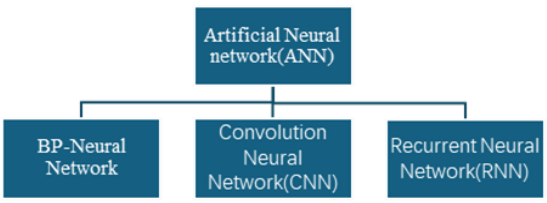

Fig 2 The component under Neural Network

The use of neural networks alone in the field of cost estimation is relatively rare. However, some studies have shown that neural networks can be used in integration with other methods to improve the accuracy and reliability of cost estimation.

For example, CHEN Dong and Zhao Pei-li (CHENG Dong, ZHAO Pei-li, 2022), in their research paper Integration and Innovation of Measurement Software Artificial Intelligence Technology in C++ Programming, point out that

the integration of BP-neural networks with measurement software in C++ Programming can give full play to their respective advantages and improve the accuracy of cost estimation. In addition, Rongchao Jiang and Huayin Han (Rongchao Jiang,Huayin Han, 2023)discussed the application of neural network and big data system integration in cost estimation, arguing that this integrated approach can provide a more effective solution for cost estimation by utilising data-driven and neural network learning capabilities.

Previous research has shown that several of the Neural Network components are applied in construction cost estimates. The specifics of the research are explained in the following sections.

2.3.2 ANN

In China, attempt to improve how preliminary cost estimate for factories is done was seen from the research by Zhuwei (Zhuwei, 2019) where ANN was adopted in the algorithm of estimating. The research found that building construction cost estimate was more accurate compared to traditional method of estimating cost. However, the study did not mention the level of accuracy using this approach. Other studies such as by (Luo,2022) integrated ANN with rough set theory for estimating construction cost. The findings showed the study takes the Yuzhu Immersed Tube Tunnel in Guangzhou, China, as a case study. According to the collected data, the estimated cost of this immersed tube is 1859090kRMB while the actual cost is 95% of the estimated cost, and the absolute error between the value of the immersed tube tunnel and the actual value after using the rough set ensemble BP neural network is 30660kRMB, and the relative error rate is 1.65%, which is able to satisfy the error within the range of 5%. The results of this study show the feasibility and applicability of the algorithm based on the fusion of rough set and BP neural network in the cost estimation of tunnel projects.

Both of the studies used ANN for preliminary cost estimate and claimed that it does improve the accuracy level of cost estimating. Hence, this research indicates that there can be a new method of improving preliminary cost estimate

2.3.3 BP-Neural Network

Apart from ANN, another branch of neural network in AI is called BP Neural Network. The BP neural network is in fact achieved by back-learning with errors and then continuously adjusting the weights of the substructures. (Pan Yuhong, 2016) The function of neural network is also known as the excitation function. (Zhang, 2022) For training of the neural network, the input value should be controlled as far as possible in a way that it will converge more quickly. But the input values should be kept within the range of faster convergence. Therefore, the data should be normalized. (Su *et al*., 2023) The BP neural network has the following three main features:

Firstly, learning the error in the reverse direction, i.e., directional propagation to the input layer.

The second is to distribute the output error signals to each small neural unit at each level.

Thirdly, the weights of each unit are corrected by combining the shared error signals.

Compared with other artificial neural networks, (Pan Yuhong, 2016) BP neural network can solve the complex problem of small samples and non-linear animals to a certain extent, and it can solve the non-linear mapping problem by learning and training the previous sample data and using computer language

Yang Jinyue in 2015 (Jinyue, 2015) proposed the use of BP neural network on the construction project cost prediction research, he constructed the construction project cost prediction index system to clarify the components of the construction project cost, to understand the importance of the construction project cost related modules, chose 26 double-storey factories with an area of not more than 500k square metres as cases, and selected 21 samples as the training set and 5 samples as the test set to obtain a model prediction error of 9.17%, which shows that the BP neural network model can control the error within 10% in general. Therefore, the prediction of the construction cost prediction model constructed by using the BP neural network is very good in predicting the relative error.

