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Cost Control Problems in Construction Projects in Congo-Brazzaville

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Abstract

This study was undertaken with the aim of achieving better cost control in construction projects in Congo-Brazzaville, through the analysis and monitoring of variances and deviations in project estimates and actual costs. Indeed, in the field of building and civil infrastructure construction in Congo-Brazzaville, cost management problems occur recurrently from the preliminary estimation stage and throughout project execution. Poorly conducted estimates often lead to either underestimation or overestimation of the project's total cost. Furthermore, a lack of coordination during construction often causes disruptions in site organization, resulting in significant financial deviations. Consequently, there is generally a noticeable gap between the estimated and the actual construction costs. In developing countries (D.C.s) such as Congo, it is uncommon for a construction project to meet both its scheduled completion time and its initial estimated budget. Chronic time and cost overruns therefore represent a major issue within the sector. The main objective of this work is to develop reliable estimation models capable of anticipating actual costs as early as the feasibility stage. For this purpose, construction cost data were collected from several design offices, covering twenty-five (25) single-storey building projects and twenty (20) two-storey (R + 1) building projects. Statistical analysis, conducted using the SPSS software through a step-by-step multiple linear regression approach, led to the development of two cost estimation models according to building type. Both models proved to be highly significant according to the ANOVA test (sig. = 0.00), with a strong predictive power confirmed by the high coefficient of determination (R^2). The models include eight and six explanatory variables respectively, each related to total cost. Validation results showed that the predicted values are very close to the observed actual values, with low residuals: from 0.04% to 1.81% for single-storey buildings and from 0.10% to 7.07% for two-storey buildings. These results indicate that the developed models provide highly reliable cost estimations, with small deviations from observed values. However, the tolerance margin—estimated at over 30% of the predicted value—remains relatively high. Thus, these models represent a relevant decision-support tool for the feasibility phase of construction projects, but still require further adjustments to improve their accuracy and to better control error margins related to real execution conditions in Congo-Brazzaville.

Keywords

Cost Management, Model, Statistics, Regression, Construction, Cost, Buildings

1. Introduction

The management of a project encompasses multidisciplinary and interdependent dimensions, integrating complex issues related to cost, time, and the use of various specific technical approaches. In the construction sector, the implementation of an effective management system should be aligned with the fundamental principles of project management. Such alignment highlights a structured process designed to better plan, organize, mobilize human resources, monitor, and control system development while optimizing costs and meeting predetermined deadlines.

In developing countries (D.C.s), however, construction projects frequently face major dysfunctions. These are often manifested through significant budget overruns, wide variations in construction costs, and considerable delays in project completion. One of the key challenges therefore lies in the difficulty of anticipating and controlling expenses related to materials, labor, and indirect costs—a persistent concern for both the scientific community and professionals in the field [1]. The main causes of these deviations are generally attributed to two determining factors: first, the use of cost estimation methods that are poorly adapted to the local context; and second, the deficient application of project management principles [2]. These shortcomings negatively affect the overall performance of projects and compromise their long-term viability.

The central objective of this study is to contribute to improved cost management in construction projects in Congo. This will be achieved through a rigorous analysis of the discrepancies between estimated and actual values, as well as the establishment of control mechanisms designed to effectively correct the deviations observed throughout the project life cycle.

2. Material and Methods

To successfully carry out this study, two methodological approaches were adopted: first, the use of survey forms for data collection; and second, the use of the SPSS software (Statistical Package for the Social Sciences) for data processing and analysis. SPSS is particularly well-suited for implementing statistical data analysis techniques. It facilitates efficient data management within a user-friendly graphical interface that combines descriptive menus with dialog boxes. In addition, this environment provides a command language that allows users to write scripts to optimize production tasks. SPSS enables the effective processing of large datasets and provides several options for organizing and summarizing statistical information.

The processing and statistical analysis of field survey data always require preliminary work involving the organization and restructuring of the collected information. SPSS offers all the necessary functionalities to perform these tasks. The software interface consists of three main windows: the Data View (or Editor), the Output Viewer, and the Syntax Editor.

This study focused exclusively on residential building constructions, taking into account the socio-economic realities of the country. It was observed that residential buildings in Congo-Brazzaville are predominantly single-storey structures, as opposed to multi-storey ones. This observation made it possible to obtain a broad range of data on single-storey residential buildings (F4 type) with average habitable areas close to 110 m^2, and two-storey residential buildings (R + 1 type) with habitable areas around 125 m^2 (**Figure 1**).

Table 1. Building area and level of standing.

	Single-storey buildings	Living area (m^2)		Two-storey buildings (R + 1)	Ground floor area (m^2)
MEDIUM STANDARD	**1**	109	MEDIUM STANDARD	**1**	122
	2	106		**2**	120
	3	110		**3**	121
	4	108		**4**	124
	5	108		**5**	121
	6	106		**6**	123
	7	107		**7**	121
	8	105		**8**	125
	9	110		**9**	120
HIGH STANDARD	**10**	105	HIGH STANDARD	**10**	120
	11	108		**11**	123
	12	106		**12**	122
	13	110		**13**	121
	14	108		**14**	120
	15	110		**15**	121
	16	105		**16**	121

Continued

17	108	**17**	121
18	105	**18**	120
19	109	**19**	122
20	105	**20**	121
21	109		
22	109		
23	108		
24	109		
25	107		

Data collection (estimates) was conducted with building and public works design offices in the city of Brazzaville. A total of one hundred (100) construction files were examined, including 25 files for single-storey buildings, 20 files for two-storey buildings (R + 1) (**Table 1**), while the remaining files corresponded to buildings with other uses (commercial, administrative, etc.). Furthermore, eight (8) categories of construction materials and the types of trades involved—considered as variables (**Table 2**) affecting construction costs—were selected for analysis.

Table 2. Variables of the construction cost function.

VARIABLES	DESIGNATION	VARIABLES	DESIGNATION
matmaco	Cost of materials used in masonry work	**matvitre**	Cost of materials used in glazing work
matchmen	Cost of materials used in carpentry and joinery work	**momccf**	Labor cost for the combined work of mason, tiler, formworker, and rebar worker
matplomb	Cost of materials used in plumbing work	**mocmv**	Labor cost for the combined work of carpenter, joiner, and glazier
matcarev	Cost of materials used in tiling and flooring work	**moplomb**	Labor cost for the plumbing trade
matcovet	Cost of materials used in roofing and waterproofing work	**moélect**	Labor cost for the electrical trade
matpeint	Cost of materials used in painting work	**mopeint**	Labor cost for the painting trade
matélect	Cost of materials used in electrical work	**coûtcons**	Construction cost

Figure 1 illustrates the floor plan of a single-storey residential building of type F4, with a total area of 110 m^2. The dwelling consists of three bedrooms, a living room combining a lounge and dining area, a functional kitchen, two terraces providing pleasant outdoor spaces, and sanitary facilities. Two corridors ensure circulation and connectivity between the different rooms, guaranteeing a well-organized and smoothly structured interior layout.

