An Efficient Novel Model for Multi-Story Building Construction Quantity Estimation using Coupled MATLAB-Revit Software

Suha Falih Mahdi Alazawy
Department of Highway and Airport Engineering, College of Engineering, University of Diyala, Ba'aqubah, Diyala, Iraq
suha.falih@uodiyala.edu.iq, falehsuha@gmail.com (corresponding author)

Saja Hadi Raheem Aldhamad
Department of Civil Engineering, College of Engineering, Al-Iraqia University, Baghdad, Iraq
saja.h.raheem@aliraqia.edu.iq

Bilal Muiassar M. Salih
Department of Civil Engineering, College of Engineering, Al-Iraqia University, Baghdad, Iraq
blal.muasser@aliraqia.edu.iq

Faiq Mohammed Sarhan Al Zwainy
Forensic DNA Center for Research and Training, Al-Nahrain University, Jadriya, Baghdad, Iraq
faiq.m.al-zwainy@nahrainuniv.edu.iq

Received: 22 August 2024 | Revised: 11 September 2024 | Accepted: 14 September 2024

ABSTRACT

The nature of the construction business and building projects necessitates the capacity to manage extensive and intricate data and documentation. The processes for documenting, exchanging, and updating data constitute one of the principal administrative challenges being currently confronted by the construction project management. As a consequence of the continued reliance on paper-based processes evidenced in the Iraqi businesses and construction projects, a considerable volume of documentation is likely to accumulate, thereby increasing the complexity and time required for specific data to be retrieved. In this study, the Support Vector Machine (SVM) and Building Information Modeling (BIM) models were used to document projects by employing the MATLAB-Revit software. The findings demonstrate that the project timeline is also recorded because it is related to the suggested model, which is designed to produce an effective model that mimics reality. A comparative analysis of the data pertaining to the foundations, columns, walls (24 cm and 12 cm), floors, and slabs of four multi-story buildings, was conducted. This analysis was divided into three categories: estimated, SVM-BIM, and actual documentation. The findings indicated that the proposed model demonstrated a high degree of accuracy in predicting the material quantities required in building construction. These values were found to be in close proximity to, and aligned with, the actual documentation.

Keywords-multi-story building; cost estimation; support vector machines; building information modeling; coupled MATLAB-revit

I. INTRODUCTION

In the initial stages of planning, the feasibility of a project can be analyzed by developing conceptual cost estimates. Inaccurate cost assessments have a detrimental impact on the viability of a project. However, an underestimated cost may lead planners to believe that it is highly practical, which would result in the client incurring additional costs during the construction phase. It is therefore essential to adopt an accurate measuring approach, as any overstatement or understatement in expenditure will have an impact on the customer's earnings. [1, 2]. The conceptual cost of a building project can be determined through the application of a variety of research methodologies, as outlined in the supplementary literature. A substantial amount of attention has been dedicated to Neural Networks (NNs) in this field, particularly over the past decade. The conceptual evolutionary cost estimation models were developed using the Evolutionary Fuzzy Neural Inference Model (EFNIM). Nevertheless, the attainment of an optimal solution necessitates an exceedingly lengthy computational period [3]. Subsequently, the SVM model was applied to the construction industry with the objective of assessing the accuracy of the conceptual cost estimate. It was recommended that a strategy based on SVM be employed to predict the cost of the construction project. The findings indicated that the least-squares SVM exhibited superior prediction accuracy compared to the NN [4].

It is essential to implement effective strategies for the treatment and continuous updating of construction management documents in order to efficiently address the common challenges posed by changes in the construction projects. Document management has become a significant concern for contemporary construction firms, with construction papers representing an integral aspect of any procedure that manages building project information [5]. The examination of data monitoring and comprehensive statistics regarding time expenditure due to the presence of incompatible information was presented. This was achieved by demonstrating how historical projects in Jeddah can be documented using BIM-3D and GIS, thus ensuring their preservation and adaptation. The findings of a global survey that involved the participation of numerous nations were analyzed, and evaluated with the objective of examining the records of managed projects and construction documents. Authors in [6] documented case studies from inception to completion, and others which employed commercial software to integrate BIM-GIS. The accurate estimation of a concept based on historical cost data is a challenging task. It is not feasible to deploy linear estimation methodologies in the construction industry [7]. The Statistical Learning Theory (SLT) in the late 1960s led to the introduction of the initial SVMs. However, in the mid-1990s, with the advent of more powerful computing resources, SVM-specific algorithms emerged, facilitating the development of several influential practical applications. The fundamental SVM, as addresses two-class problems in which data are divided along a hyperplane, as determined by a set of support vectors [8, 9]. This section provides an introductory overview of SVM

