BIM-Enabled Coordination and 5D Cost Estimation of Alternative Walling Systems for a Mixed-Use Building in Yaoundé, Cameroon

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ABSTRACT

Cost overruns remain endemic in construction, and unreliable quantities are among their most persistent causes. This paper reports a model-based estimating workflow applied to a real, not-yet-started four-storey (R+3) mixed-use building with an accessible roof terrace at Damas, Yaoundé, Cameroon. Four discipline models covering architecture, structure, electrical services and plumbing were authored in Autodesk Revit, verified against the Eurocodes in Robot Structural Analysis, federated and clash-tested in Navisworks Manage, and exported in IFC 4 to CostX for automated quantity take-off and bill production. Three walling variants sharing an identical reinforced-concrete frame were then generated by wall-type substitution: hollow sandcrete block (V1), stabilised interlocking compressed earth block (V2) and fired clay brick (V3). Coordination surfaced 233 interdisciplinary clashes, 44.6 % of them at the architecture–structure interface, and four iterations were needed to clear the federated model. Model-based quantities agreed with an independent manual take-off to within +1.8 % to +6.1 % on concrete, formwork, masonry and floor finishes, while take-off effort fell from 41 h to 6 h, a reduction of 85.4 %. The comparison also exposed a unit error in the manual reinforcement take-off, which returned 226 kg/m³ against 116 kg/m³ from the model and would have inflated the bill by about 29.0 million FCFA, or 11.2 % of the project cost. On the 5D bills, V2 returned the lowest total cost at 245,817,921 FCFA (157,576 FCFA/m²), 5.35 % below V1, together with 59 days (13.8 %) saved on the critical path, whereas V3 cost 0.47 % more than V1. Most of the V2 advantage arose not from the price of the block but from the elimination of rendering, a saving the model quantified automatically. Ten of the sixteen work packages were identical across the three variants and accounted for 57.4 % of direct cost, which bounds the achievable saving. The study demonstrates a reproducible 5D route to design-stage cost control in a low-maturity BIM market and shows that walling choices should be appraised on whole-project cost rather than on unit material price.

Keywords: 5D BIM, Building Information Modelling, clash detection, compressed earth blocks, construction cost estimation, quantity take-off

INTRODUCTION

Urban growth is concentrating construction demand in the countries least equipped to absorb it. Rather more than half of the world population now lives in cities, and the share is projected to reach about 68 % by 2050, with the increase falling overwhelmingly on Africa and Asia (United Nations, 2019; UN-Habitat, 2016). Construction is therefore an expanding sector, yet its record on delivering to budget is poor. In the reference study of large infrastructure programmes, Flyvbjerg et al. (2003) found that 86 % of projects overran their budgets, by an average of 28 %. In Cameroon the sector accounts for a significant share of gross domestic product and of formal employment, and the same pressures apply with fewer institutional buffers: contractors work on thin margins, price volatility on cement and steel is high, and design information is frequently incomplete when tenders are priced.

A substantial part of this problem originates upstream, in the way quantities are produced. Conventional practice separates the drawing, the measurement, the priced bill and the programme into distinct artefacts maintained by different people in different tools, so every design change must be propagated by hand and every propagation is an opportunity for omission or transcription error. Take-off from two-dimensional drawings is slow, weakly auditable and sensitive to the individual measurer, and the resulting inaccuracies feed directly into the tender price and into subsequent claims (Monteiro and Martins, 2013; Alathamneh et al., 2024). Because the estimate is produced only once the design is essentially fixed, it also arrives too late to influence the decisions that determine most of the cost.

Building Information Modelling (BIM) addresses this by making the model, rather than the drawing, the source of truth. Its fifth dimension links model objects to cost data so that quantities and prices update as the design evolves (Eastman et al., 2011; Azhar, 2011), and a consistent body of evidence reports faster measurement, better traceability and improved completeness where 5D workflows are properly implemented (Smith, 2016; Vigneault et al., 2020; Pishdad and Onungwa, 2024). The benefit is conditional. Model-based quantities inherit the quality of the model: mis-set parameters and wrongly classified objects propagate silently into the bill, which is why automated take-off is increasingly paired with explicit precision checks (Valinejadshoubi et al., 2024). Mapping objects to measurement rules is a further obstacle, since commercial take-off engines embed the conventions of the country in which they were written (Abanda et al., 2017). Automation therefore substitutes one class of error for another, and any credible claim about 5D reliability requires a control measurement against which the model output can be tested.

Coordination is the second lever. Clash detection on a federated model relocates the discovery of interdisciplinary conflicts from the site, where correction means demolition and rework, to the design office (Eastman et al., 2011; Hasannejad et al., 2023). Its value is largest precisely where contingency budgets are smallest, and it also improves the estimate itself, since a model that still contains conflicting geometry cannot yield trustworthy quantities.

BIM uptake in sub-Saharan Africa nonetheless remains limited. Saliu et al. (2024) rank software and training costs, shortages of cross-disciplinary expertise, weak stakeholder collaboration and poor interoperability as the leading regional barriers, and a five-country study covering Cameroon, Gabon, Chad, Angola and the Republic of the Congo reports that only a small minority of professionals have any formal BIM training (Bikoumou Gambat et al., 2026). Demonstration projects worked end-to-end on a real local building, with local prices and productivity rates, remain scarce; most published 5D case studies come from markets whose cost structures do not transfer.

The third strand concerns walling materials. Stabilised compressed earth blocks (CEB) have been advocated for decades in West and Central Africa on grounds of cost, embodied energy and use of locally available laterite (Houben and Guillaud, 1994), and interlocking variants that dispense with most of the bedding mortar have attracted renewed attention (Koudje and Adjovi, 2025). The economic case, however, is usually made at the level of the wall. That framing is misleading for a client, who pays for a building rather than for an envelope, and it ignores the second-order consequences of the choice on rendering, painting and programme. A model-based comparison can close this gap, because it holds every other element of the building constant while a single parameter is varied.