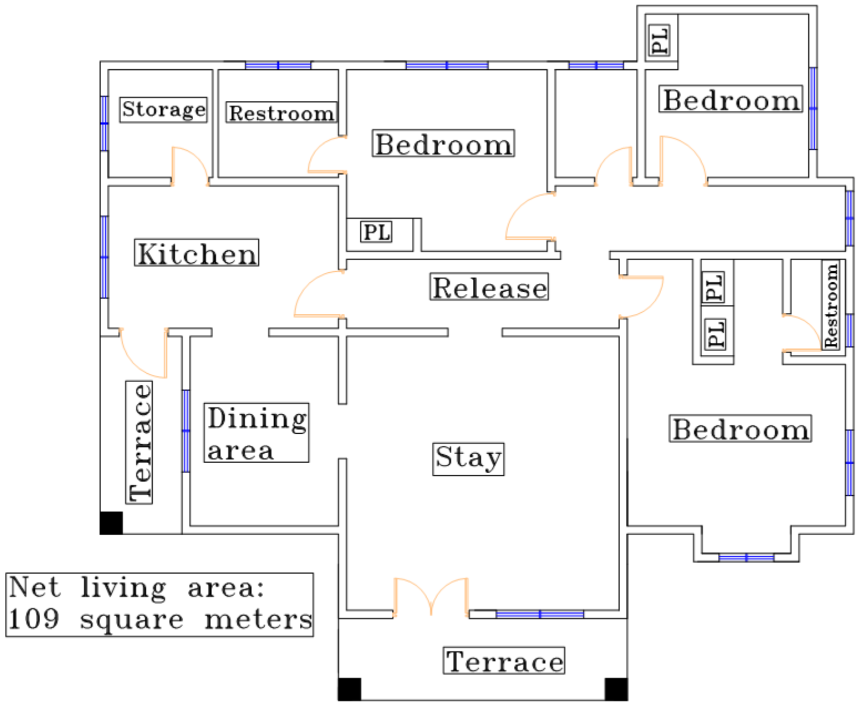

Figure 1. Floor plan of a Single-Storey F4-Type house.

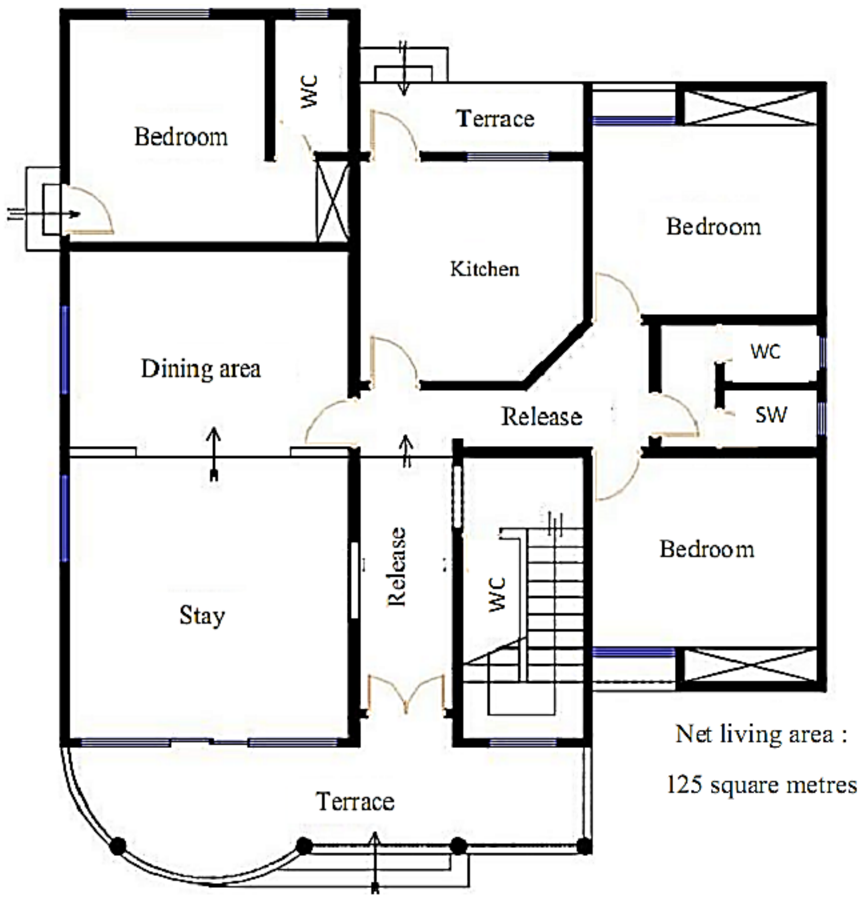

Figure 2. Ground floor plan of a residential house.

Figure 2 and Figure 3 present the floor plans of the ground floor and the upper floor, respectively, of a two-storey residential building (R + 1 type). This building comprises four bedrooms, a living room with an adjoining dining area, a fitted kitchen, and an office providing a separate workspace. It also features two terraces and two balconies, offering pleasant outdoor spaces. Sanitary facilities are provided on each floor, ensuring comfort and functionality. The overall layout of the building promotes a harmonious distribution of living spaces and smooth circulation between the different areas.

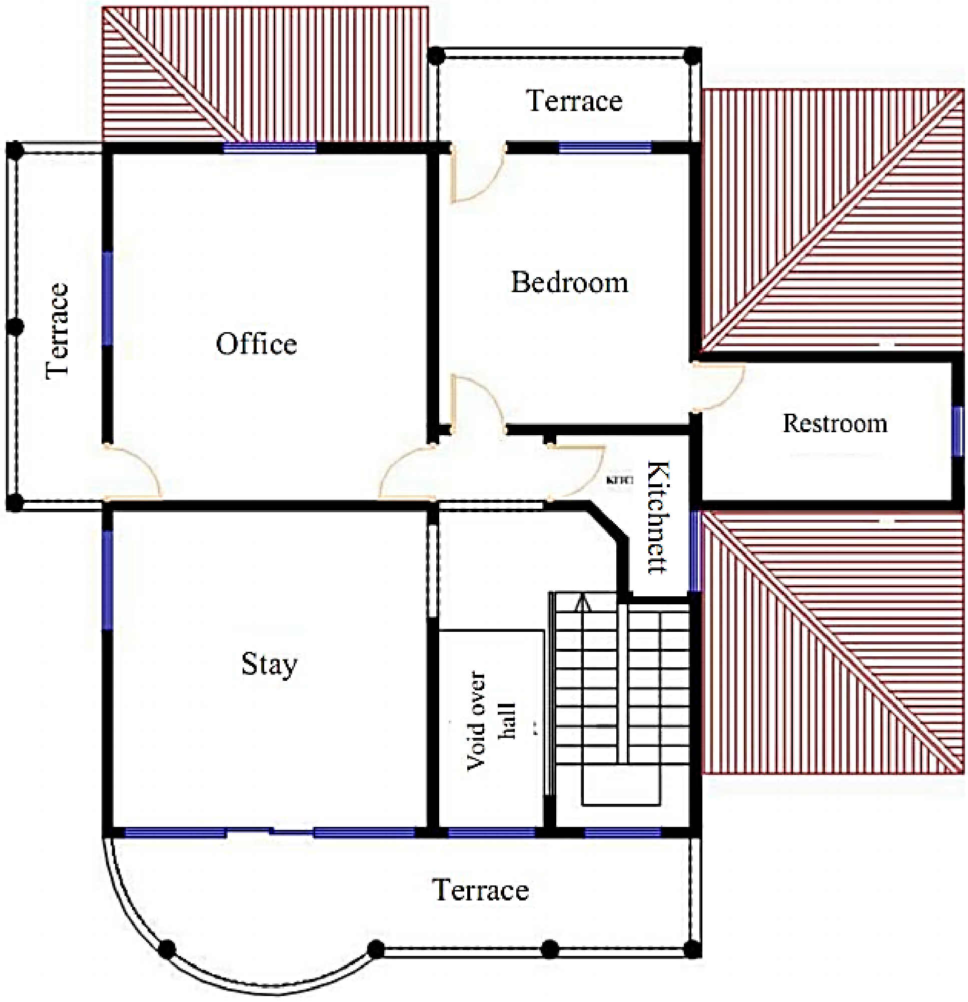

Figure 3. First floor plan of a Two-Storey residential house (R + 1).

The purpose of this data is to establish a linear relationship (regression) between construction costs and the endogenous variables in order to predict construction expenses. Indeed, linear regression, as a modeling tool, enables such predictions. The endogenous variables used are of two types: materials and labor. Regarding materials, the decomposition diagram of a substructure (Figure 4) allowed for the identification of all the elementary components required in a construction project.