A Least-Square Support Vector Machine (LS-SVM) represents a novel approach to machine learning that builds upon the foundations of standard SVM. In contrast to the standard SVM, which is associated with a lengthy and computationally intensive quadratic programming problem, the LS-SVM necessitates the resolution of a restricted number of linear equations. Furthermore, the LS-SVM incorporates a least-squares costing methodology [9]. SVMs are designed with the specific purpose of developing an innovative ability to assign scenarios to distinct categories based on the class labels provided. The following formula can be used to describe the largest range hyperplane:

$$y = b + \sum w_i y_i x(i) x \qquad (1)$$

where *x* is a test example and *x*(*i*) are the support vectors. The SVM is tasked with learning the parameters *b* and w_i, which are responsible for determining the hyperplane. The resolution of the following problem is necessary to generate an ideal hyperplane through convex QP:

$$Minimize\ \frac{1}{2}\|w\|^2$$

$$Subject\ to\ y_i(wx_i + b) \geq 1, i = 1, \dots, n \qquad (2)$$

where $K(x(i), x)$ is the kernel function. Several kernels are available to create the inner products needed to construct SVMs with different nonlinear decision surfaces. The most commonly deployed kernel function is the Gaussian Radial Basis Function $K(x,y) = exp\,(-1/\delta^2(x-y)^2$ and the polynomial kernel $K(x,y) = (xy + 1)^d$, where d is the degree of the polynomial kernel and δ^2 is the bandwidth of the Gaussian radial basis function [10-12]. The application of SVMs to regression tasks, with a particular focus on the LS-SVM variant aims to minimize prediction errors by finding a function that closely fits the training instances, thereby reducing the risk of overfitting:

$$Minimize\ \frac{1}{2}\|w\|^2$$

$$Subject\ to\ y_i(wx_i + b) \leq \varepsilon \qquad (3)$$

where ε≥0 represents the bound on the prediction error. The previously mentioned convex optimization problem will be feasible if $f = \langle w,x \rangle + b$ exists in reality and approximates all pairs (x_i, y_i) with ε precision. In order to address the constraints that are typically unattainable, the loose variables φ_i, j_i^* are inserted into the optimization problem:

$$Minimize\ \frac{1}{2}\|w\|^2 + C\sum_{i=1}^{l}(\varphi_i, \varphi_i^*)$$

$$Subject\ to \begin{cases} y_i - \langle w, x_i \rangle - b \leq \varepsilon + \varphi_i \\ \langle w, x_i \rangle + b - y_i \leq \varepsilon + \varphi_i^* \\ \qquad \varphi_i, \varphi_i^* \end{cases} \qquad (4)$$

By employing the constant C, it is possible to ascertain the trade-off between f-flatness and the maximum permissible deviation (ε). This optimization issue may be formulated as a dual problem by the construction of a Lagrange function, which is:

$$b^* = y_i - \langle w, x_i \rangle - \varepsilon, 0 \leq \lambda_i \leq C, i = 1, \dots, l$$

$$b^* = y_i - \langle w, x_i \rangle - \varepsilon, 0 \leq \lambda_i^* \leq C, i = 1, \dots, l \qquad (5)$$

$$\lambda_i, \lambda_i^* \geq 0$$

Applying the Lagrangian yields the optimum parameters $w^*$and b^*:

$$L = \frac{1}{2}\|w\|^2 + C\sum_{i=1}^{l}(\varphi_i, \varphi_i^*) - \sum_{i=1}^{l}\lambda_i(\varepsilon + \varphi_i - y_i + \langle w, x_i \rangle + b) - \sum_{i=1}^{l}\lambda_i^*(\varepsilon + \varphi_i^* - y_i + \langle w, x_i \rangle - b) \qquad (6)$$

In a manner analogous to the preceding classification, the interior products of nonlinear problems may be modified through the utilization of appropriate kernels. The establishment of a maximum *C* on the absolute magnitudes of the coefficients demonstrates the trade-off between minimizing prediction error and maximizing the correlation function's flatness. The shape of the regression function is constrained by an upper limit, which the user must specify. As the value of *C* increases, the function was made to approach the data more closely. The method uses least absolute-error regression, with a constraint on the magnitude of the coefficients, in the event of degenerate behavior when ε=0. In this instance, all the training samples are transformed into support vectors. Conversely, if the value of *C* is sufficiently large, the resulting error is reduced to zero. Regardless of the value of C, the method provides a flattest curve that encompasses the data. [13-15]. The technique provides a flattest curve that encompasses the data, regardless of the value of *C*, provided that it is sufficiently large to cause the error to decline to zero [16]. BIM is defined as "an ever-evolving collaboration tool that facilitates integrated design and construction management." The assessment of a building design's sustainability is a relatively straightforward process, as it entails a number of fundamental functions for the analysis of buildings. [17, 18]. BIM initiatives have the potential to facilitate multidisciplinary collaboration, reduce contract value by 10%, achieve time savings of 7% on projects due to early collision detection, and produce cost estimates in as little as 80% of the time when compared to traditional methods [19]. This results in enhanced team collaboration, which in turn leads to a reduction in errors, increased productivity, efficiency, quality, and sustainability. [20]. BIM can assist in meeting the client's demands for consistent cost, quality, and timely delivery in a manner that is both efficient and effective. The specific characteristics in question may be attributed to the general information contained within the BIM, which also contributes to defining the framework in accordance with the data available for use. This is dependent upon the phase of the project in question, the requirements of the project at hand, and the quality standards of the company in question. [21, 22]. Prior research has demonstrated the efficacy of BIM in addressing design issues, monitoring project progress through the usage of visualized deadlines, and conducting simulations for integrated project delivery [23]. The findings demonstrated the value of utilizing BIM technology throughout the building stage for overcoming difficulties related to the particular implementation procedure, improving construction quality, reducing construction costs, and meeting the criteria for green construction management [24].