2.3.4 CNN

Convolutional Neural Network (CNN) is a multi-layered feedforward neural network proposed by a group of scientists led by Kunihiko Fukushima. (Su *et al*., 2023) It is a multi-layered feedforward neural network whose main feature is the backpropagation method for training. (Sun *et al*., 2022) It is currently a widely used neural network model in various industries. The neural network contains many mapping relations, in which the weights and thresholds of the convolutional neural network are adjusted through continuous error backward learning, and the square sum of the errors of the whole neural network is minimized in the end. (Hosseini & Chitsaz, 2023) It has been the dominant method in computer vision tasks since it shared amazing results at the ImageNet Large Scale Object Recognition Competition.(Zhang *et al*., 2024b) The 2012 Visual Recognition Competition (ILSVRC) CNN has achieved very impressive performances in various domains.(Han *et al*., 2024) Gulshan and Ehteshami Bejnordi *et al*. demonstrated the potential of deep learning for diabetic retinopathy screening, skin lesion classification and lymph node metastasis detection, respectively.(Sherly Alphonse *et al*., 2023) In turn, radiology researchers have become interested in CNNs and several studies have been published in the areas of lesion

detection, classification, segmentation, and image reconstruction. (Hasan *et al*., 2023) Unlike It is different from the application of CNN as image processing in the medical field as the field of architecture, convolutional neural networks are more often combined with BIM to solve the problem of building energy consumption, based on the optimization of convolutional neural networks and BIM, the energy consumption of the building is reduced by 24.52%, and the natural lighting is increased by 18.98%. (F. Xu & Liu, 2023a) Secondly the use of convolutional neural networks for classification of buildings is also a direction of interest for researchers, in 2024 Hafidz R. Firmansyah (Firmansyah *et al*., 2024) demonstrated that convolutional neural networks justify rapid seismic vulnerability assessment at the urban scale. Compared with other neural networks, convolutional neural networks have higher accuracy in processing large amounts of complex data. (Han *et al*., 2024) However in 2021 Xiaojuan Xue (Xiaojuan Xue, 2020) ventured a vision Convolutional Neural Networks be used to reduce errors in construction cost estimation. XUE's result is the use of Convolutional Neural Networks (CNN) to reduce the cost of building cost estimation to 23.78% by computer simulation using 50 cases of highway in China. Wang (Wang, 2021) show that CNN has many advantages, the most important of which is that Convolutional Neural Networks can automatically extract features without the need to manually design and extract features related to construction costs such as features of building materials, design parameters, etc. CNN can automatically learn features at various levels from the original data, which saves a lot of manpower and time costs. Dou (Dou, 2023) show that hese advantages save a lot of labour and time costs, and can capture potential features that may be overlooked manually to increase the correctness of the calculation.They also require fewer parameters to be considered, making them an attractive deep learning method, especially in the case of preliminary building estimates where large amounts of data are required to be processed. The basic principle of convolutional neural networks is shown in Fig.3 below:

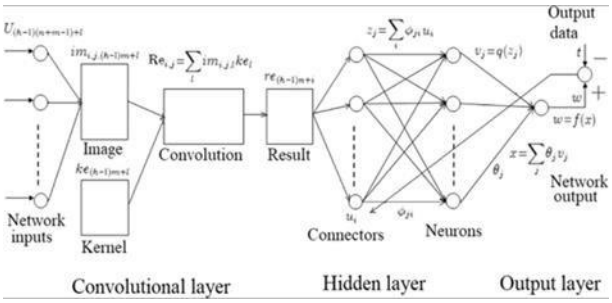

Fig.3 Basic principle of convolutional neural networks (José de Jesús Rubio a, 2024)