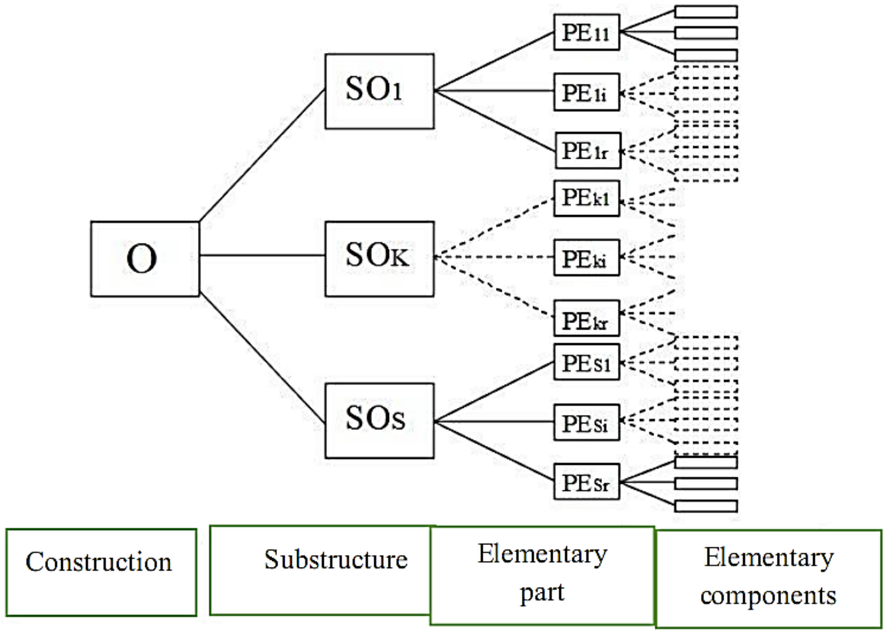

Figure 4. Decomposition diagram of a work into Sub-Works (DDSO).

The DDSO made it possible to identify the different elementary components of a given sub-work (**SOk**). By subsequently aggregating the quantities of a given material (**matj**) contained in various sub-works—which significantly reduces the number of initial variables—the total quantity of **matj** required for the entire project can be determined. The entire procedure described above can be summarized in tabular form (**Table 3**).

Table 3. Distribution of material quantities by sub-works.

Materials sub-works	mat1	mat2	...	matj	...	matp
SO1	mat11	mat2	...	matj1	...	matp1
SO2	mat12	mat22	...	matj2	...	matp2
⋮						
SOk	mat1k	mat2k	...	matjk	...	matpk
⋮	⋮	⋮	...		...	
SOs	mat1s	mat2s	...	matjs	...	matps
$\sum_{k=1}^{s} matjk$						

To reduce the number of variables, the less significant elementary components among the materials were excluded. Trades were grouped according to their versatility (for example, carpenter-joiner, mason-tiler, etc.). Indeed, versatility is a labor strategy aimed at reducing indirect labor costs, improving productivity, and minimizing staff turnover [3]. The calculation of the endogenous variables (cij) is performed using the matrix model.

3. Results and Interpretations

3.1. Statistical Data Processing

Table 4 and Table 5 present the dependent variable, "costcons", representing the construction cost, along with all the explanatory variables included in the model. The explanatory variables total thirteen (13): matmaco, matchmen, matplomb, matcarev, matcovet, matpeint, matélect, matvitremomccf, mocmv, moplomb, moélect, and mopeint. Statistical analysis was carried out using IBM SPSS Statistics 26, employing the stepwise method, which allows for the progressive selection of the most significant variables for explaining the dependent variable.

This study was limited to deductive statistics, with particular focus on the multiple linear regression model and analysis of variance (ANOVA), in order to assess the contribution of each explanatory variable to the model. The detailed results of these analyses are presented in Table 5 and Table 6, which summarize the estimated coefficients, significance levels, and the main statistical indicators of the selected model.

Table 4. Construction costs of Single-Storey buildings.

N°	**Coûtcons (FCFA)**	matmaco	**matchmen**	matplomb	**matcarev**	matcovet	matpeint	matélect	matvitre	momccf	mocmv	**moplomb**	moélect	**mo-peint**
1	19 817 992	5 459 400	3 246 500	1 465 000	2 660 594	1 165 000	800 500	1 121 500	596 500	1 623 998	1 001 600	293 000	224 300	160 100
2	22 269 506	3 706 980	4 036 500	1 885 000	2 421 125	1 656 000	1 251 500	1 358 500	1 500 000	1 532 026	1 798 125	471 250	339 625	312 875
3	22 527 062	6 173 250	4 047 100	1 070 000	2 113 300	1 092 500	1 231 000	1 244 500	1 050 000	2 071 637	1 547 400	267 500	311 125	307 750
4	22 942 740	6 012 075	2 968 500	2 298 000	2 691 975	976 500	850 500	2 602 800	718 600	1 740 810	932 720	459 600	520 560	170 100
5	23 019 243	6 012 175	2 965 500	2 398 000	2 671 975	976 500	850 500	2 602 800	718 600	1 740 812	932 120	459 600	520 561	170 100
6	23 393 544	8 275 000	3 770 500	2 750 000	551 100	1 235 000	677 000	1 118 020	1 118 000	1 765 220	1 224 700	550 000	223 604	135 400
7	25 327 452	5 617 150	3 423 100	2 113 000	4 621 860	1 670 000	1 149 000	2 009 100	503 000	2 047 802	1 119 220	422 600	401 820	229 800
8	26 058 150	6 960 450	3 057 500	6 380 000	1 782 700	830 500	1 276 000	1 167 510	177 800	1 845 630	813 160	1 278 000	233 500	255 400
9	26 572 140	7 460 450	3 057 500	6 390 000	1 782 700	830 500	1 277 000	1 167 500	177 800	1 848 630	813 160	1 278 000	233 500	255 400
10	28 709 220	8 690 225	5 315 000	2 800 000	637 725	2 571 900	1 109 500	1 802 500	997 500	1 865 590	1 776 880	560 000	360 500	221 900
11	28 724 687	7 292 050	3 825 000	2 045 000	2 849 000	1 952 500	1 460 000	2 241 200	1 315 000	2 535 262	1 773 125	511 250	560 300	365 000
12	29 985 876	8 124 760	5 313 000	1 535 000	3 966 475	2 064 000	1 179 995	1 800 000	1 005 000	2 418 247	1 676 400	307 000	360 000	235 999
13	29 275 590	6 994 464	5 275 450	1 700 000	2 454 111	3 290 600	1 327 500	2 398 500	955 700	1 889 715	1 904 350	340 000	479 700	265 500
14	29 239 775	8 867 590	4 421 200	1 608 000	3 464 030	1 060 000	664 500	2 176 500	1 130 000	3 082 905	1 652 800	402 000	544 125	166 125
15	29 403 783	6 793 968	4 926 900	1 440 000	2 973 498	3 234 000	1 717 500	2 200 000	587 080	2 441 866	1 749 596	360 000	550 000	429 375
16	30 105 630	10 513 375	3 431 000	5 685 000	591 150	1 232 500	1 561 000	909 000	1 165 000	2 220 905	1 165 700	1 137 000	181 800	312 200
17	31 345 344	7 982 000	4 636 500	2 650 000	2 440 020	3 029 000	1 639 000	2 284 600	1 460 000	2 084 404	1 825 100	530 000	456 920	327 800
18	31 929 648	10 870 540	4 807 000	1 450 000	2 967 300	2 815 000	694 000	1 914 200	1 090 000	2 767 568	1 742 400	290 000	382 840	138 800
19	37 467 037	11 603 730	3 204 000	3 670 000	3 950 400	2 260 000	1 461 000	2 357 000	1 467 500	3 888 532	1 732 875	917 500	589 250	365 250
20	39 181 800	6 800 500	3 781 000	2 310 000	1 117 100	8 433 000	1 607 000	1 754 500	1 570 000	7 917 600	2 756 800	462 000	350 900	321 400
21	43 808 580	9 228 500	5 882 500	6 765 000	3 188 150	3 213 000	1 250 000	5 819 000	1 161 000	2 483 330	2 051 300	1 353 000	1 163 800	250 000

Continued

22	45 896 375	10 715 950	4 190 500	11 940 000	2 390 350	2 598 500	1 432 000	3 272 000	177 800	3 276 575	1 741 700	2 985 000	818 000	358 000
23	49 418 910	9 054 800	7 984 000	8 020 000	4 497 125	3 063 500	1 213 000	5 309 000	2 041 000	2 710 385	2 617 700	1 604 000	1 061 800	242 600
24	49 769 850	11 418 750	8 005 000	5 920 000	4 525 625	3 042 500	1 213 000	5 309 000	2 041 000	3 188 875	2 617 700	1 184 000	1 061 800	242 600
25	52 700 854	11 562 175	6 141 000	5 180 000	4 100 440	2 060 000	2 944 568	6 553 000	4 019 500	3 665 654	3 055 125	1 045 000	1 638 250	736 142

Table 5. Construction costs of Two-Storey buildings (R + 1 Type).