The most popular software is Autodesk Revit, which is a tool for examining three-dimensional models used in the fields of design, engineering, and construction. Furthermore, it performs clash detection analysis, facilitates design team cooperation, manages project model coordination, and oversees scheduling. It is also employed for photorealistic rendering when high-quality photographs of projects are required. A BIM tool, developed by Bentley Systems, Revit, is a highly sophisticated software with features that facilitate the step-by-step documentation of tasks [25]. The software is used for the management of construction project schedules, as well as in a multitude of civil construction projects, including the development of structures, infrastructure, roadways, and bridges [26, 27]. This suggests that the advancement of BIM technology has facilitated the integration and interchange of building information across different life phases. The BIM framework is founded upon three fundamental concepts: BIM Lenses, BIM Stages and BIM Fields. The term "BIM lenses" is used to describe a number of different approaches to understanding the BIM domain. These can be broadly classified into two categories, those which focus on identifying and highlighting the aspects of the domain that meet the necessary requirements for study, and secondly, those which seek to filter out and exclude the aspects which do not meet the required criteria. The usage of the SVM plugin in conjunction with BIM software facilitates the interfacing of BIM frameworks with SVM stages. The integration of SVM-BIM is still in progress for both the academic and industrial sectors, but it offers advantages. Although still in its infancy, BIM has the potential to enhance green building design in a variety of ways [28]. The complexity of the concept of sustainability and the challenge of incorporating it into the initial modeling stages, along with the usage of techniques for object mapping and data processing, were identified as the two principal obstacles in this regard [29, 30]. Nevertheless, the application of BIM integration in green building design has attracted growing interest, given its enhanced effectiveness and sustainability [31, 32]. This paper introduces a novel model that merges SVM and BIM in order to enhance construction project documentation and cost estimation in Iraqi projects. By employing cross-validation, the model ensures precise outcomes and addresses deficiencies in existing methodologies. By deploying advanced technologies, this model not only ameliorates the accuracy of cost estimation but also improves efficiency, therefore providing a pioneering solution for the effective management of the construction projects.

II. METHODOLOGY

The methodology presented in the current paper is divided into several sections, each contributing to the fulfilment of the objective. The initial strategy entails the integration of multiple software applications or expert bills of quantity, complemented by the incorporation of external data. The second technique involves the analysis of construction supplies through the integration of variables derived from a BIM model and SVM data. The third strategy employs an efficacious interconnection between BIM models and the SVM database, hence ensuring a well-informed decision-making process [33]. Nevertheless, it should be noted that SVM-BIM integration is not without its limitations. This study demonstrates the integration of SVM tools with MATLAB-Revit software for the purpose of enhancing construction project management, as portrayed in Figure 1. The process involves the transfer of SVM data from BIM models to specific software, thereby certifying compatibility and efficiency. The use of SVM profiles within the BIM model facilitates the establishment of a seamless workflow, optimizing project documentation and cost estimation.

In this study, the building information modeling software was applied to conduct a quantity and quality assessment of four multistory structures:

- Project one: Al-Maaref Residential Building. As depicted in Figure 2(a), this is one of the private sector initiatives in Theqar Governorate, Iraq, where this project is considered to be one of the most significant projects. The total area was about 650 m^2. The local company was awarded the contract at an estimated cost of \$1,050,000. The structure was 14 m high and had four floors. This structure houses thirty-five apartments.

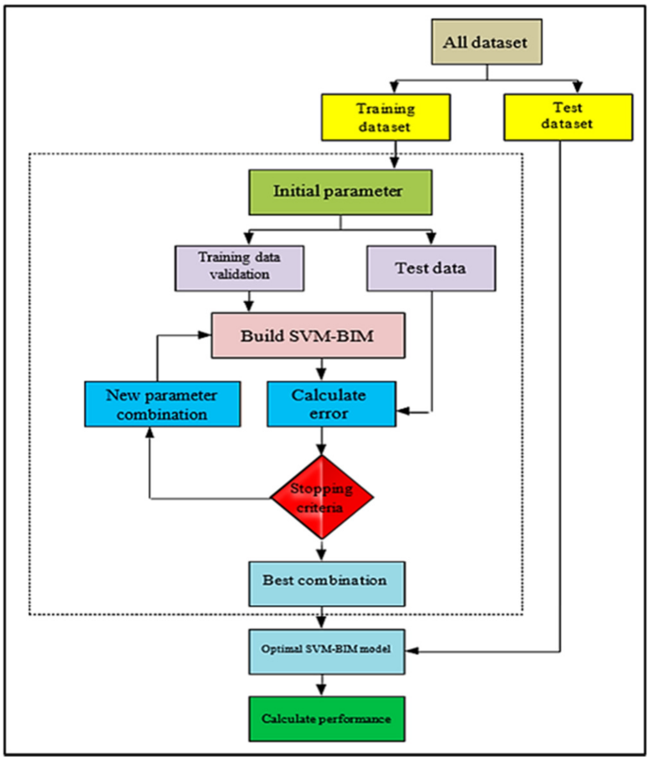


Fig. 1. The proposed SVM-BIM model.

Fig. 2. Selected multi-story case studies: (a) Al-Maaref resident building, (b) Kanan health department, (c) Civil engineering department, (d) Al-Shefaa health department.