This paper accordingly asks how far an integrated BIM workflow can improve the reliability of design-stage cost information for a building in Yaoundé, and what it reveals about the economics of alternative walling systems. The objectives are to build and structurally verify a coordinated multidisciplinary model of a real R+3 mixed-use building; to quantify the coordination problems the federated model exposes; to test model-based quantities against an independent manual take-off and measure the associated effort; and to derive, on a common basis, the durations and costs of three walling variants differing in nothing but the infill. The contribution is threefold: a reproducible Revit–Robot–Navisworks–CostX chain documented with local rates and productivity data; quantified evidence, from an African case, of both the accuracy and the failure modes of automated take-off; and a demonstration that whole-project appraisal materially changes the ranking a wall-level comparison would produce.

METHODOLOGY

Research design

The study follows a single-case, design-science strategy: a real project is carried through a complete digital estimating chain, and the outputs of each stage are verified against an independent reference wherever one can be constructed. The work is organised in three phases, shown in Figure 1. Phase 1 assembles the input data and produces the discipline models. Phase 2 verifies the structure, federates the models, resolves the conflicts and generates the design variants. Phase 3 derives durations, quantities and costs, and compares the variants. Autodesk Revit 2025 was used for authoring, Autodesk Robot Structural Analysis Professional for structural verification, Autodesk Navisworks Manage 2024 for federation, clash detection and 4D simulation, and Exactal CostX for take-off and bill production.

The single-case design is deliberate, and it fixes the kind of inference the study can support. The claim advanced here is analytical rather than statistical: what is offered for transfer is the workflow, the verification logic and the mechanism by which a walling choice propagates into rendering, painting and programme, not the specific percentages. The case was selected because it is typical of the reinforced-concrete frame with masonry infill that dominates urban construction in Yaoundé, because it had not started on site, and because the four discipline drawings and the geotechnical investigation were all available. It is not claimed to represent high-rise, industrial or geometrically irregular buildings, other procurement routes, or markets with different relative prices for cement, labour and land. Section 3.7 states the boundary conditions under which the findings would be expected to hold, and Section 4 sets out the multi-case replication needed to test them.

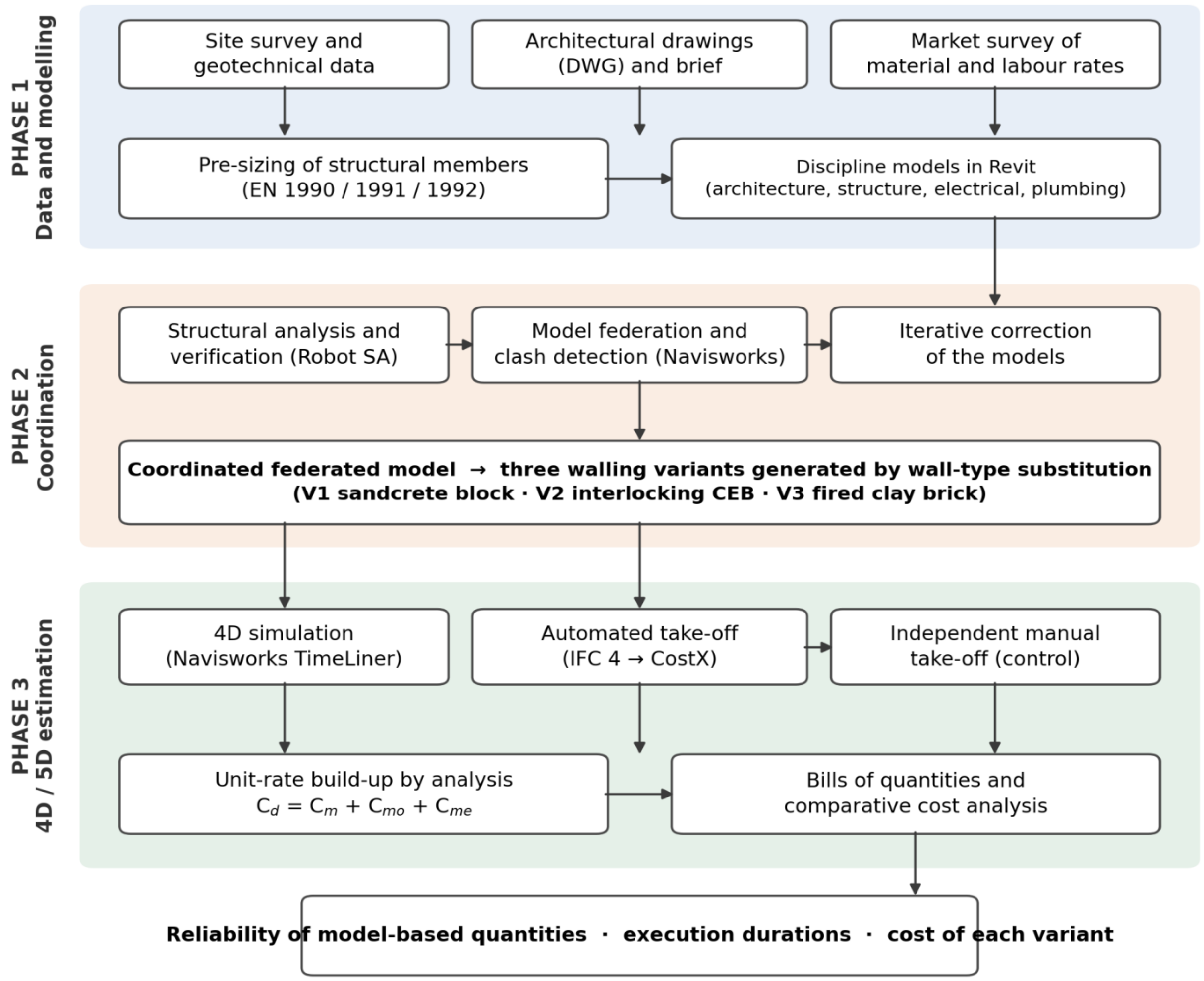


Figure 1. Three-phase research workflow, from data acquisition to comparative cost analysis.