N°	Coûtcons (FCFA)	matmaco	matchmen	matplomb	matcarev	matcovet	matpeint	matélect	matvitre	momccf	mocmv	moplomb	moélect	mopeint
1	42 710 468	14 892 900	3 914 000	3 850 000	3 092 575	995 000	2 656 400	2 307 500	2 460 000	4 496 368	1 842 250	962 500	576 875	664 100
2	52 429 062	20 788 275	3 306 500	3 310 000	3 349 275	4 852 500	2 198 200	2 588 500	1 550 000	6 034 387	2 427 250	827 500	647 125	549 550
3	53 704 025	16 935 720	5 828 000	3 530 000	5 591 000	2 250 000	2 662 500	4 111 000	2 055 000	5 631 680	2 533 250	882 500	1 027 750	665 625
4	55 829 025	16 935 720	7 528 000	3 530 000	5 591 000	2 250 000	2 662 500	4 111 000	2 055 000	5 631 680	2 958 250	882 500	1 027 750	665 625
5	62 285 037	24 239 675	3 723 000	5 135 000	3 945 395	2 165 500	2 516 200	5 482 800	2 975 000	7 046 267	1 772 700	1 283 750	1 370 700	629 050
6	64 635 787	22 748 340	8 071 500	3 565 000	4 550 700	2 685 000	2 471 590	4 031 500	3 585 000	6 824 760	3 585 375	891 250	1 007 875	617 897
7	72 655 775	26 425 600	7 795 000	4 020 000	5 505 100	4 786 000	2 914 920	3 948 000	2 730 000	7 982 675	3 827 750	1 005 000	987 000	728 730
8	74 540 550	21 791 200	10 996 000	6 345 000	7 206 920	4 508 500	1 818 700	5 013 500	2 680 000	7 249 530	3 636 900	1 586 250	1 253 375	454 675
9	75 520 209	29 448 187	3 318 449	5098480	5 636 295	1 466 719	4 165 948	5 133 549	3 492 800	7 339 866	7 645 610	1205523	632 917	935 866
10	77 194 846	26 121 270	1 587 139	3822860	10 198 820	2 565 575	4 601 984	6 648 396	2 744 023	7 196 421	7 935 018	1915257	1 008 122	849 961
11	80 547 662	29 428 780	8 000 500	6 205 000	5 114 850	3 007 000	2 222 000	6 790 000	3 670 000	8 635 907	3 669 375	1 551 250	1 697 500	555 500
12	84 191 698	20 780 280	5 852 000	4 620 000	6 779 925	3 756 500	1 732 600	4 299 000	2 990 000	27 560 205	3 149 625	1 155 000	1 074 750	441 813
13	84 832 975	35 331 395	7 247 500	4 635 000	9 044 485	2 393 000	3 897 000	3 938 000	1 380 000	11 093 970	2 755 125	1 158 750	984 500	974 250
14	88 302 656	19 251 200	11 465 000	4 475 000	11 914 300	8 221 000	3 492 620	5 066 000	4 040 000	9 349 650	7 117 800	1 342 500	1 519 800	1 047 786
15	88 581 968	39 024 950	6 391 000	4 420 000	6 789 925	4 337 500	2 883 200	4 009 000	3 010 000	11 453 718	3 434 625	1 105 000	1 002 250	720 800
16	91 879 006	41 600 065	1 568 500	8 170 000	3 357 040	5 559 000	4 735 600	5 103 000	3 410 000	11 239 276	2 634 375	2 042 500	1 275 750	1 183 900
17	93 098 718	37 732 335	4 591 000	8 170 000	3 629 040	5 559 000	4 735 600	6 053 000	4 009 000	10 340 343	3 539 750	2 042 500	1 513 250	1 183 900
18	96 141 506	41 600 065	4 978 500	8 170 000	3 357 040	5 559 000	4 735 600	5 103 000	3 410 000	11 239 276	3 486 875	2 042 500	1 275 750	1 183 900
19	97 361 218	37 732 335	8 001 000	8 170 000	3 629 040	5 559 000	4 735 600	6 053 000	4 009 000	10 340 343	4 392 250	2 042 500	1 513 250	1 183 900
20	115 374 206	40 960 665	9 671 500	7 886 000	9 553 800	5 174 000	4 548 900	6 684 500	7 820 000	12 628 616	5 666 375	1 971 500	1 671 125	1 137 225

Table 6. Description of variables for Single-Storey buildings.

	N	Range	Minimum	Maximum	Average	Standard deviation	Variance
Coûtcons	25	32882862	19817992	52700854	31955631.49	9556776.858	9.133×10^{13}
matmaco	25	7896750	3706980	11603730	8087612.25	2146976.039	4.609×10^{12}
matchmen	25	5039500	2965500	8005000	4468470.00	1409286.326	1.986×10^{12}
matplomb	25	10870000	1070000	11940000	3658680.00	2688676.932	7.228×10^{12}
matcarev	25	4070760	551100	4621860	2696393.12	1199474.436	1.438×10^{12}
matcovet	25	7602500	830500	8433000	2254100.00	1551468.179	2.407×10^{12}
matpeint	25	2280068	664500	2944568	1273462.52	461901.467	2.133×10^{11}

Continued

matélect	25	5644000	909000	6553000	2499689.20	1568805.924	2.461×10^{12}
matvitre	25	3841700	177800	4019500	1149735.20	782405.641	6.121×10^{11}
momccf	25	6385574	1532026	7917600	2586159.12	1285486.279	1.652×10^{12}
mocmv	25	2241965	813160	3055125	1680870.24	610704.060	3.729×10^{11}
moplomb	25	2717500	267500	2985000	778692.00	611935.248	3.744×10^{11}
moélect	25	1456450	181800	1638250	542743.20	352600.180	1.243×10^{11}
mopeint	25	600742	135400	736142	279024.64	123002.987	1.512×10^{10}

Table 7. Description of variables for Two-Storey buildings (R+1 Type).