- Project two: Kanan Health Department. This project is categorized as a public sector initiative, as illustrated in Figure 2(b). The total area was about 2,250 m^2. The local company was contracted to carry out the work at a cost of approximately \$2,700,000. The structures were 20 m high and had seven stories. This structure houses seventy-two clinic rooms.
- Project three: Civil Engineering Department. It is located at Al-Salam University, Iraq. This project is categorized as a public sector initiative, as evidenced in Figure 2(c). The total area was approximately 400 m^2. The local company was awarded the project at a cost of approximately \$1,800,000. The structures consisted of eight floors with a height of 24 m. On each floor there were 15 offices, 5 large classrooms with 120 seats and 3 health facilities.
- Project four: Al-Shefaa Health Department. This project is considered a private sector project, as shown in Figure 2(d). The total area was approximately 750 m^2. The project was assigned to a local company at an estimated cost of \$1,650,000. The total height of the building was 17 m and it had seven floors. The ground floor started at a height of 2.55 m and ended at a height of 4.55 m. It contained 28 apartments, and each flat included 3 clinic rooms: reception, kitchen and sanitary facilities.

The SVM-BIM model was implemented on a dataset derived from real construction data, with the objective of assessing the impact of six key components on project costs. A robust validation strategy is employed to evaluate the efficacy of cost estimation at the conceptual stage, thereby aiding in site investigations and owner requirement categorization. The effectiveness of the suggested approach is evaluated using three indicators: Mean Absolute Percentage Error (MAPE), Mean Square Error (MSE), and the percentage between the actual and the estimated values (7-9):

$$\text{MAPE} = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{y_i-\widehat{y_i}}{y_i}\right| \times 100\% \quad (7)$$

$$\text{MSE} = \frac{\sum_{i=1}^{N}(y_i-\widehat{y_i})^2}{\sum_{i=1}^{N}(y_i-\bar{y})^2} \quad (8)$$

where y_i and $\hat{y}_i$represent the actual and estimated values of the i-th dataset, respectively. y is the average of the actual data and N is the amount of data. In order to achieve the desired outcomes, it is necessary to adhere to the following:

- A novel SVM-BIM model was developed using the MATLAB-Revit software to record the scheduled time of the projects.
- A comparison of the volumes of the SVM-BIM documentation with those of the manual documentation is required.
- The quantity of the actual documentation must be evaluated in comparison to that of SVM-BIM.

III. RESULTS AND DISCUSSION

A comprehensive analysis was applied to all structural elements pertaining to each of the case studies under consideration. To give an example, in Project two, the structural elements of the basic structure are shown in Figure 3, which was created using the Revit software. In order to facilitate the requisite comparisons within the current research methodology, all construction materials employed in the field were duly enumerated. The principal outcomes are presented and discussed in comparison with the Quantity Take-Off (QTO) among the as-planned quantity (estimated), the actual quantity, and the as-built quantity computed by the proposed SVM-BIM model.

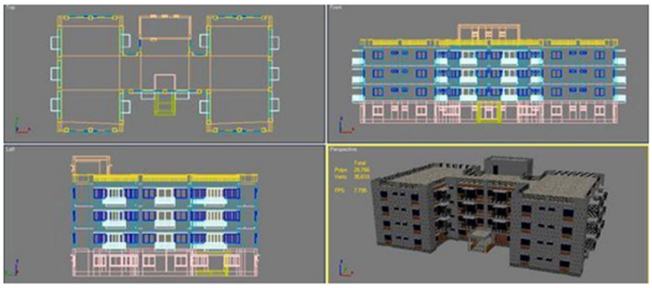


Fig. 3. Structural elements of project two.

A. *Quantities of the Materials*

a) Quantities of the Foundation Works

Project one shows the variation in foundation quantities: estimated 228 m^3, actual 220 m^3, and model calculated 223.25 m^3. Table I presents the details of these figures and the discrepancies: actual vs. estimated (-3.51%), SVM-BIM vs. estimated (-2.08%), and model vs. actual (1.48%). This comparison underlines the efficiency of the model in approximating the actual construction quantities with high accuracy. The percentage was calculated according to the following equations:

$$\text{Percentage between Actual and Estimated} = (\text{Actual}-\text{Estimated})/\text{Estimated} \times 100\ \% \tag{9}$$

$$\text{Percentage between SVM}-\text{BIM and Estimated} = (\text{BIM}-\text{Estimated})/\text{Estimated} \times 100\ \% \tag{10}$$

$$\text{Percentage between SVM}-\text{BIM and Actual} = (\text{BIM}-\text{Actual})/\text{Actual} \times 100\ \% \tag{11}$$

TABLE I. QUANTITIES OF THE FOUNDATION

Details		Project			
		1	2	3	4
Quantity (m^3)	BOQ (estimated)	228	660	330	460
	BOQ (actual)	220	650	319	451
	BOQ (SVM-BIM)	223.25	652.65	322	454
Comparison percentage (%)	Actual & estimated	-3.51	-1.52	-3.33	-1.96
	SVM-BIM & estimated	-2.08	-1.11	-2.42	-1.30
	SVM-BIM & actual	1.48	0.41	0.94	0.67

The results demonstrated that modern technologies, such as SVM-BIM, can be used to predict the actual quantities of building foundations. For projects two, three, and four, Tables II-VI show other comparative percentages between the estimated quantities, SVM BIM model predictions, and actual documentation for building components, such as foundations, columns, walls, floors and slabs.