The case study

The case is a mixed-use building at Damas, in the sixth district of Yaoundé (3°52′14″ N, 11°31′42″ E, 726 m above sea level), comprising a ground floor and three upper storeys under an accessible roof terrace, with retail units at ground level and offices and apartments above. The plot covers 1,240 m² and the footprint 392 m². The project had not started on site, which is what makes the comparison meaningful: the variants remained genuinely open. Three hand-auger boreholes to 4.50 m and two dynamic penetration tests identified 0.40 m of topsoil over compact red lateritic clay to 3.20 m, then sandy saprolite, with no water table encountered; an allowable bearing pressure of 0.20 MPa was adopted at a founding level of −1.80 m. The climate is humid tropical, with a mean annual temperature of 24.1 °C, rainfall of 1,612 mm and relative humidity of 80 %. The three metres of lateritic clay in the footprint are directly relevant to one variant, since they permit on-site block production. Table 1 summarises the geometry.

Table 1. Geometric and functional characteristics of the case-study building.

Characteristic	Value	Unit
Number of storeys	Ground floor + 3, with accessible roof terrace	—
Building footprint	392	m²
Total floor area	1,560	m²
Overall height	13	m
Clear storey height	3.25	m
Structural grid	11 longitudinal lines × 6 transverse lines	—
Maximum beam span	5.4	m
Number of columns	29	—
Total infill masonry area	1,421.35	m²
of which façade walls	862.1	m²
of which internal partitions	559.25	m²

Cost and productivity data

Material prices were collected from six suppliers in Yaoundé during January 2026 and cross-checked against recent public-works schedules of rates and against the priced bill of a comparable reference project; the value retained for each item is the mean of the offers received, delivered to site. Labour rates were obtained from four contractors in the city. Daily output rates were taken from the contractors' own records for sandcrete and fired clay masonry; for interlocking CEB, which is less common locally, the rate rests on fewer references, which is treated as a limitation. Table 2 reports the inputs that govern the comparison.

Table 2. Unit rates of the principal materials and labour, Yaoundé market, January 2026.

Item	Unit	Rate (FCFA)	Offers
Cement CPJ 35, 50 kg bag	bag	5,500	6
Washed river sand	m³	12,000	5
Crushed aggregate 5/15	m³	18,000	5
High-bond reinforcement HA 500	kg	850	4
Formwork timber	m²	3,500	5
Hollow sandcrete block 15 × 20 × 40	unit	425	6
Interlocking compressed earth block (produced on site)	unit	180	—

Hollow fired clay brick 30 × 15 × 20	unit	590	3
Selected and screened lateritic soil	m^3	3,500	—
Manual CEB press, hire	day	25,000	2
Bedding mortar, 400 kg/m^3 mix	m^3	56,350	computed
Skilled mason	day	8,000	4
Labourer	day	3,500	4

Modelling and structural verification

Four discipline models were authored in Revit from the architect's DWG drawings and from the pre-sizing of the structural members carried out to EN 1990, EN 1991 and EN 1992. The federated model contains 1,847 parametric objects across five levels, at LOD 350 for the structure and LOD 300 for the architecture, which is sufficient for coordination, measurement and estimating at detailed-design stage but does not anticipate construction-stage modifications. Materials, dimensions and level of insertion were carried on every object so that schedules could be generated without manual re-entry.

The analytical model was transferred to Robot Structural Analysis, where supports, materials, load cases and combinations were defined to the Eurocodes, using C25/30 concrete and HA 500 reinforcement throughout. Permanent structural loads were derived by the software from the geometry and a reinforced-concrete unit weight of 25 kN/m^3; non-structural permanent loads were computed by hand from the build-up of each element, and imposed loads were assigned by occupancy category to EN 1991-1-1. The governing combinations were $1.35\ G_{1k} + 1.35\ G_{2k} + 1.50\ Q_k$, the crossed unfavourable case $1.35\ G_{1k} + 1.00\ G_{2k} + 1.50\ Q_k$, and the characteristic and quasi-permanent serviceability cases. The analysis was run under the heaviest variant so that a single enveloping design would be valid for all three; this assumption is tested in Section 3.1.

Generation of the design variants

The three variants were produced inside the same Revit model by substituting the wall type of the infill. The frame, the foundations, the floors, the openings, the services and the finishes specification were left untouched, so that any observed difference in quantity, duration or cost is attributable to the infill alone. Each variant was then saved as an independent model and checked geometrically before being passed to coordination and measurement. Table 3 defines them. The set spans a deliberate gradient of departure from dominant local practice: V1 reproduces the standard Yaoundé solution; V2 introduces dry-stacked interlocking blocks that eliminate almost all bedding mortar and one face of render, at the price of requiring trained masons and protection against rising damp; V3 uses the technically strongest unit, whose firing raises both its price and its embodied impact.

Table 3. Definition of the three walling variants.

Design attribute	**V1 — Sandcrete block**	**V2 — Interlocking CEB**	**V3 — Fired clay brick**
Load-bearing frame	Reinforced concrete C25/30	Reinforced concrete C25/30	Reinforced concrete C25/30
Foundations	Isolated pad footings	Isolated pad footings	Isolated pad footings
Infill unit	Hollow sandcrete block	Compressed earth block stabilised with 8 % cement, 29.5 × 14 × 9.5 cm	Hollow fired clay brick
	15 × 20 × 40 cm		30 × 15 × 20 cm
Units per m^2	12.5	24	16.7

Finished wall thickness (cm)	15	14	15
Compressive strength, dry / wet (MPa)	4.5 / 4.2	4.0 / 2.2	8.5 / 8.1
Water absorption (%)	12	18	9
Laying method	Mortar bed, 15 mm joints	Dry interlocking, levelling mortar only	Mortar bed, 12 mm joints
Surface treatment	Render to both faces	External face fair-faced	External face fair-faced
Supply	Local factory	Produced on site by press	Regional brickworks
Labour requirement	Standard	Masons trained in the technique	Standard
Particular constraint	None	Protection against rising damp	Delivery lead time

Clash detection

The four discipline models were federated in Navisworks Manage and three tests were configured in Clash Detective, each pairing the structure with one other discipline: architecture (T1), electrical services (T2) and plumbing (T3). The structure appears in all three because the cost of correcting a structural element after casting far exceeds that of relocating a service or a partition. Hard clashes were run at a tolerance of 10 mm, supplemented by a 50 mm clearance test to capture proximity conflicts that would obstruct installation or maintenance. Each conflict was located, classified and corrected in the source Revit model, and the test re-run until no critical physical conflict remained.