2.4 Wolfpack Algorithms

But convolutional neural networks also need more layers and more complex structures to complete the learning task at the same time, to quickly complete the training and learning process, convolutional neural networks need more powerful data processing capabilities or more computational resources. (Dou, 2023) Therefore, the wolfpack Algorithm is introduced, wolfpack algorithms have the advantage of global search (Zhu & Wei, 2018). As a recently proposed group intelligence optimization algorithm, excels in parameter seeking. (He *et al*., 2024) Jiangyuan Zhu in 2018 (Zhu, 2018) showed that demonstrated the wolfpack algorithm to find the optimal solution by simulating the group behaviour of organisms in nature, the wolfpack algorithm has strong local search ability and fast convergence characteristics in dealing with multi-peak function optimization problems can be better to find multiple local optimal solutions and for the construction industry construction projects Wang in 2021(Wang, 2021)has showed that have diversity and complexity of different types, sizes, regions of the construction cost of the larger factors affecting the convolutional The neural network can learn the characteristics of different building projects, and the wolf pack algorithm can optimise the parameters to adapt to various situations, so that the model can perform better in the face of different building data with strong adaptability.

The advantages of wolfpack algorithm and convolution neural network are effectively integrated using wolfpack algorithm to optimize the neural network, the most important thing is the design of the structure. (Wu, 2022) Neural networks can provide reasonable auxiliary functions for wolfpack algorithms, and wolfpack algorithms can be built based on neural networks. The wolfpack algorithm optimizes the connection right of the neural network, the wolfpack algorithm is also able to optimize the weights of the neural network in the corresponding function, firstly adjusting the relevant data so that the neural network has a better connection ability and then all data from the project evaluation system are included in the weights of the neural network. (Zhu & Wei, 2018)

To select the optimal connections in the automatic screening of data and to improve the efficiency of its parameter optimization, the wolf pack algorithm is adopted to solve the weights and biases. Therefore, we invoke the wolf pack algorithm to optimize the model of the convolutional neural network to improve the accuracy values

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2.5 CNN + Wolfpack Algorithms

Through the article above, we have learnt about the features of CNN and Wolfpack algorithms. In the article published by Wang in 2021(Wang, 2021), it is shown that based on the actual work experience, choose to simulate the model through 100 single-storey factories cases, and the results show that compared with the BP neural network wolf pack algorithm, the optimised convolutional neural network model can obtain a better estimation accuracy, with an average relative error of 0.16%.The author found though other article which on the one hand, the convolutional neural network and wolf pack algorithm have complementary functions, convolutional neural network is good at feature extraction and pattern recognition, while wolf pack algorithm is good at optimisation search. On the other hand, according to article (Zhu, 2018), the CNN parameter adjustment method is too single and often relies on gradient descent and other algorithms, which is easy to fall into the local optimal solution, while the wolf pack algorithm, as a group intelligence algorithm, searches the global search space by simulating the hunting behaviour of wolves, which effectively avoids the local optimal solution, and finds a better parameter value to improve the model performance.

Table 2 *Artifical Intelligence Application of a table*

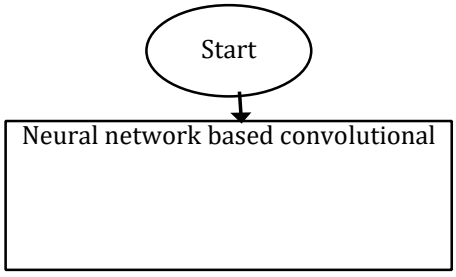
Artificial Intelligence Application	Building category	Number of data samples or case study name	Accuracy cost level	Reference
ANN	Tube Tunnel	YUZHU Tube Tunnel	98.35%	(Luo,2022)
BP-Neural network	Double-storey factories	26	90.83%	(Jinyue, 2015)
CNN	Highway	50	76.22%	(XIAOJUAN XUE, 2020)
CNN + Wolf Pack	Single-storey factories	100	99.84%	(Wang, 2021)

3. Research Methodology

This research adopts a simulation model based on case studies. Software used to analyze data will be Pytorch/Python. The algorithms of the software are customized to suit CNN. The steps for customizing the algorithm in Pytorch/Python follows the work by (Xiaojuan Xue, 2020) and (Wang, 2021) This two research are referred because the data that they use to analyze were on construction costs.

In order to analyse the accuracy level of the cost estimation, this research follows the work by Xue (Xiaojuan Xue, 2020) to understand the specific steps and process acquired for comparing the findings to ascertain the accuracy level of cost estimation.