TABLE II. QUANTITIES OF THE COLUMN WORKS

Details		Project			
		1	2	3	4
Quantity (m^3)	BOQ (estimated)	63	188	95.5	128
	BOQ (actual)	61	128	91.5	122
	BOQ (SVM-BIM)	60.75	652.65	91.125	121.6
Comparison percentage (%)	Actual & estimated	-3.17	-1.52	-4.19	-4.69
	SVM-BIM & estimated	-3.57	-1.11	-4.58	-0.500
	SVM-BIM & actual	-0.41	0.14	-0.41	-0.33

TABLE III. QUANTITIES OF THE WALLS (24 cm)

Details		Project			
		1	2	3	4
Quantity (m^3)	BOQ (estimated)	360	1,080	540	720
	BOQ (actual)	366	1,098	549	732
	BOQ (SVM-BIM)	367.1	1,101	550.4	734
Comparison percentage (%)	Actual & estimated	1.67	1.67	1.67	1.67
	SVM-BIM & estimated	1.94	1.94	1.93	1.94
	SVM-BIM & actual	0.27	0.27	0.26	0.27

TABLE IV. QUANTITIES OF THE WALLS (12 cm)

Details		Project			
		1	2	3	4
Quantity (m^3)	BOQ (estimated)	1638	4904	2450	3295
	BOQ (actual)	1639	4915	2458.5	3280
	BOQ (SVM-BIM)	1640	4912	2462	3272
Comparison percentage (%)	Actual & estimated	0.06	0.22	0.35	-0.46
	SVM-BIM & estimated	0.12	0.16	0.49	-0.70
	SVM-BIM & actual	0.06	-0.06	0.14	-0.24

TABLE V. QUANTITIES OF THE FLOOR

Details		Project			
		1	2	3	4
Quantity (m^3)	BOQ (estimated)	335	996	507	670
	BOQ (actual)	330	988	492	658
	BOQ (SVM-BIM)	332.1	991.6	488.6	662.8
Comparison percentage (%)	Actual & estimated	-1.49	-0.80	-2.96	-1.79
	SVM-BIM & estimated	-0.86	-0.44	-3.63	-1.07
	SVM-BIM & actual	0.64	0.36	-0.69	0.73

TABLE VI. QUANTITIES OF THE SLAB

Details		**Project**			
		1	2	3	4
Quantity (m^3)	BOQ (estimated)	865	2595	1295	1730
	BOQ (actual)	838.5	2525.5	1255.66	1688
	BOQ (SVM-BIM)	835.85	2515.85	1263.75	1678.55
Comparison percentage (%)	Actual & estimated	-3.06	-2.68	-3.04	-2.43
	SVM-BIM & estimated	-3.37	-3.05	-2.41	-2.97
	SVM-BIM & actual	-0.32	-0.38	0.64	-0.56

The Tables manifest the accuracy of the model in predicting material quantities for construction projects, highlighting its effectiveness through case studies and comparisons with existing data. They are likely to stress the superior performance of the SVM-BIM model in estimating costs and quantities compared to traditional methods, providing valuable insights into the applicability and value of the model in construction quantity take-off.

B. Comparison of the Quantities

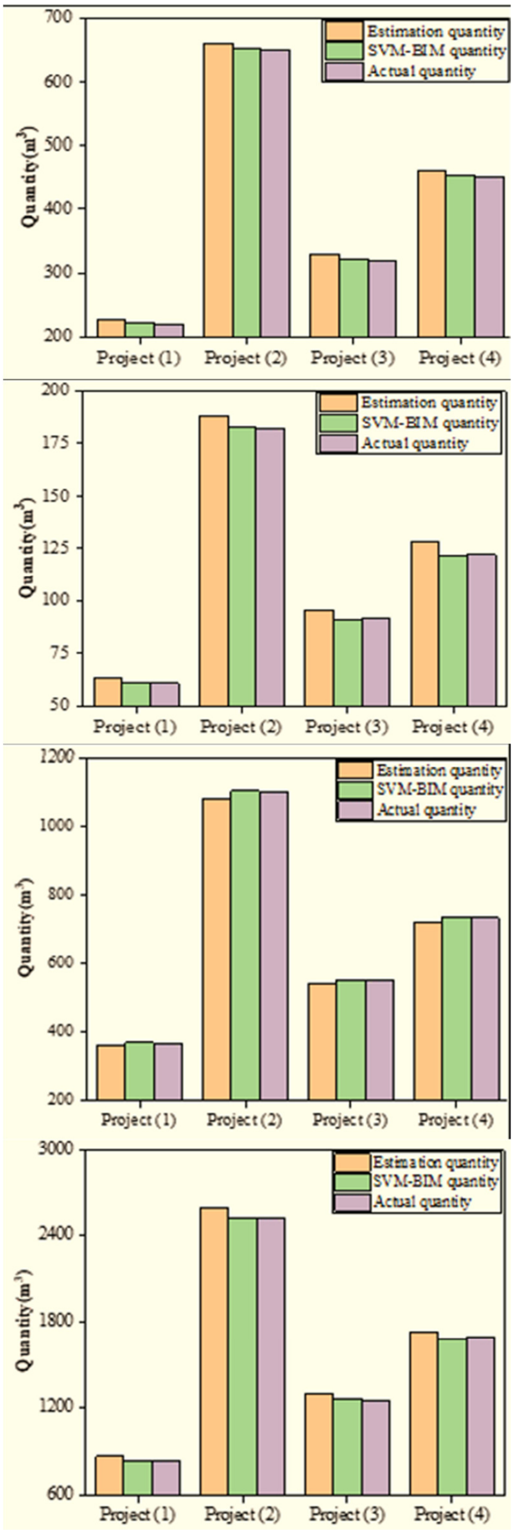
Figure 4(a-f) presents a comparative analysis of the SVM-BIM (as-built), conventional estimating (as-plan), and actual quantities of projects one, two, three, and four. It is evident that the proposed model (SVM-BIM) demonstrates an exceptional capacity to predict the quantities of all structural design elements with unparalleled precision. This exemplifies the model's efficacy in estimating construction costs for buildings across diverse areas and floors. With regard to the principal elements of the construction activities associated with the selected projects, it was established that the accuracy of the quantities removed through the usage of the BIM (as-built) technique for projects one, two, three, and four exhibited error rates of 0.7, 0.3, 0.52, and 0.74, respectively. In accordance with the specifications outlined in (12):