	N	Range	Minimum	Maximum	Avarage	Standard deviation	Variance
Coûtcons	20	72663738	42710468	115374206	77590819.85	18182771.946	$3,306 \times 10^{14}$
matmaco	20	26707165	14892900	41600065	28188447.85	9146904.480	$8,366 \times 10^{13}$
matchmen	20	9896500	1568500	11465000	6191704.40	2840568.421	$8,068 \times 10^{12}$
matplomb	20	4860000	3310000	8170000	5356367.00	1821927.177	$3,319 \times 10^{12}$
matcarev	20	8821725	3092575	11914300	5891826.25	2569786.796	$6,603 \times 10^{12}$
matcovet	20	7226000	995000	8221000	3882489.70	1816741.104	$3,300 \times 10^{12}$
matpeint	20	3003000	1732600	4735600	3319383.10	1088486.488	$1,184 \times 10^{12}$
matélect	20	4482500	2307500	6790000	4823712.25	1254951.464	$1,574 \times 10^{12}$
matvitre	20	6440000	1380000	7820000	3203741.15	1336458.969	$1,786 \times 10^{12}$
momccf	20	23063837	4496368	27560205	9465746.90	4855908.903	$2,357 \times 10^{13}$
mocmv	20	6162318	1772700	7935018	3900526.40	1805408.115	3,259 × 1012
moplomb	20	1215000	827500	2042500	1394801.50	460541.552	$2,120 \times 10^{11}$
moélect	20	1120625	576875	1697500	1153370.70	329527.229	$1,085 \times 10^{11}$
mopeint	20	742087	441813	1183900	818702.65	262310.651	$6,880 \times 10^{10}$

Table 6 and Table 7 provide the description of the variables used in the two models for estimating building costs. The first sample includes 25 complete files of similar single-storey buildings of type f4 (110 m^2), while the second sample includes 20 complete files of two-storey buildings with a ground floor area similar to the f4 type (110 m^2).

thus, for each construction cost variable, there are 25 observations for single-storey buildings and 20 observations for r+1 buildings. the elements that have the most significant impact on construction cost are those with the highest mean values, among which the following were identified in descending order:

1) For single-storey buildings

Material variables: matmaco, matchmen, matplomb, matcarev, matcovet, matélect, matpeint, matvitre.

Labor variables: momccf, mocmv, moplomb, moélect, mopeint.

2) For R + 1 type buildings

Material variables: matmaco, matchmen, matcarev, matplomb, matélect, matcovet, matpeint, matvitre.

Labor variables: momccf, mocmv, moplomb, moélect, mopeint.

For each variable, we obtained a range, which corresponds to the difference between the maximum and minimum values of the considered variable. This difference is more pronounced for the variables matplomb and matmaco in single-storey buildings, and matmaco and momccf in R + 1 buildings.

The smallest standard deviations for each category of variables, that is, material costs and labor costs, are observed for matpeint and mopeint. They are 461,901 FCFA and 123,003 FCFA for single-storey buildings, and 1,088,486 FCFA and 262,311 FCFA for two-storey buildings, respectively.

This indicates that, in both samples, the buildings are more similar in terms of painting costs (matpeint) compared to other material cost variables. Likewise, the buildings are more similar in terms of labor costs for painting (mopeint) compared to other labor cost variables. In other words, the observations for the explanatory variables matpeint and mopeint are much closer to each other relative to the other variables in their category. Consequently, the scatter plots are much more concentrated for these two variables.

This similarity can be explained by the fact that paint is applied to walls of buildings with practically the same floor areas, and essentially the same quality of paint is used for all the dwellings (oil-based or alkyd paints). Between 2010 and 2020, painting costs did not vary significantly.

Variance, which is the square of the standard deviation, measures the variability of a variable around its mean. The higher the variance, the more information there is to study. In our case, the variance of the dependent variable Coûtcons is very high: 9.133×10^{13} FCFA for single-storey buildings and 3.306×10^{14} FCFA for R+1 buildings. This could be explained by the disparities in the quality and specifications of the constructions within the samples used to develop the models.

For the variance of the variable matmaco, it can be assumed that concrete is a very expensive material whose price may fluctuate from year to year. Additionally, this variability can be explained by differences in architectural or engineering design choices (foundation types, wall types, floor types, and dimensions of load-bearing elements), even though the selected buildings have nearly identical floor areas. Indeed, the design layout significantly impacts masonry material costs, as the volumes, surfaces, and lengths of elements vary according to the chosen plan.

The variance of other explanatory variables also varies greatly according to construction quality. For example, regarding roofs and frameworks, there is a wide range of roof shapes and materials used: gable roofs, flat roofs, hipped roofs with gutters, and terrace roofs.

3.2. Construction of Models for Single-Storey and Two-Storey Buildings

By performing a stepwise analysis using SPSS, eight (08) models were successively tested for single-storey buildings. The first linear model was established with the first variable introduced in the table according to the F-probability criterion. The second model included the first two variables, also following the F-probability criterion, and so on, until Model No.8 was constructed.

Similarly, six (06) models were successively tested for two-storey buildings in the same manner, leading up to Model No.6.

The eight models for single-storey buildings and the six models for two-storey buildings were tested to estimate the dependent variable, retaining only the most significant independent variables (predictors) introduced in the tables.

The contribution of the other variables in the cost estimation or prediction equations did not significantly change the estimated construction cost. These variables were therefore eliminated from the models.

Variables eliminated for the single-storey building models: matchmen, matpeint, matélect, matvitre, mopeint.

Variables eliminated for two-storey building models: matchmen, matpeint, matélect, mocmv, moplomb, moélect, mopeint.

The intersection of the most significant variables between the single-storey and two-storey buildings includes: momccf, matplomb, matmaco, matcovet, matcarev.

It should be noted that the inclusion or elimination of variables is carried out according to the F-probability criterion:

1) If, for a model, the probability of an independent variable is $F \leq 0.050$, that is, the probability of making an error regarding an independent variable is less than 0.05, the model includes the variable.

2) If, for a model, the probability of an independent variable is $F \geq 0.100$, that is, the probability of making an error regarding an independent variable is greater than 0.10, the model eliminates the variable.

It is on this basis that the identified models were considered statistically significant.

Table 8. Summary of models for Single-Storey buildings.

Model	R	R squared	Adjusted R-squared	Standard error of the estimate
1	0.46[a]	0.716	0.704	5200708.410
2	0.913[b]	0.833	0.818	4075079.055
3	0.964[c]	0.930	0.920	2699109.199
4	0.987[d]	0.973	0.968	1711942.588
5	0.993[e]	0.986	0.982	1291155.071
6	0.998[f]	0.996	0.995	684666.481
7	0.999[g]	0.998	0.998	468051.318
8	1.000[h]	0.999	0.999	361014.957

The multiple correlation coefficients R (**Table 8**) for the eight models are all above 0.8, indicating that the dependent variable (Coûtcons) is strongly correlated with the explanatory "predictor" variables retained by the eight models.

The quality of a model's fit is assessed using the coefficient of determination R^2. Thus, the seventh and eighth models are "better" than the first six in terms of explanatory power, accounting for up to 99.8% of the variance in construction costs (Coûtcons). The adjusted R-squared values (R_a^2) are 0.998 and 0.999, compared to 0.704 - 0.995 for the first six models. Therefore, the last two models better explain the variance of the dependent variable (construction cost). Moreover, it should be noted that the standard error of the estimate is lowest for model 8.

Table 9. Summary of models for Two-Storey buildings.

Model	R	R squared	Adjusted R-squared	Standard error of the estimate
1	0.826a	0.682	0.665	10526805.015
2	0.915b	0.838	0.819	7740821.270
3	0.961c	0.924	0.910	5454447.349
4	0.982d	0.964	0.955	3861174.288
5	0.988e	0.976	0.967	3296336.232
6	0.993f	0.987	0.981	2513962.714

The multiple correlation coefficients R (**Table 9**) of the six models are all above 0.8, indicating that the dependent variable (Coûtcons) is strongly related to the explanatory predictor variables selected by the six models. The adjusted R-squared (R_a^2) values of the last two models are 0.967 and 0.981, compared to 0.665 to 0.955 for the first four models. Therefore, the last two models better explain the variance of the dependent variable (construction cost). However, it is worth noting that the standard error of the estimate for Model 6 is the lowest.

3.3. Analysis of Variance (ANOVA)

ANOVA is a statistical test used to verify whether multiple samples come from the same population or not. In this study, the analysis of variance allowed us to determine whether the observations we obtained all belong to the same family of buildings. To do this, we compared the means of the groups formed according to the classification criteria submitted to the analysis and found that, for the eight (08) single-story building models, the total sum of squares was 2,191,967,613,958,231.000, and for the six (06) models for 2-story buildings, the total sum of squares was 6,281,650,717,309,287.000. We observed that there is no significant variability among these means for each of the classification criteria considered.