4D simulation and duration estimating

The construction programme was built activity by activity in the TimeLiner module and linked to the model objects by automatic association rules. Durations were not estimated globally but derived from the measured quantities and from crew output, so that the programme is a direct function of the model:

$$D_i = Q_i / P_i , \quad with \ \ P_i = N_i \cdot r_i \qquad (1)$$

where D_i is the duration of activity i in working days, Q_i the quantity in its measurement unit, P_i the daily output of the assigned crew, N_i the number of productive operatives and r_i the individual output rate. Durations were rounded up to the next whole day. The total labour input follows as $H = \Sigma \ N_i \cdot D_i \cdot 8$, the working day being fixed at eight hours. The total project duration is the critical path through the network, not the arithmetic sum of the activity durations, because the finishing and services packages run in parallel.

Model-based quantity take-off and its verification

The coordinated model was exported in IFC 4 and imported into CostX. Dimension groups were configured by element category and by the quantity to be extracted (volume, area, length, perimeter or count), and the project was structured into work packages covering earthworks, foundations, superstructure, masonry, waterproofing and the finishing and services trades.

Because automated measurement can fail silently, the output was tested against an independent manual take-off produced from the same drawings. The relative deviation of each item was computed as:

$$E = | \ Q\_CostX - Q\_ref \ | \ / \ Q\_ref \times 100 \qquad (2)$$

where Q_CostX is the automatically extracted quantity and Q_ref the reference quantity obtained by manual measurement. The time spent producing each take-off was recorded so that accuracy and effort could be reported together.

Unit rates and cost aggregation

For the work items that drive the comparison, that is the masonry trades, unit rates were built up by analysis rather than taken from a schedule, so that the mechanism of any cost difference remains visible:

$$C\_d = C\_m + C\_mo + C\_me \qquad (3)$$

where C_m is the material cost including a 5 % allowance for waste and breakage, C_mo the labour cost derived from the same output rates used in the programme, and C_me the cost of plant and small tools. Each bill item was then priced and aggregated:

$$M_i = Q_i \times PU_i\,, \quad C\_D = \Sigma\, M_i\,, \quad C\_T = C\_D + C\_I \qquad (4)$$

with M_i the amount of item i, PU_i its unit rate, C_D the direct cost, C_I the indirect cost taken at 18 % of direct cost, and C_T the total construction cost. Variants were compared through the relative cost deviation:

$$\Delta C = (\, C_i - C\_ref\,) \,/\, C\_ref \times 100 \qquad (5)$$

taking V1, the dominant local solution, as the reference. Work packages were finally ranked by their contribution to total cost in order to identify where optimisation effort has the greatest leverage.

RESULTS AND DISCUSSION

The federated model and the invariance of the frame

Figure 2 shows the architectural and structural models. The analytical model comprises 29 columns, 136 beams, four floor levels, two stair cores and 29 pad footings. Pre-sizing converged on a single 40 × 30 cm section for all columns and principal beams, a regularity that is itself economically useful because it limits the number of distinct formwork sets and standardises the reinforcement cages. Isolated footings of 2.20 × 2.20 × 0.50 m (ten) and 1.90 × 1.90 × 0.45 m (nineteen) were adopted against the allowable bearing pressure of 0.20 MPa. Total structural quantities are 271.46 m³ of concrete, 31,480 kg of reinforcement and 2,236.80 m² of formwork, giving an overall steel ratio of 116 kg/m³ that sits within the 100–130 kg/m³ band usual for buildings of this type.

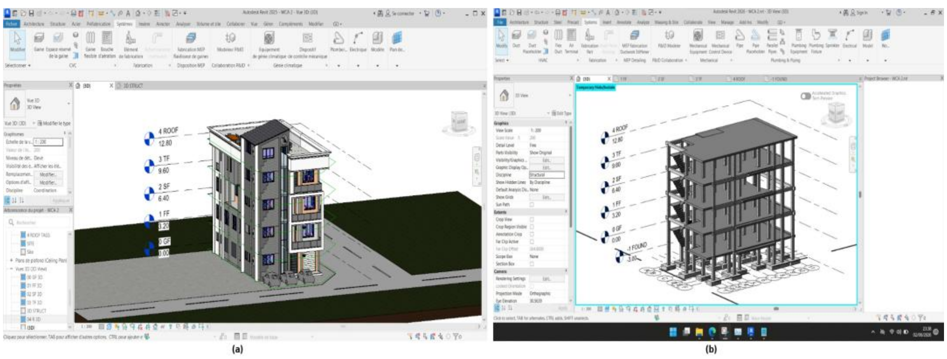


Figure 2. The Revit model of the case-study building: (a) architectural model; (b) structural model.