Figure 4 shows steps to build a CNN neural network model.



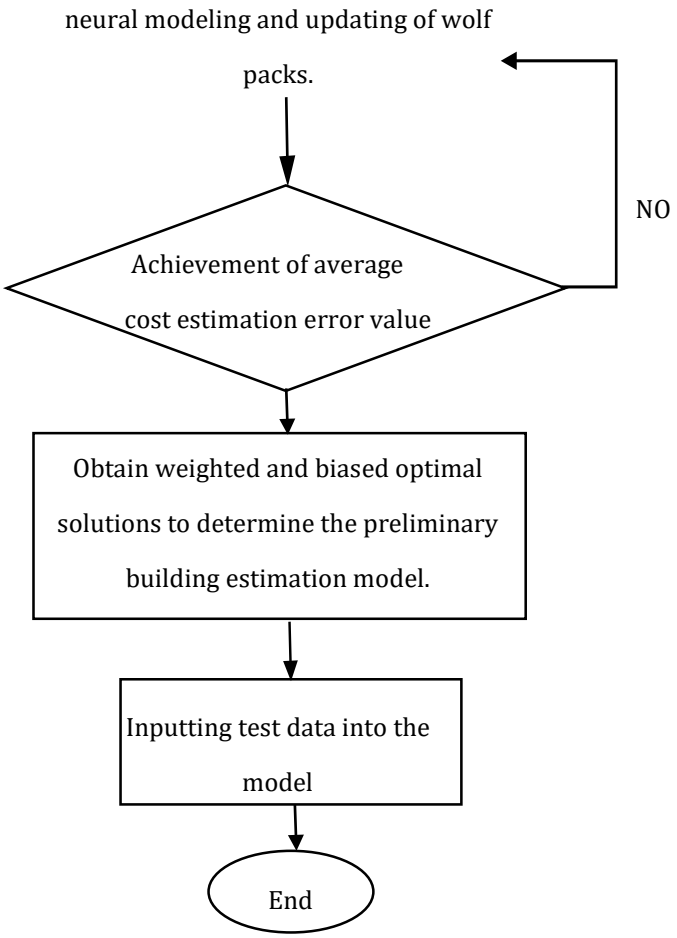
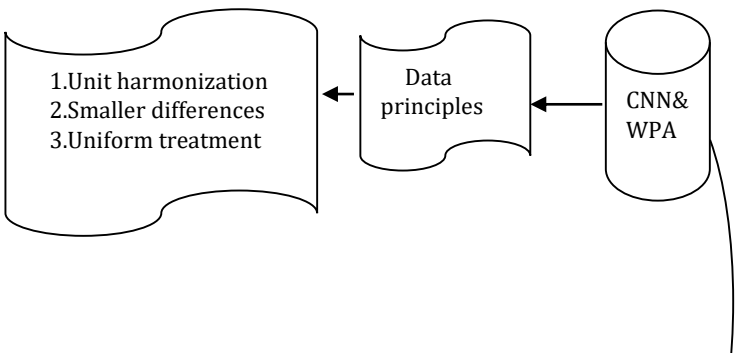


Fig. 4 Build a CNN

3.1 Principles for selecting influencing factors

In order to ensure the accuracy of the model, building construction cost estimate prediction indicators should be a comprehensive and accurate description of the construction project, and the number of indicators should be appropriate, the number of too few is likely to reduce the prediction accuracy, the number is too easy to lead to model complexity, in addition, the identification of indicators should be combined with the specific conditions of the project.. (Luo Sujun, Ren Bin, 2022)

This study starts from the characteristics of the preliminary design stage of buildings combined with the composition of the construction and selects the factors affecting the estimation of the cost of building projects by taking into full consideration of the relevant factors affecting the estimated cost of buildings. (Rongchao Jiang Huayin Han Huangyao Xu, 2023) Reasonable selection of input and output characteristics of variables, can be attributed to the factors affecting the two major categories of the first category refers to the physical consumption in the project cost, which is determined by the characteristics of the building itself; the second category refers to the labor, material and equipment costs and machinery costs, as well as the direct costs calculated on the basis of the physical consumption, which vary according to market conditions and regional differences. (CHEN Zhen, 2023). Figure 5 is show in diagram briefly what are the process to compare.