The analyses showed that the eight (08) and six (06) models obtained are significant overall, as sig. = 0.000.

Note: The Type I error risk, or significance (sig.), indicates the risk of making a mistake regarding the direction of the regression. If sig. < 0.05, one can conclude the existence of a linear regression model at the 0.05 significance level (at the significance threshold indicated by the sig. statistic).

3.4. The Regression Coefficient

3.4.1. For Single-Story Buildings

The software first constructed a model using moélect as the explanatory variable, then a second model with matmaco and matcovet, and so on. It stopped at the 8th model with eight independent variables, since adding a 9th variable would not have significantly improved the explained variance and could have introduced collinearity issues.

The coefficients are significant, except for the constants β_0 in models 6 and 7, which are not significant (sig. > 0.05). However, this does not affect the slope of the regression line, *i.e.*, the direction of the relationship found. A high significance value for the constant merely indicates that this constant is not significantly different from zero. The 95% confidence intervals for all coefficients further confirm the above results. Indeed, except for models 1, 2, 3, 4, 5, and 8, the value 0 is included in the confidence intervals for the constants β_0 of models 6 and 7. Therefore, we can consider that the null hypothesis for the coefficients can be rejected, except for the constants.

The prescribed limits for tolerance and VIF (variance inflation factor) are: tolerance > 0.3 and VIF < 3.3 [4]. When these conditions are met, it indicates that the explanatory variables are weakly correlated, which is a sign of good model quality. In our case, only models 1, 2, 3, and 4 satisfy both conditions. However, collinearity diagnostics will confirm or refute any collinearity issues.

Note : The tolerance of a variable is a measure of collinearity. Tolerance is expressed as $1-R^2$. The VIF (Variance Inflation Factor) is simply the inverse of tolerance ($VIF = 1/\text{tolerance}$). Some statisticians suggest that a tolerance below 0.1, corresponding to a VIF above 10, should raise a warning [5]. Others consider that a VIF of 4 or higher already indicates severe collinearity among the independent variables [6]. In any case, both VIF and tolerance are useful indicators because they show which variables may be problematic, but they do not provide information about the cause of the problem.

3.4.2. For R + 1 Type Buildings

The coefficients are also significant, except for the constants in models 2, 3, 4, 5, and 6. We can also consider that the null hypothesis for the coefficients is negligible, since the constants β_0 do not affect the slope of the regression line, *i.e.*, the direction of the relationship found.

3.5. Collinearity Diagnostics

The SPSS software performs a so-called singular value decomposition, which is a technique somewhat similar to principal component analysis. The program attempts to extract uncorrelated dimensions from the predictive data. The variances of the different predictors are distributed across the different dimensions so that the sum of variance in each column equals 1 or 100%. We look for proportions above 0.9. If, in a row, we find two or more variance proportions of around 0.90, it indicates that these predictors have a collinearity problem.

We observe that the variables matplomb and moplomb have proportions above 0.90 for single-story buildings, indicating a collinearity issue. This means that the number of variables in our regression line (model) can be reduced, since matplomb can be expressed as a function of moplomb. This collinearity relationship is logical because labor costs are inherently linked to material costs.

For two-storey type buildings, collinearity issues are observed between the variables matmaco and matplomb.

3.5.1. For Single-Story Buildings

$$\begin{aligned}\tilde{C}_T &= 848847.047 + 5.361(\text{moelect}) + 1.100(\text{matmaco}) + 0.938(\text{matcovet}) \\ &\quad +2.357(\text{matplomb}) + 4.849(\text{mocmv}) + 1.159(\text{matcarev}) \\ &\quad -4.811(\text{moplomb}) + 0.399(\text{momccf})\end{aligned} \tag{5.1}$$

$B_0 = 848847.047$	$\beta_2 = 1.100$	$\beta_4 = 2.357$	$\beta_6 = 1.159$	$\beta_4 = 2.357$
$\beta_1 = 5.361$	$\beta_3 = 0.938$	$\beta_5 = 4.849$	$\beta_7 = -4.811$	

These regression coefficients are provided with a 95.0% confidence interval.

Bo: [30318.170; 1667375.924];	B_3: [0.699; 1.177];	B_6: [0.981; 1.338];
B_1: [4.312; 6.410];	B_4: [1.994; 2.719];	B_7: [−6.351; −3.270];
B_2: [0.999; 1.202];	B_5: [4.192; 5.505];	B_8: [0.160; 0.637].

The construction cost can thus be calculated with a certain margin of tolerance. Indeed, the lower estimate $\tilde{C}_{Tb}$ and the upper estimate $\tilde{C}_{Th}$ are given by the following expressions, respectively:

$$\begin{aligned}\tilde{C}_{Tb} &= 30318.170 + 4.312(\text{moelect}) + 0.999(\text{matmaco}) + 0.699(\text{matcovet}) \\ &\quad +1.994(\text{matplomb}) + 4.192(\text{mocmv}) + 0.981(\text{matcarev}) \\ &\quad -6.351(\text{moplomb}) + 0.399(\text{momccf})\end{aligned} \tag{5.2}$$

$$\begin{aligned}\tilde{C}_{Th} &= 1667375.924 + 6.410(\text{moelect}) + 1.202(\text{matmaco}) + 1.177(\text{matcovet}) \\ &\quad +2.719(\text{matplomb}) + 5.505(\text{mocmv}) + 1.338(\text{matcarev}) \\ &\quad -3.270(\text{moplomb}) + 0.637(\text{momccf})\end{aligned} \tag{5.3}$$

Thus, we have a cost margin such that: $M = \left(\tilde{C}_{Th} - \tilde{C}_{Tb}\right)2$.

Finally, the complete expression for the total construction cost can be written as:

$$\begin{aligned}\tilde{C}_T &= 848847.047 + 5.361(\text{moelect}) + 1.100(\text{matmaco}) + 0.938(\text{matcovet}) \\ &\quad +2.357(\text{matplomb}) + 4.849(\text{mocmv}) + 1.159(\text{matcarev}) \\ &\quad -4.811(\text{moplomb}) + 0.399(\text{momccf}) \pm M\end{aligned} \tag{5.4}$$

3.5.2. For Two-Storey Buildings

$$C_T = 5184569.577 + 0.947(\text{matmaco}) + 2.274(\text{matcarev}) + 2.491(\text{matplomb}) + 0.769(\text{momccf}) + 2.055(\text{matvitre}) + 1.313(\text{matcovet}) \quad (5.5)$$

$B_0 = 5184569.577$	$\beta_2 = 2.274$	$\beta_4 = 0.769$	$\beta_6 = 1.313$
$\beta_1 = 0.947$	$\beta_3 = 2.491$	$\beta_5 = 2.055$	

These regression coefficients are provided with a 95.0% confidence interval.