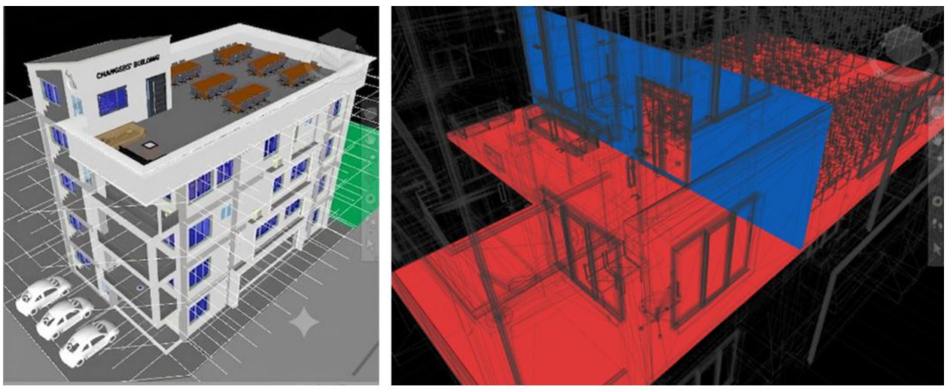
The most consequential result of this phase is reported in Table 4. Every global verification is satisfied with a wide margin: the horizontal displacement at roof level reaches only 32 % of the code limit and the deflections stay below half of their admissible values, a behaviour governed by the shear walls and by the modest height of the building. That reserve of capacity validates the methodological premise of the comparison. The self-weight of the infill ranges from 7.58 kN/m for fired clay to 8.92 kN/m for CEB, a spread of 17.7 %, but referred to the total vertical reaction of 1,021.63 kN the additional load is under 3 % of the force delivered to the foundations and is absorbed entirely within the available margins. The frame can therefore remain identical whichever masonry is selected. Without this check the comparison would have been confounded by differences in the structure itself, and the cost differences reported later could not have been attributed to the walling.

Table 4. Self-weight of the infill walls and global verification of the frame.

Quantity	V1	V2	V3	Limit / remark
Masonry alone (kN/m)	6.48	8.06	6.72	—
Render (kN/m)	1.73	0.86	0.86	Two faces for V1, one for V2 and V3
Total wall, 3.20 m high (kN/m)	8.21	8.92	7.58	Spread of 17.7 % between extremes
Horizontal displacement at roof (mm)	8.4	8.4	8.4	H/500 = 26.0; 32 % utilised
Maximum inter-storey drift (mm)	2.7	2.7	2.7	h/300 = 10.8
Maximum beam deflection (mm)	9.1	9.1	9.1	L/250 = 21.6
Total vertical base reaction (kN)	1,021.63	1,021.63	1,021.63	Governing (V2) case
Fundamental period (s)	0.42	0.42	0.42	—

Interdisciplinary coordination

The first coordination run on the federated model returned 233 conflicts. Figure 3 shows the Clash Detective environment and a representative hard clash in which a wall passes through a slab. Their distribution is given in Table 5 and Figure 4(a). Architecture against structure accounts for 104 conflicts, or 44.6 % of the total, which reflects the density of interfaces between those two disciplines rather than any particular weakness in the design. Conflicts involving the services are fewer, 73 for electrical and 56 for plumbing, but they are not less serious: a cable route or a soil stack discovered after casting is corrected by coring or by re-routing, both of which cost far more than the equivalent edit at design stage.



(a) (b)

Figure 3. Coordination in Navisworks Manage: (a) the federated model of the building; (b) a hard clash between a wall and a slab, highlighted in the Clash Detective viewport.

Table 5. Distribution and resolution of the clashes detected in the first coordination run.

Discipline pair	Hard	Clearance	Sequencing	Total	Share (%)
Architecture / structure (T1)	78	21	5	104	44.6
Electrical / structure (T2)	54	16	3	73	31.3

Structure / plumbing (T3)	41	13	2	56	24
Total	**173**	**50**	**10**	**233**	**100**

Four conditions dominate. A beam downstand crossing a door opening occurred 31 times and was resolved by raising the opening and forming an integral lintel; a partition thickness incompatible with the column face occurred 24 times; a conduit passing through a principal beam occurred 28 times and was resolved by transferring the run to the suspended ceiling; and a soil stack crossing a beam occurred 22 times, resolved by introducing a dedicated vertical service duct. One group is worth isolating: eleven conflicts in T1 arose from the 14 cm finished thickness of the V2 walls against the 15 cm assumed elsewhere. Left undetected, that single-centimetre discrepancy would have produced misaligned faces and remedial rendering across the building. It is precisely the class of error that a two-dimensional workflow does not catch, because no drawing ever shows the two conditions together.

Resolution converged rapidly, as Figure 4(b) shows: 233 conflicts fell to 47 after the first correction cycle, a reduction of 79.8 %, then to six and finally to none in the fourth run. Four cycles is a modest coordination effort for a building of this size, and the outcome is a model whose geometry is internally consistent. That consistency is a precondition for the measurement that follows, not merely a by-product of it.

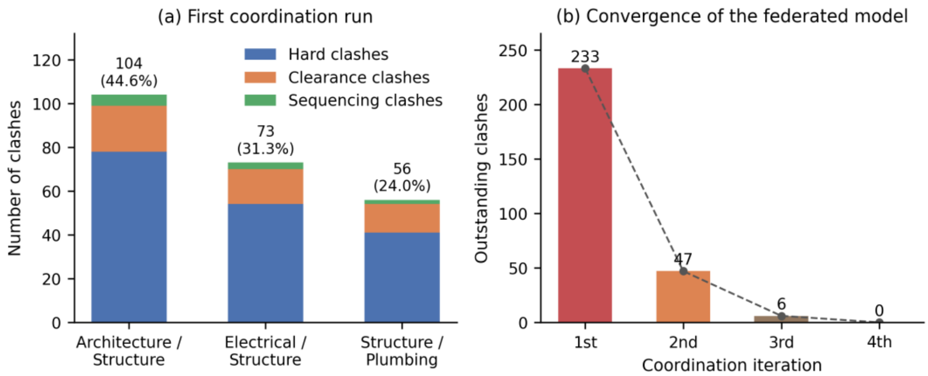


Figure 4. Clash detection outcomes: (a) distribution of the 233 conflicts of the first run by discipline pair and by nature; (b) convergence of the federated model over four coordination iterations.