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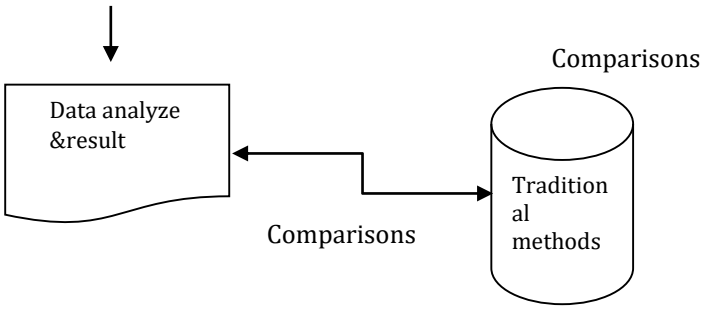

Fig 5 The process to compare

3.2 Selection of model input indicators

In the preliminary design stage of residential buildings, many specific technical parameters are still unclear, and the selection of data focuses on the consideration of the engineering characteristics of the residential building itself. (Chen Zhen, 2023) Such as architectural features, structural features, as follows (Zhou Jie, 2022). As for the first part:

(1) Architectural features. It is mainly a reflection of the scale of the residential building, including the total floor area, underground area, above ground area, building height, and the number of floors above ground.

(2) Structural characteristics. It mainly includes structure type, seismic intensity, structure material and stair structure.

As for the second part of the preliminary estimation of the installation cost such as labor cost machinery cost, according to the case elaboration in the (Chen Zhen, 2023), we can see for the study of the project cost in the China, one part of the authors only take the project cost data within the same indeed or similar time period as the research object without considering it regionally and temporally; and the other part of the scholars mostly select the project cost index as the dynamic adjustment factor, but the engineering cost index relies on the compilation and release of the government cost management department, and there is a delay. (Luo Sujun, Ren Bin, 2022)To improve the accuracy of the project cost estimation and the generalization ability of the calculation model, we can select the factors affecting the installation cost are the two indexes that are more closely related to the project cost and easier and timelier to obtain: the construction labor cost price and the construction material cost index, which will be taken from the Malaysian construction website. (Kim K J., 2010)

According to the introduction of the CNN model above, the CNN mainly consists of a convolutional layer, a pooling layer and a fully connected layer. The pooling layer is used to compress the feature map, extract the main features, and reduce the dimensionality to reduce the amount of data; however, in this study, the dimensionality of the data used is not very high, and the characterization is not very strong; therefore, we choose to delete the pooling layer according to the Xiaojuan Xue's (Xiaojuan Xue, 2020)method to avoid the necessary data being deleted by the neural network. The data was then analysed by integrating the data in Table 1. Some of the data on the impact of the selection of building materials on the initial cost of the building according to N3C, as well as the estimated and actual values of the initial cost of the building, were then extracted through a convolutional layer and then a fully connected layer was used at the end of the neural network to create a combination of the nonlinear features and to make a prediction

3.3 Case Study Selection

For this research, building cost data from China will be used as shown in Table 3.

Table 3 *Building cost data of a table*

Total number of samples	Building Category	Location	Building area above ground	Building area below ground	Total building height	Average price of steel reinforcement	Average price of concrete	Actual construction cost per square meter
1	Residential	China	111041.85	0	117	6060.00	566.00	0.748
2	Residential	China	54256.26	0	152	6060.00	425.00	0.799
3	Residential	China	72689.19	0	24	5100.00	456.00	0.793
4	Carpark	China	0	15648.42	4.5	5100.00	586.00	0.547
5	Carpark	China	0	366.71	4.5	5100.00	425.00	0.176
29	Carpark	China	0	27828.40	4.5	5811.00	650.35	0.257

Data input into the model for simulations are List down the specific unit data for each sample of building