Bo: [−363591.850; 10732731.004];	B_3: [1.074; 3.909];	B_6: [0.460; 2.166].
B_1: [0.727; 1.168];	B_4: [0.493; 1.045];	
B_2: [1.666; 2.881];	B_5: [0.752; 3.358];	

The construction cost can thus be calculated with a certain margin of tolerance. Indeed, the lower estimate $\tilde{C}_{Tb}$ and the upper estimate $\tilde{C}_{Th}$ are given by the following expressions, respectively:

$$C_{Tb} = -363591.850 + 0.727(\text{matmaco}) + 1.666(\text{matcarev}) + 1.074(\text{matplomb}) + 0.493(\text{momccf}) + 0.752(\text{matvitre}) + 0.460(\text{matcovet}) \quad (5.6)$$

$$C_{Th} = 10732731.004 + 1.168(\text{matmaco}) + 2.881(\text{matcarev}) + 3.909(\text{matplomb}) + 1.045(\text{momccf}) + 3.358(\text{matvitre}) + 2.166(\text{matcovet}) \quad (5.7)$$

The complete expression for the total construction cost can be written as:

$$\tilde{C}_T = 5184569.577 + 0.947(\text{matmaco}) + 2.274(\text{matcarev}) + 2.491(\text{matplomb}) + 0.769(\text{momccf}) + 2.055(\text{matvitre}) + 1.313(\text{matcovet}) \pm M \quad (5.8)$$

3.6. Model Verification

3.6.1. For Single-Story Buildings

Let us consider House No.1. Applying the formula gives:

$$\tilde{C}_T = 848847.047 + 5.361(224300) + 1.100(5459400) + 0.938(1165000) + 2.357(1465000) + 4.849(1001600) + 1.159(2660594) - 4.811(293000) + 0.399(1623998) \quad (6.1)$$

$$\tilde{C}_T = 18,932,326.35F$$

We observe that the estimated total cost $\tilde{C}_T$ is very close to the actual total cost C_T (19,817,992 F). The residual value is very small:

$$e = CT - C_T = 36,818F \quad (6.2)$$

$$\tilde{C}_{Tb} = 15,394,732F$$

$$\tilde{C}_{Th} = 23,109,812F$$

The corresponding margin is: $M = 3,857,540F$.

By proceeding in the same way for House No. 20, we find an estimated total cost of 39,164,278 F, which is very close to the actual total cost (39,181,800 F).

$$e = 17,521F$$

The calculation of the margin gives $M = 8,501,661F$.

3.6.2. For Two-Storey Buildings

Let us consider House No. 10. Applying the formula gives:

$$\begin{aligned}\tilde{C}_T &= 5184569,577 + 0.947(26121270) + 2.274(10198820) \\ &+2.491(3822860) + 0.769(7196421) \\ &+2.055(2744023) + 1.313(2565575)\end{aligned} \quad (6.3)$$

$$\tilde{C}_T = 77,177,888F$$

We observe that the estimated total cost $\widetilde{CT}$ is very close to the actual total cost $CT(77,194,846F)$. The residual value is very small:

$$e = CT - C_T = 16,958F \quad (6.4)$$

By proceeding in the same way for House No. 17, we find an estimated total cost of 93,010,184 F, which is very close to the actual total cost (93,098,718 F).

$$e = 88,534F$$

Table 10. Summary of results for Single-Story buildings.

Construction number	Actual cost (FCFA)	Estimated cost (FCFA)	Residuals	% residuals in absolute value	Margin	% Margin
1	19 817 992	19 781 173	36 819	0.19	7 715 080	39
2	22 269 506	22 612 814	−343 308	1.54	9 301 653	42
3	22 527 062	22 346 416	180 646	0.80	8 663 705	38
4	22 942 740	22 711 401	231 339	1.01	8 848 501	39
5	23 019 243	22 921 127	98 116	0.43	8 840 597	38
6	23 393 544	23 425 836	−32 292	0.14	8 717 668	37
7	25 327 452	25 296 448	31 004	0.12	9 816 990	39
8	26 058 150	26 170 915	−112 765	0.43	10 458 878	40
9	26 572 140	26 745 682	−173 542	0.65	10 561 809	40
10	28 709 220	28 758 202	−48 982	0.17	10 562 828	37
11	28 724 687	28 977 200	−252 513	0.88	11 355 836	40
12	29 985 876	29 483 981	501 894	1.67	10 744 772	36
13	29 275 590	29 404 676	−129 086	0.44	10 961 715	37
14	29 239 775	29 629 881	−390 106	1.33	11 201 326	38
15	29 403 783	28 870 753	533 029	1.81	11 348 674	39

Continued

16	30 105 630	29 697 476	408 154	1.36	11 045 898	37
17	31 345 344	31 125 587	219 757	0.70	11 558 518	37
18	31 929 648	32 514 034	−584 386	1.83	11 553 263	36
19	37 467 037	37 660 646	−193 609	0.52	14 676 346	39
20	39 181 800	39 164 278	17 522	0.04	17 003 322	43
21	43 808 580	44 321 613	−513 033	1.17	16 672 578	38
22	45 896 375	45 764 100	132 275	0.29	20 670 561	45
23	49 418 910	49 548 135	−129 225	0.26	18 444 483	37
24	49 769 850	49 423 651	346 199	0.70	17 858 721	36

Table 11. Summary of results for Two-Storey buildings.

Construction number	Actual cost (FCFA)	Estimated cost (FCFA)	Residuals	% residuals in absolute value
1	42 710 468	45 730 453	−3 019 985	7.07
2	52 429 062	54 929 553	−2 500 491	4.77
3	53 704 025	54 237 897	−533 872	0.99
4	55 829 025	54 237 897	1 591 128	2.85
5	62 285 037	64 278 161	−1 993 124	3.20
6	64 635 787	62 096 775	2 539 012	3.93
7	72 655 775	70 774 875	1 880 900	2.59
8	74 540 550	75 016 716	−476 166	0.64
9	75 520 209	73 337 114	2 183 095	2.89
10	77 194 846	77 177 888	16 958	0.02
11	80 547 662	78 272 502	2 275 160	2.82
12	84 191 698	84 059 996	131 702	0.16
13	84 832 975	85 265 516	−432 541	0.51
14	88 302 656	87 942 053	360 603	0.41
15	88 581 968	89 280 303	−698 335	0.79
16	91 879 006	95 514 730	−3 635 724	3.96
17	93 098 718	93 010 184	88 534	0.10
18	96 141 506	95 514 730	626 776	0.65
19	97 361 218	93 010 184	4 351 034	4.47
20	115 374 206	117 918 654	−2 544 448	2.21

The residuals are very small compared to the actual total cost of the different houses, ranging from 0.04% to 1.83% for single-story buildings (**Table 10**) and from 0.02% to 7.07% for R + 1 type building (**Table 11**). The residual plots versus houses also show that all positive or negative deviations are very close to the normal axis at 0. However, the margins are relatively large, representing more than 36% of the predicted value. This could certainly be due to the composition of the initial sample, where the constructions considered, although of the same type, do not always have identical characteristics, particularly in building size.

Still aiming to test the two obtained models, we consider the results for single-story and two storey building constructions with approximate areas of 110 m^2 and 125 m^2, respectively. The construction cost per square meter varies from one company to another, and especially in the informal sector, it is a price that is not even standardized. We used data from the Ministry of Construction, Urbanism, and Housing (MCUH).

The price per square meter in the Congo for medium-standard construction is 450,000 F CFA [7].

By applying the estimation method per covered square meter for House No. 24, a medium-standard single-story house with a total living area of 109 m^2, we obtain the following value according to the standard:

Medium Standard (Single-Story House):

$$CT = 109\text{m}^2 \times 450,000F$$

$$CFA = 109/\text{m}^2 = 49,050,000F\ CFA$$

We observe that the estimated cost (49,050,000 F) using the covered square meter method for House No. 24 is not far from the actual cost (49,769,850 F). The residual is 719,850 F, or 1.45% of the actual cost, compared to a residual of 346,199 F, or 0.70% of the actual cost, using the statistical-matrix method.

The value obtained with the covered square meter estimation method (47,250,000 F) falls well within the margin interval predicted by the model. It is true that the tolerance margin reaches values exceeding 36% of the estimated cost. This could be explained by the disparity in the construction standards of the sample used to implement the model.

Application to House No.18 (Two-Storey building , Medium Standard):

$$CT = 2 \times 120\text{m}^2 \times 450,000F$$

$$CFA/\text{m}^2 = 108,500,000F\ CFA$$

The estimated cost (108,500,000 F) using the covered square meter method for House No. 18 is somewhat higher than the actual cost (96,141,506 F). The residual is 12,358,494 F, or 12.85% of the actual cost, compared to a residual of 626,775 F, or 0.65% of the actual cost, using the statistical-matrix method.