Reliability and productivity of model-based take-off

The coordinated model was exported in IFC 4 and measured in CostX; Figure 5 shows the extraction in progress, with the principal structural quantities visible in the workbook. Table 6 and Figure 6 compare the automated output with the independent manual take-off.

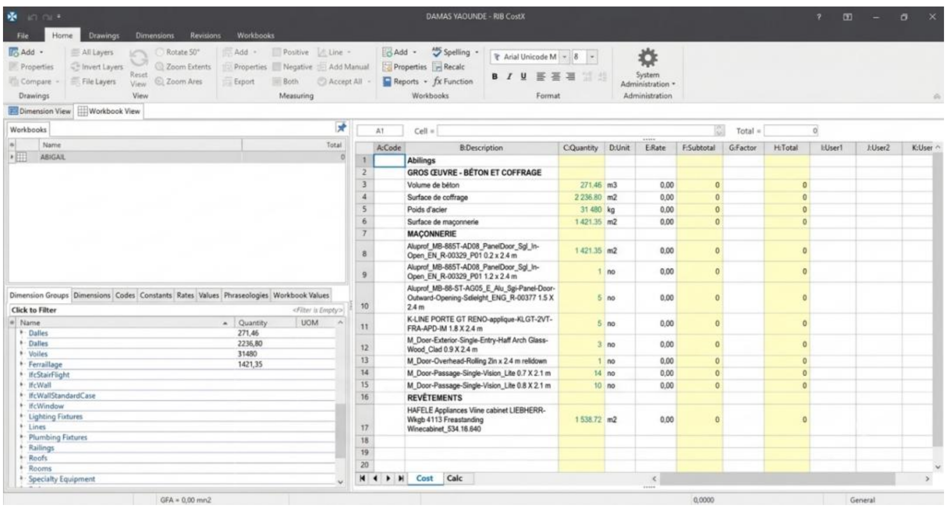


Figure 5. Automated quantity extraction from the IFC 4 model in CostX, showing dimension groups and the generated workbook.

Table 6. Model-based versus manual quantity take-off.

Work item	Manual take-off	Model-based (CostX)	Absolute difference	Deviation E (%)
Concrete volume (m³)	258.29	271.46	13.17	5.1
Formwork area (m²)	2,107.64	2,236.80	129.16	6.1
Reinforcement (kg)	**58,355**	**31,480**	**−26,875**	**−46.1**
Masonry area (m²)	1,384.50	1,421.35	36.85	2.7
Floor finish area (m²)	1,512.00	1,538.72	26.72	1.8
Take-off production time (h)	**41**	**6**	**−35.0**	**−85.4**

On four of the five measured items the two methods agree closely, within +1.8 % to +6.1 %. The model consistently returns slightly the larger quantity, which is the expected direction: automated measurement captures small returns, upstands and junction volumes that a manual measurer tends to simplify away. Deviations of this order are compatible with the values reported in the wider literature on BIM-based take-off (Alathamneh et al., 2024) and are small relative to the contingency normally carried at detailed-design stage.

The reinforcement line behaves differently, and is the more instructive result. The manual take-off returned 58,355 kg against 31,480 kg from the model, a deviation of 46.1 %. Because both figures refer to the same concrete volume the discrepancy is diagnosable rather than merely large: the manual measurement implies a steel ratio of 226 kg/m³ against 116 kg/m³ from the model, the first roughly double the range usual for a regular frame of this height and the second squarely within it. Tracing the item back identified a unit error in the manual measurement of the shear-wall reinforcement. Valued at the in-place rate of 1,080 FCFA/kg used in the bill, the surplus 26,875 kg represents about 29.0 million FCFA, or 11.2 % of total project cost. The important point is not that a measurer erred, which is unremarkable, but that the error was silent: nothing in a conventional workflow would have flagged it, because there was no second measurement to compare against. The model provided not a guarantee of correctness but an independent estimate whose disagreement forced an investigation, which is consistent with the argument of Valinejadshoubi et al. (2024) that automated take-off needs an explicit verification layer rather than blind trust.

The productivity result is unambiguous. Measurement time fell from 41 h to 6 h, a reduction of 85.4 %, and re-measuring a variant after substituting the wall type cost only the time needed to re-run the extraction. It is that second property, rather than the first, which made a three-variant comparison feasible within the resources of a single study: under a manual regime the exercise would have required three complete take-offs.

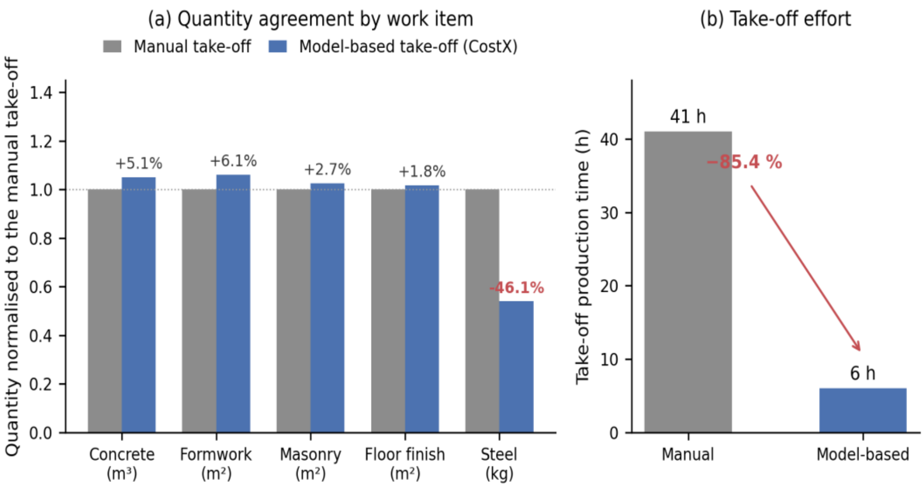


Figure 6. Comparison of manual and model-based take-off: (a) quantities normalised to the manual measurement, with the percentage deviation of each item; (b) take-off production time.