Table 4 *Specific unit data of a table*

Data	Unit of Analysis
Building area above ground	m^2
Actual Building Cost	CNY ¥
Building area below ground	m^2
Total building height	m
Average price of steel reinforcement	CNY¥/T
Average price of concrete	RMB/m^3
Actual construction cost per square meter	CNY¥/10000/m^2

3.4 Relative error

Relative error is expressed as the ratio of the absolute error of the measurement to the actual measured value. (Zulfiqar *et al*., 2023) Relative error is usually more meaningful than absolute error because if the difference between the estimated cost of the preliminary construction cost and the actual cost of the construction is small, the magnitude of the relative error is also smaller because it quantifies the percentage error. (Ren *et al*., 2023)

The formula for the relative error is

$$(x_0 - x) \div x = r\text{elative error} \quad (1)$$

Indicates an estimate of the preliminary cost of construction, representing the actual cost of the initial cost of construction. (Yang *et al*., 2023)

4. Conclusion

This article exploring the status of initial cost estimation of construction proposed the use of wolf pack algorithm optimized convolutional neural network and breaking the long-standing perception that convolutional neural networks are unsuitable for handling large amounts of data in the construction industry, the optimised convolutional neural network using the wolf pack algorithm has better capabilities in processing parameters and global grasping but the construction estimation method is flexible specific conclusions need to be decided according to the actual situation

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Liu Yuexiang and, Nurul Sakina Mokhtar Azizi;* ***data collection:*** *Liu Yuexiang;* ***analysis and interpretation of results:*** *Liu Yuexiang;* ***draft manuscript preparation:*** *Liu Yuexiang and, Nurul Sakina Mokhtar Azizi. All authors reviewed the results and approved the final version of the manuscript.*

References

Blüher, T., Billiet, H., & Stark, R. (2022). Model Building for better Transfer of AI Systems using Reinforcement Learning from Simulation to the Physical World. *Procedia CIRP*, *109*, 113–118 https://doi.org/10.1016/J.PROCIR.2022.05.223

CHENG Dong, ZHAO Pei-li. (2022). Integration and Innovation of Measurement Software Artificial Intelligence Technology in C++ Programming. China Academic Journal Electronic Publishing House http://doi.org/10.3969/j.issn.1006-4311.2022.26.031

CHEN Zhen. (2023). Research on Cost Estimation Method of Different Stages of Overseas Engineering Projects. *Value Engineering, 99-101.* https://doi.org/10.14018/j.cnki.cn13-1085/n.2020.09.041

Cynthia Changxin Wang. (2014). A Comparison of Using Traditional Cost Estimating Software and BIM for Construction Cost Control. 2014 International Conference on Construction and Real Estate Management, 26-34. https://doi.org/10.1061/9780784413777.031

Dou, H. &. (2023). Understanding neural network through neural level visualization. *Neural Networks,168, 484-495*. https://doi.org/10.1016/J.NEUNET.2023.09.030

Firmansyah, H. R., Sarli, P. W., Twinanda, A. P., Santoso, D., & Imran, I. (2024). Building typology classification using convolutional neural networks utilizing multiple ground-level image process for city-scale rapid seismic vulnerability assessment. *Engineering Applications of Artificial Intelligence*, 131 https://doi.org/10.1016/J.ENGAPPAI.2023.107824

F.H. Abanda, B. K.-F. (2017). BIM – New rules of measurement ontology for construction cost estimation. *Engineering Science and Technology,* 443-459.https://doi.org/10.1016/j.jestch.2017.01.007

Fitzgerald, A. A. (2010). A survey of current cost estimating practices in the UK. *Construction Management and Economics*, 161-172. https://doi.org/10.1080/014461900370799

Mirarchi, C. (2017). Comparison between traditional and digital preliminary cost-estimation approaches. *Innovative Infrastructure,* https://doi.org/1-8. /10.1007/s41062-017-0066-7