This clearly demonstrates the reliability of cost estimates provided by the statistical-matrix model rather than by the per-square-meter method (see **Figure 5** and **Figure 6**).

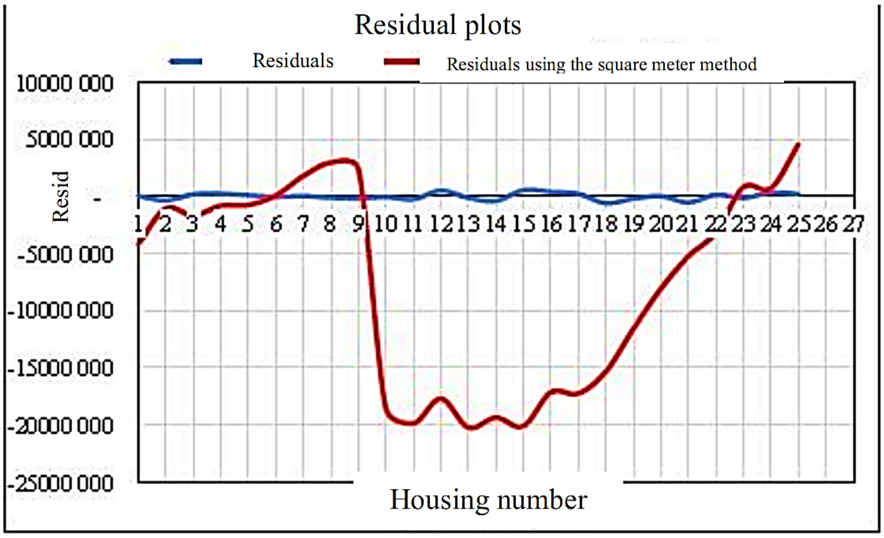

Figure 5. Residual plot for Single-Story houses.

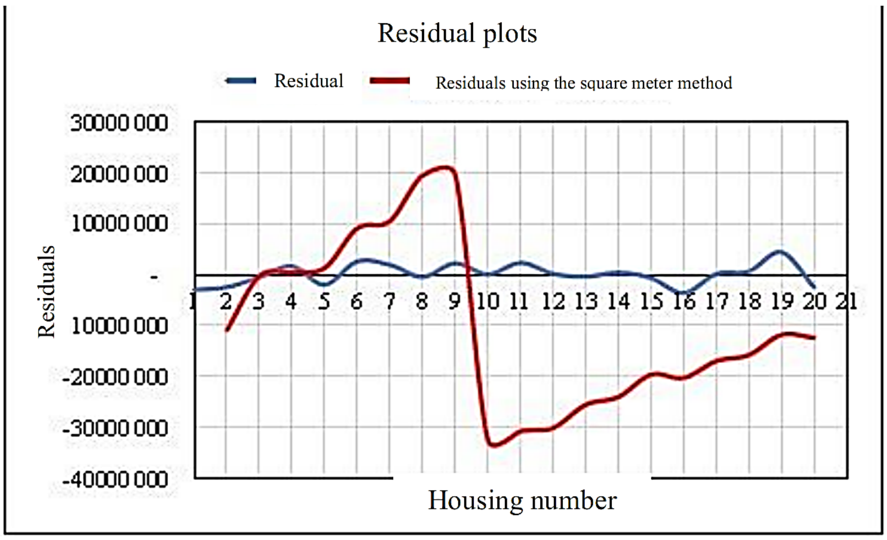

Figure 6. Residual plot for Two-Storey buildings.

It can be observed that the residual values provided by the statistical-matrix model are very close to the normality curve (zero-residual curve), especially for the residual plot of single-story houses. We can conclude that the MSMECC method is highly effective in determining construction costs regardless of the level of standard.

However, the residual values given by the covered square meter method are much larger. On the red curves in Figure 5 and Figure 6, two levels of standard (fairly good and good) and an intermediate standard can be observed. At both the beginning and the end of the curves, the covered square meter estimation method produces values that are relatively close to the normality curve. This clearly shows that this method is effective in determining construction costs when the level of standard is well controlled.

On the other hand, when the standard is not well controlled (intermediate standard), large residual values are observed on the curves.

4. Discussions

Several researchers have worked on the issue of construction cost estimation [8] [9], but very few have attempted to use statistical data from similar buildings, relying on a detailed decomposition of works into sub-works to reliably predict construction costs [10] [11]. Our study fits into this innovative approach, analyzing a sample of 25 single-story houses and 20 R + 1 houses in the city of Brazzaville.

We observed that the costs associated with different construction variables vary significantly over time and between buildings of the same type. This variability is mainly explained by fluctuations in the materials market, which are influenced by macroeconomic factors, as highlighted by Gwang *et al.* [12] and AlTalhoni *et al.* [13]. It illustrates the economic instability in Sub-Saharan African countries, where inflation, supply tensions, and fiscal policies directly affect the final project cost.

The statistical analysis, conducted using SPSS software, generated eight (08) significant models for single-story houses. This approach, based on multiple regression, aligns with a methodological trend validated by other authors, such as Ganiyu *et al.* [9] and Jana *et al.* [14], who demonstrated the value of such modeling for cost forecasting in developing countries.

The major predictive variables identified in our study-moélect, matmaco, matcovet, matplomb, mocmv, matcarev, moplomb, momccf-show a certain stability compared to those proposed by Louzolo [15], although some differences are noticeable. In his study on 18 F4-type houses, Louzolo also identified eight relevant variables, including matmaco, matcovet, matplomb, and matcarev, confirming the robustness of these variables as reference indicators.

However, differences remain, particularly in the observed values of the variable matmaco (masonry materials), which in our sample (2010-2020) ranges from 3,706,980 F to 11,603,730 F, compared to a wider range in Louzolo's study [15], from 2,058,544 F to 17,196,230 F. This variation can be explained by the more constrained economic context in the late 2000s, when the price of a cement bag reached up to 15,000 F CFA, compared to about 3,500 F CFA in the following decade. The source of data also plays a role: our data comes from technical design offices, whereas Louzolo relied on financial institution archives, which may introduce structural biases.

Regarding multicollinearity issues between variables, Louzolo simplified his model by retaining four main variables : momccf, matcovet, matmaco, and matchmen. This simplification, also necessary in our case, highlights the importance of controlling interdependencies between variables to avoid redundancy and strengthen model validity. Comparing our results suggests the existence of a core set of reliable predictive variables : matmaco, matcovet, matplomb, matcarev, and momccf, which are essential for a quick and relatively accurate estimation of the construction cost of F4-type houses.

5. Conclusions

Controlling construction costs in developing countries (D.C.s) remains a major challenge, particularly due to difficulties in forecasting and managing the costs of materials, labor, and overheads. This study focused on the issue of construction cost estimation in the Republic of Congo, emphasizing reliable cost prediction rather than optimization.

The method used relies on data from previously completed real estate projects. These data were analyzed using the statistical-matrix model, inspired by the approach developed by Pettang, and applied to two types of residential buildings: single-story (RDC) and two-storey building, all of type T4 with comparable floor areas. However, generalizing this model to different building types has limitations, as each type would require specific coefficients to ensure reliable estimates.

Given the limited sample size, the selection of explanatory variables was restricted to thirteen, grouped according to construction trades. Special attention was given to multi-skilled trades, which promote more flexible labor. Statistical analysis, conducted using SPSS in Stepwise mode, allowed the development of two predictive models: one for single storey buildings with eight variables (including moélect, matmaco, matplomb), and one for two-storey buildings with six variables.

Although the predicted values are close to the actual values, the models exhibit a margin of error of approximately 30%, likely due to variations in the characteristics of the analyzed buildings. These models are therefore most applicable at the feasibility stage. In the long term, the use of more advanced tools such as BIM (Building Information Modeling) or neural networks could significantly improve the accuracy of cost estimates in the African context.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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