Execution durations from the 4D simulation

Six of the nine construction phases have identical durations across the three variants, because the frame, the services and the finishing packages are common. Only three activities vary: the masonry itself, the rendering and the painting. Table 7 gives their durations and the resulting critical paths, and Figure 7 presents them graphically.

Table 7. Durations of the variant-dependent activities and total execution time.

Activity / measure	V1 — Sandcrete	V2 — Interlocking CEB	V3 — Fired clay
Infill masonry: quantity (m²)	1,421.35	1,421.35	1,421.35
Infill masonry: crew output (m²/day)	24	32	20.8
Infill masonry: duration (days)	60	45	69
Rendering: quantity (m²)	2,842.70	568.54	1,421.35
Rendering: duration (days)	38	8	19
Painting and finishes: quantity (m²)	4,354.70	2,080.54	2,933.35
Painting and finishes: duration (days)	28	14	19
Total of the variable activities (days)	126	67	107
Total duration on the critical path (days)	**427**	**368**	**408**
Deviation from V1 (%)	—	**−13.8**	**−4.4**
Labour input (man-days)	4,961	4,549	4,847
Average workforce on site	11.6	12.4	11.9

V2 completes 59 days ahead of V1, a saving of 13.8 %. Two mechanisms produce it. The dry interlocking joint raises crew output from 24.0 to 32.0 m² per day, shortening the masonry from 60 to 45 days; and, more significantly, leaving the external face fair-faced cuts the rendering from 2,842.70 to 568.54 m², an 80 % reduction that compresses that activity from 38 days to eight. V3 gains only 19 days, because its saving on render is largely offset by a slower laying rate of 20.8 m² per day, itself a consequence of using 16.70 units per square metre against 12.50 for V1. Over the whole programme V2 mobilises 4,549 man-days against 4,961 for V1, a saving of 412 man-days, although its average workforce is higher at 12.4 against 11.6: the site is shorter but denser, which is a real operational consideration for a contractor with limited supervision capacity.

Because the 32.0 m²/day adopted for interlocking CEB rests on the weakest evidence of the three output rates, its influence on this result was bounded rather than assumed away. Holding every other input constant and re-applying Equation (1), a rate of 28.0 m²/day lengthens the masonry from 45 to 51 days and reduces the saving from 59 to 53 days, or 12.4 %; the limiting case in which dry stacking confers no productivity advantage whatever, at 24.0 m²/day, gives 60 days of masonry and a saving of 44 days, or 10.3 %. The direction of the programme result is therefore robust to this uncertainty, because 44 of the 59 days come from the reduction in rendering and painting rather than from the laying rate; only the magnitude is sensitive.

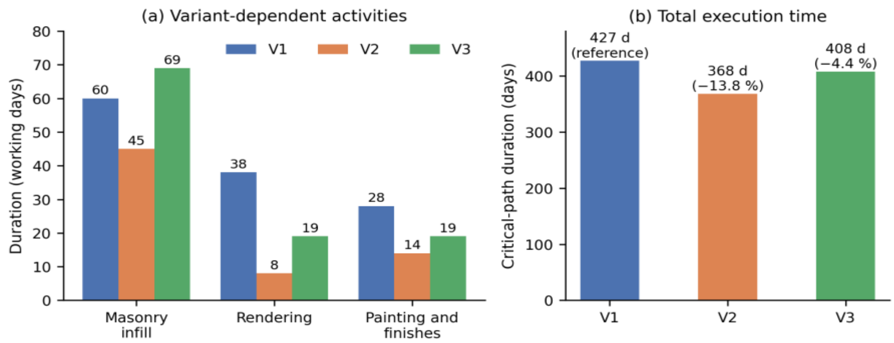


Figure 7. Execution durations from the 4D simulation: (a) the three variant-dependent activities; (b) total duration on the critical path.

Unit-rate build-up for the masonry

Table 8 decomposes the direct cost of one square metre of finished wall, and Figure 8 displays it. The rates retained are 8,600 FCFA/m² for V1, 6,380 FCFA/m² for V2 and 13,480 FCFA/m² for V3.

Table 8. Unit-rate build-up for one square metre of infill masonry (FCFA).

Cost component	V1 — Sandcrete	V2 — Interlocking CEB	V3 — Fired clay
Units per m² × unit price (FCFA)	12.50 × 425	24.00 × 180	16.70 × 590
Mortar consumption (m³/m²)	0.02	0.004	0.018
Materials including 5 % waste, C_m	6,761.48	4,772.67	11,410.67
Labour, C_mo	1,586.50	1,187.50	1,824.00
Plant and small tools, C_me	250	420	250
Direct cost C_d	**8,597.98**	**6,380.17**	**13,484.67**
Rate adopted (FCFA/m²)	**8,600**	**6,380**	**13,480**

The build-up shows where each variant's position comes from. V2 is the cheapest per square metre for two compounding reasons: the block itself is cheaper because it is produced on site from soil already present in the excavation, and the dry joint reduces mortar consumption from 0.020 to 0.004 m³/m², an 80 % reduction. Its higher plant cost, reflecting press hire, offsets only a small part of that. V3 is expensive for a single dominant reason: at 590 FCFA per brick and 16.70 bricks per square metre, the units alone cost 9,853 FCFA/m², more than the entire V1 rate. Comparison at unit-price level, which is how these materials are usually discussed on site, is therefore actively misleading: the CEB is cheaper than the sandcrete block per unit by 58 %, but per square metre of wall the advantage is 25.8 %, because more than twice as many blocks are required.