Han, Q., Qian, X., Xu, H., Wu, K., Meng, L., Qiu, Z., Weng, T., Zhou, B., & Gao, X. (2024). DM-CNN: Dynamic Multi-scale Convolutional Neural Network with uncertainty quantification for medical image classification. *Computers in Biology and Medicine*, 168. https://doi.org/10.1016/j.compbiomed.2023.107758

Hasan, M. M., Hossain, M. M., Rahman, M. M., Azad, A. K. M., Alyami, S. A., & Moni, M. A. (2023). FP-CNN: Fuzzy pooling-based convolutional neural network for lung ultrasound image classification with explainable AI. *Computers in Biology and Medicine,* 165, https://doi.org/10.1016/J.COMPBIOMED.2023.107407

He, Y., Wang, J., Liu, X., Wang, X., & Ouyang, H. (2024). Modeling and solving of knapsack problem with setup based on evolutionary algorithm. *Mathematics and Computers in Simulation, 219*, 378–403. https://doi.org/10.1016/J.MATCOM.2023.12.033

José de Jesús Rubio a, D. G. (2024). Stable convolutional neural network for economy applications. *Engineering Applications of Artificial Intelligence*, 132,https://doi.org/10.1016/j.engappai.2024.107998

Kim K J. (2010). Preliminary Cost Estimation Model using Case-Based Reasoning and Genetic. J*ournal of Computing in Civil Engineering ASCE*, 499-505. https://doi.org/10.1061/(ASCE)CP.1943-5487.0000054

Kouslous Vasily, Koehn Edward. (1974). Predesign Cost-Estimation Function for Buildings[J]. *Journal of the Construction Division ASCE*, 589-604. https://doi.org/10.1061/JCCEAZ.000046

Luo Sujun, R. B. (2022). Study on Cost Modeling and Estimation of Tunnel Engineering Based on BP. *Engineering Cost Management*, 45-51. https://doi.org/10.19730/j.cnki.1008-2166.2023-03-045

Ngo, Q.-H., Nguyen, B. L. H., Vu, T. V., Zhang, J., & Ngo, T. (2024). Physics-informed graphical neural network for power system state estimation. *Applied Energy, 358*. 122602. https://doi.org/10.1016/J.APENERGY.2023.122602

PengAlex ZHAO, Changxin Cynthia WANG. (2014). A Comparison of Using Traditional Cost Estimating Software and BIM for Construction Cost Control. *ICCREM*, 256-264. https://doi.org/10.1061/9780784413777.031

PAN Yuhong, Z. Y. (2016). Research on Highway Engineering Cost Estimation Based on the GA-BP Algorithm. *JOURNAL OF CHONGQING JIAOTONG UNIVERSITY (NATURAL SCIENCE)*, 141-145. https://doi.org/10.1007/978-3-662-46994-1_37

Pal, R., Roy, S., & Thakur, B. (2022a). Assessment of energy efficiency for traditional non-engineered and engineered residential buildings – A case of North-Eastern India. *Materials Today: Proceedings, 61, 440–451.* https://doi.org/10.1016/J.MATPR.2021.11.538

Rongchao Jiang Huayin Han Huangyao Xu. (2023). Application of Big Data and Artificial Intelligence Technology. *China Academic Journal Electronic Publishing House*, 32-37. https://doi.org/2096-255X（2020）07-0032-06

Ren, M., Zhao, S., & Wang, M. (2023). Optimal subsampling for least absolute relative error estimators with massive data. *Journal of Complexity, 74,* 101694. https://doi.org/10.1016/J.JCO.2022.101694

Sherly Alphonse, A., Abinaya, S., & Abirami, S. (2023). Alibaba and forty thierves algorithm and novel Prioritized Prewitt Pattern (PPP)-based convolutional neural network (CNN) using hyper spherically compressed weights for facial emotion recognition. *Journal of Visual Communication and Image Representation, 97,* 103948. https://doi.org/10.1016/J.JVCIR.2023.103948

Sun, H., Niu, Y., Li, C., Zhou, C., Zhai, W., Chen, Z., Wu, H., & Niu, L. (2022). Energy consumption optimization of building air conditioning system via combining the parallel temporal convolutional neural network and adaptive opposition-learning chimp algorithm. *Energy, 259.* 125029 https://doi.org/10.1016/J.ENERGY.2022.125029