$$\text{Accuracy (as} - \text{built vs. SVM} - \text{BIM)} = 100\% - \text{root mean square error} \quad (12)$$

The degree of accuracy (actual vs. SVM-BIM) for project one is 100% - 0.7%= 99.3%. The accuracy of the quantities extracted using the coupled SVM-BIM (as-built) methodology for projects one, two, three, and four was found to be 99.3%, 99.7%, 99.48%, and 99.26%, respectively, in accordance with the predictions of (12). The relatively low error rate in terms of the modeling in SVM-BIM can be attributed to the fact that actual measurements from the site are also subject to potential errors caused by the implementers. In comparison, the estimating (as-plan) approach yielded error rates of 2.34, 2.0, 3.19, and 2.61 for projects one, two, three, and four respectively, according to (13):

$$\text{Accuracy (as} - \text{built vs. SVM} - \text{BIM)} = 100\% - \text{root mean square error} \quad (13)$$

The accuracy of the estimation in comparison to the SVM-BIM is 100% -2.34%= 97.66%. This is repeated for project one, two, three, and four, resulting in 98%, 96.81%, 95.76%, and 97.39%, respectively. The results of the statistical analysis provide compelling evidence of the enhanced accuracy of the SVM-BIM methodology. In conclusion, it can be stated that the proposed model is a reliable tool for forecasting the actual costs of tenders for buildings and relatively large construction projects, as well as for monitoring and controlling the quantities of structural concrete elements throughout the implementation process.



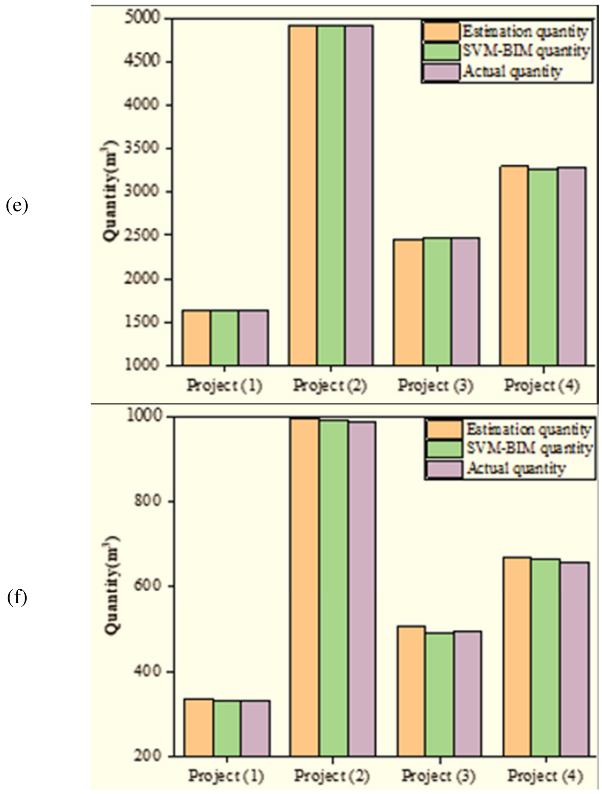


Fig. 4. Comparison of SVM-BIM (as-built), estimation (as-planned), and actual quantities for (a): foundation quantities, (b): column quantities, (c): wall 24 cm quantities, (d): wall 12 cm quantities, (e): floor quantities, (f): slab quantities.

IV. CONCLUSIONS

The objective of this research is to examine the application of a newly developed Support Vector Machine Building Information Modeling (SVM-BIM) model, created using the MATLAB-Revit software, in the estimation of construction materials for four multi-story projects. The principal arguments presented in the conclusions are:

- Regarding the foundation quantities, the percentage of the differences between the actual and estimated quantities is -3.51%. In comparison, the percentage of the differences between the quantities calculated by the proposed model and the actual quantities is less than 1.48%.
- Regarding the column quantities, the percentage of the discrepancy between the actual and estimated quantities is -3.17%, while the percentage of the discrepancy between the proposed model and actual quantities is less than -0.41%.
- The quantities of walls (24 cm) demonstrate that the percentage difference between the actual and estimated quantities is less than 1.67%, while the percentage difference between the SVM-BIM model and actual quantities is less than 0.27%.
- The quantities of walls (12 cm) demonstrate that the discrepancy between the actual and estimated quantities is less than -4.0%. Conversely, the discrepancy between the calculated model quantities and the actual quantities is less than -0.12%.
- The results reveal that the discrepancies between the actual and estimated floor quantities are less than -0.79%, while the discrepancies between the proposed model quantities and the actual quantities are less than -0.12%.
- The slab quantities demonstrate that the percentage difference between the actual and estimated quantities is less than 0.06%, while the percentage difference between the SVM-BIM model and actual quantities is less than 0.12%.
- The accuracy of the quantities removed using the coupled SVM-BIM (as-built) technique was found to be 99.3%, 99.7%, 99.48%, and 99.26% for the selected projects one, two, three and four, respectively.
- The proposed SVM-BIM model exhibits an exceptional capacity to predict the quantities of all structural design elements with unparalleled precision. This reflects the model's remarkable efficacy in estimating the costs of constructing buildings in diverse settings and on varying floors.

REFERENCES

[1] M.-Y. Cheng, H.-C. Tsai, and E. Sudjono, "Conceptual cost estimates using evolutionary fuzzy hybrid neural network for projects in construction industry," *Expert Systems with Applications*, vol. 37, no. 6, pp. 4224–4231, Jun. 2010, https://doi.org/10.1016/j.eswa.2009.11.080.

[2] S. H. N. Alani and A. H. Mahmoud, "Factors Affecting the Cost Management of Iraqi Construction Firms," *Engineering, Technology & Applied Science Research*, vol. 13, no. 6, pp. 12001–12005, Dec. 2023, https://doi.org/10.48084/etasr.5212.

[3] V. B. Chandanshive and A. R. Kambekar, "Prediction of Building Construction Project Cost Using Support Vector Machine," *Industrial Engineering and Strategic Management*, vol. 1, no. 1, pp. 31–42, Dec. 2021, https://doi.org/10.22115/iesm.2021.297399.1015.

[4] C.-C. Chang and C.-J. Lin, "Training v-Support Vector Classifiers: Theory and Algorithms," *Neural Computation*, vol. 13, no. 9, pp. 2119–2147, Sep. 2001, https://doi.org/10.1162/089976601750399335.

[5] S.-L. Chan and N.-N. Leung, "Prototype Web-Based Construction Project Management System," *Journal of Construction Engineering and Management*, vol. 130, no. 6, pp. 935–943, Dec. 2004, https://doi.org/10.1061/(ASCE)0733-9364(2004)130:6(935).

[6] H. R. Abed, W. A. Hatem, and N. A. Jasim, "Role of BIM technology in enhancing safety analysis of Iraqi oil projects," *Asian Journal of Civil Engineering*, vol. 21, no. 4, pp. 695–706, Jun. 2020, https://doi.org/10.1007/s42107-020-00231-5.

[7] N. I. Sapankevych and R. Sankar, "Time Series Prediction Using Support Vector Machines: A Survey," *IEEE Computational Intelligence Magazine*, vol. 4, no. 2, pp. 24–38, May 2009, https://doi.org/10.1109/MCI.2009.932254.

[8] C. J. C. Burges, "A Tutorial on Support Vector Machines for Pattern Recognition," *Data Mining and Knowledge Discovery*, vol. 2, no. 2, pp. 121–167, Jun. 1998, https://doi.org/10.1023/A:1009715923555.

[9] V. N. Vapnik, *The Nature of Statistical Learning Theory*. New York, NY, USA: Springer, 2000

[10] K.-Y. Chen and C.-H. Wang, "Support vector regression with genetic algorithms in forecasting tourism demand," *Tourism Management*, vol. 28, no. 1, pp. 215–226, Feb. 2007, https://doi.org/10.1016/j.tourman.2005.12.018.

[11] D. R. Salgado and F. J. Alonso, "An approach based on current and sound signals for in-process tool wear monitoring," *International*

Journal of Machine Tools and Manufacture, vol. 47, no. 14, pp. 2140–2152, Nov. 2007, https://doi.org/10.1016/j.ijmachtools.2007.04.013.

[12] K. Duan, S. S. Keerthi, and A. N. Poo, "Evaluation of simple performance measures for tuning SVM hyperparameters," *Neurocomputing*, vol. 51, pp. 41–59, Apr. 2003, https://doi.org/10.1016/S0925-2312(02)00601-X.

[13] R. Alsultani, I. Karim, and S. Khassaf, "Nonlinear Dynamic Response Analysis of Coastal Pile Foundation Bridge Pier Subjected to Current, Wave and Earthquake Actions: As a model of civilian live," *Res Militaris*, vol. 12, no. 2, pp. 6133–6148, Dec. 2022.

[14] S. Naımı and M. O. M. A. Hanoun, "Comparison of Equivalent Static Analysis and Mode Combination Method for Concrete Buildings According to Turkish Standard," *International Journal of Electronics Mechanical and Mechatronics Engineering*, vol. 8, no. 4, pp. 1609–1616, Oct. 2018.

[15] F. Magrassi, A. Del Borghi, M. Gallo, C. Strazza, and M. Robba, "Optimal Planning of Sustainable Buildings: Integration of Life Cycle Assessment and Optimization in a Decision Support System (DSS)," *Energies*, vol. 9, no. 7, Jul. 2016, Art. no. 490, https://doi.org/10.3390/en9070490.