Savas Bayram, Ph.D.1. (2016). Efficacy of Estimation Methods in Forecasting Building Projects' Cost. *American Society of Civil Engineers*, 142(11). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001183

Tao Qian. (2021). A preliminary study of the use of artificial intelligence technology in engineering costing. *China Academic Journal Electronic Publishing House*, 174-175.

https://doi.org/1674-1900（2021）16-0174-02

Wang Shuping, Huang lianghui. (2021). Construction Engineering Cost Estimation Based on Convolution Neural Network. *Microcomputer Applications,* 37(7). https://doi.org/007-757X(2021)07-0048-04

Wen-der Yu wenderyu and Mirosław J. Skibniewski. (2009). Integrating Neurofuzzy System with Conceptual Cost Estimation to Discover Cost-Related Knowledge from Residential Construction Projects. *Journal of Computing in Civil Engineering*, 23-26. https://doi.org/10.1061/(ASCE)0887-3801(2010)24:1(35)

Wang, S. L. (2021). Construction Engineering Cost Estimation Based on Convolution Neural Network. Microcomputer Applications. Microcomputer Applications, 48-51.

Wang qiong. (2021). Construction Costing for Artificial Intelligence. *Journal of information technology in Civil Engineering and Architecture,* https://doi.org/120-124. 10.14181/j.cnki.1002-851x.202010069

Wu, Y. (2022). Application of neural network prediction model based on Wolf Pack algorithm in electricity sales side. *Asia Conference on Power and Electrical Engineering (ACPEE)*, 15-17 https://doi.org/10.1109/ACPEE53904.2022.9783936

Xiaojuan Xue, Y. J. (2020). Expressway Project Cost Estimation With. IEEE, 48-66. https://doi.org/10.1109/ACCESS.2020.3042329

Xu, F., & Liu, Q. (2023a). Building energy consumption optimization method based on convolutional neural network and BIM. *Alexandria Engineering Journal*, 77, 407–417. https://doi.org/10.1016/j.aej.2023.06.084

Yang Xu, Shuang Cao. (2023). Building Engineering Cost Prediction Model Based on TSNE and Improved Grey Correlation Algorithm. *Procedia Computer Science*, 956-965. https://doi.org/10.1016/j.procs.2023.11.126

Yang, F., Li, Z., Xue, Y., & Yang, Y. (2023). A penalized least product relative error loss function based on wavelet decomposition for nonparametric multiplicative additive models. *Journal of Computational and Applied Mathematics*, 432 https://doi.org/10.1016/j.cam.2023.115299

Zhou Jie. (2022). Case Design of Engineering Quantity Estimation Based on R Software. China Academic *Journal Electronic Publishing House*, 20-28. https://doi.org/10.19730/j.cnki.1008-2166.2021-06-020

Zhang, H. (2022). A novel method based on a convolutional graph neural network for manufacturing cost estimation. *Journal of Manufacturing Systems*, 837-852. https://doi.org/10.1016/J.JMSY.2022.10.007

Zhu, J., & Wei, Z. (2018). Research of Wolf Pack Algorithm. *International Conference on Intelligent Transportation*, 25-26. https://doi.org/10.1109/ICITBS.2018.00180

Zhuwei, C. (2019). Integrated Cost Estimation System Based on Artificial Intelligence. *Technical Economy*, 38-39. https://doi.org/10. 3969/ j. issn.1006 − 5539. 2020. 01. 020

Zhang, Y., Li, N., Zhao, T., & Li, Z. (2024b). An energy-saving design method for residential building group based on convolutional neural network. *Journal of Building Engineering*, 82https://doi.org/10.1016/j.jobe.2023.108291

Zulfiqar, U., Du, X., Song, Q.-Y., Xiao, Z.-H., & Sreeram, V. (2023). Relative error-based time-limited H2 model order reduction via oblique projection. *Journal of the Franklin Institute,*25-27 https://doi.org/10.1016/J.JFRANKLIN.2023.12.051