[16] C. K. Anand and B. Amor, "Recent developments, future challenges and new research directions in LCA of buildings: A critical review," *Renewable and Sustainable Energy Reviews*, vol. 67, pp. 408–416, Jan. 2017, https://doi.org/10.1016/j.rser.2016.09.058.

[17] A. Haruna, N. Shafiq, and O. A. Montasir, "Building information modelling application for developing sustainable building (Multi criteria decision making approach)," *Ain Shams Engineering Journal*, vol. 12, no. 1, pp. 293–302, Mar. 2021, https://doi.org/10.1016/j.asej.2020.06.006.

[18] R. M. ElBatran and W. S. E. Ismaeel, "Applying a parametric design approach for optimizing daylighting and visual comfort in office buildings," *Ain Shams Engineering Journal*, vol. 12, no. 3, pp. 3275–3284, Sep. 2021, https://doi.org/10.1016/j.asej.2021.02.014.

[19] Y. H. Lee, L. S. Thien, Y. Y. Lee, S. Y. Wong, C. S. Tan, and C. S. Chai, "Transformation from 2D structural drawing to building information model: Perspectives from a small-scaled company," *Materials Science and Engineering*, vol. 943, no. 1, Oct. 2020, Art. no. 012063, https://doi.org/10.1088/1757-899X/943/1/012063.

[20] I. A. Bhatti, A. H. Abdullah, S. Nagapan, N. B. Bhatti, S. Sohu, and A. A. Jhatial, "Implementation of Building Information Modeling (BIM) in Pakistan Construction Industry," *Engineering, Technology & Applied Science Research*, vol. 8, no. 4, pp. 3199–3202, Aug. 2018, https://doi.org/10.48084/etasr.2145.

[21] M. Mert, "Building information modeling (BIM) approach for construction management and interoperability analysis," M.S. thesis, Polytechnic of Milan, Italy, 2020.

[22] D. M. A. Morsi, W. S. E. Ismaeel, A. Ehab, and A. A. E. Othman, "BIM-based life cycle assessment for different structural system scenarios of a residential building," *Ain Shams Engineering Journal*, vol. 13, no. 6, Nov. 2022, Art. no. 101802, https://doi.org/10.1016/j.asej.2022.101802.

[23] H. V. Tirunagari and V. Kone, "Simulation of Construction Sequence using BIM 4d Techniques," *International Journal of Recent Technology and Engineering (IJRTE)*, vol. 7, no. 6C2, pp. 877–881, Apr. 2019.

[24] J. Xu, "Research on Application of BIM 5D Technology in Central Grand Project," *Procedia Engineering*, vol. 174, pp. 600–610, Jan. 2017, https://doi.org/10.1016/j.proeng.2017.01.194.

[25] V. Konyushkov, S. Sotnikov, V. Veretennikov, and I. Ershov, "Application of 4D BIM modelling in planning and construction of zero cycle works," *E3S Web of Conferences*, vol. 164, Jan. 2020, Art. no. 08024, https://doi.org/10.1051/e3sconf/202016408024.

[26] B. Succar, "Building information modelling framework: A research and delivery foundation for industry stakeholders," *Automation in Construction*, vol. 18, no. 3, pp. 357–375, May 2009, https://doi.org/10.1016/j.autcon.2008.10.003.

[27] M. Laakso, "The IFC Standard - A Review of History, Development, and Standardization," *Journal of Information Technology in Construction*, vol. 17, pp. 134–161, May 2012.

[28] E. Krygiel and B. Nies, *Green BIM: Successful Sustainable Design With Building Information Modeling by Eddy Krygiel and Bradley Nies*, 1st ed. Alameda, CA, USA: SYBEX Inc., 2008.

[29] A. H. Oti, W. Tizani, F. H. Abanda, A. Jaly-Zada, and J. H. M. Tah, "Structural sustainability appraisal in BIM," *Automation in Construction*, vol. 69, pp. 44–58, Sep. 2016, https://doi.org/10.1016/j.autcon.2016.05.019.

[30] T. A. Nguyen, T. A. Nguyen, and T. V. Tran, "Building Information Modeling (BIM) for Construction Project Schedule Management: A Review," *Engineering, Technology & Applied Science Research*, vol. 14, no. 2, pp. 13133–13142, Apr. 2024, https://doi.org/10.48084/etasr.6834.

[31] B. Soust-Verdaguer, C. Llatas, and A. García-Martínez, "Critical review of bim-based LCA method to buildings," *Energy and Buildings*, vol. 136, pp. 110–120, Feb. 2017, https://doi.org/10.1016/j.enbuild.2016.12.009.

[32] K. Safari and H. AzariJafari, "Challenges and opportunities for integrating BIM and LCA: Methodological choices and framework development," *Sustainable Cities and Society*, vol. 67, Apr. 2021, Art. no. 102728, https://doi.org/10.1016/j.scs.2021.102728.

[33] R. Jin, B. Zhong, L. Ma, A. Hashemi, and L. Ding, "Integrating BIM with building performance analysis in project life-cycle," *Automation in Construction*, vol. 106, Oct. 2019, Art. no. 102861, https://doi.org/10.1016/j.autcon.2019.102861.