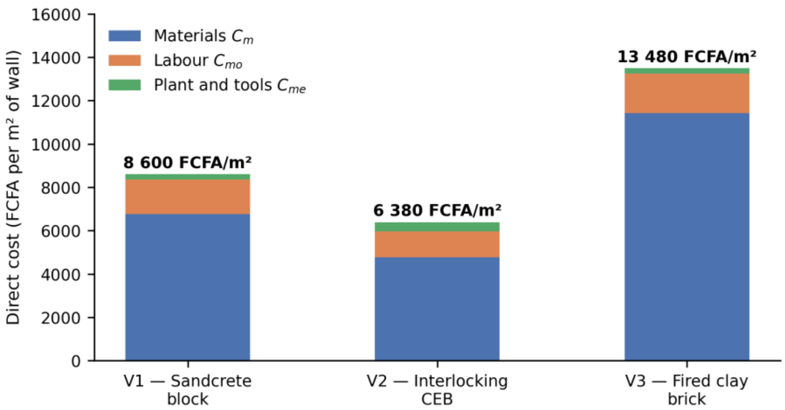


Figure 8. Composition of the direct cost of one square metre of infill masonry for each variant.

Comparative cost of the three variants

Table 9 sets out the priced bill by work package, and Figure 9 summarises the totals. Of the sixteen packages, only six differ between variants: the four elevation packages, the rendering package and the painting package. The ten identical packages amount to 126,238,320 FCFA, or 57.4 % of the direct cost of V1. This is the single most important structural fact of the comparison, and it is one that a wall-level analysis conceals entirely:

nearly three-fifths of the project cost is simply not addressable by the choice of infill, which mechanically bounds the deviation that any walling decision can produce.

Table 9. Comparative bill of quantities by work package (FCFA).

No.	Work package	V1	V2	V3
1	Preliminaries and earthworks	7,367,000	7,367,000	7,367,000
2	Setting out	520,000	520,000	520,000
3	Foundations and substructure	20,614,320	20,614,320	20,614,320
4	Ground-floor elevation	17,050,202	16,261,353	18,784,250
5	First-floor elevation	17,050,202	16,261,353	18,784,250
6	Second-floor elevation	17,050,202	16,261,353	18,784,250
7	Third-floor elevation	17,050,202	16,261,353	18,784,250
8	Floors, slabs and stairs	36,507,000	36,507,000	36,507,000
9	Drainage and ancillary works	2,682,000	2,682,000	2,682,000
10	Rendering, screeds and pointing	15,392,650	11,555,005	12,478,882
11	Finishes and waterproofing	23,318,000	23,318,000	23,318,000
12	Timber joinery	6,988,000	6,988,000	6,988,000
13	Metal and aluminium joinery	12,692,000	12,692,000	12,692,000
14	Painting	10,257,270	5,481,534	7,272,435
15	Electrical and low-current services	11,250,000	11,250,000	11,250,000
16	Plumbing and sanitary fittings	4,300,000	4,300,000	4,300,000
	Direct cost C_D	**220,089,050**	**208,320,272**	**221,126,636**
	Indirect cost C_I (18 %)	**39,616,029**	**37,497,649**	**39,802,794**
	Total cost C_T	**259,705,079**	**245,817,921**	**260,929,430**
	Cost per m² of floor area	**166,478**	**157,576**	**167,262**
	Deviation ΔC from V1	**—**	**−5.35 %**	**0.47%**

V2 is the least expensive solution at 245,817,921 FCFA, a saving of 13,887,158 FCFA or 5.35 % against V1, and 157,576 FCFA per square metre of floor area against 166,478 for V1. V3 costs 0.47 % more than V1: its savings on rendering and painting almost, but not quite, compensate for the price of the brick. Decomposing the V2 saving is revealing. The four elevation packages contribute 3,155,396 FCFA, which is exactly the masonry area multiplied by the difference in unit rate; rendering contributes 3,837,645 FCFA and painting 4,775,736 FCFA. In other words, two-thirds of the economy comes not from the masonry at all but from the finishing operations that the choice of masonry makes unnecessary. That result would be invisible to a comparison conducted at the level of the wall, and it is the clearest demonstration in this study of why a model-based, whole-project appraisal changes the answer rather than merely refining it.

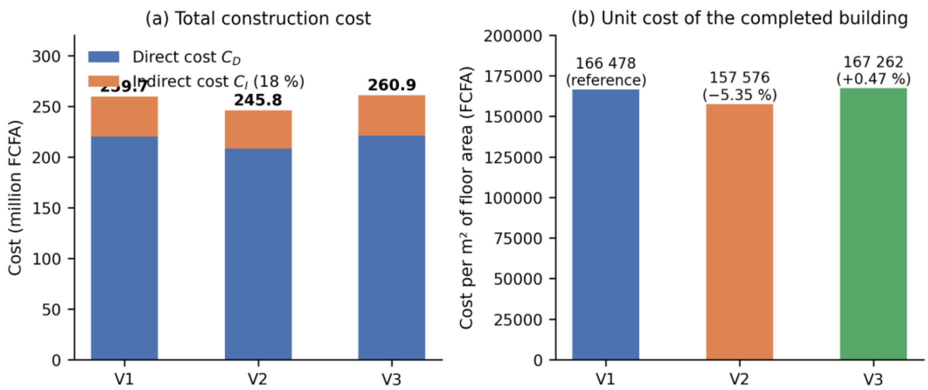


Figure 9. Comparative cost of the three variants: (a) direct and indirect construction cost; (b) cost per square metre of floor area.

Ranking the packages by contribution confirms where leverage actually lies: floors, slabs and stairs alone represent 16.59 % of direct cost, finishes and waterproofing 10.59 %, foundations 9.37 %, and each elevation package 7.75 %. A client seeking substantial savings would therefore gain more from re-examining the floor system than from any walling decision, a conclusion that follows directly from the 5D bill and would be difficult to establish with confidence without one.

DISCUSSION

Three findings deserve emphasis. First, the value of the model here lay less in the speed of measurement than in the redundancy it created. The 85.4 % time saving matches the upper range of published values, which is unsurprising for a building of this geometric regularity, but the error it exposed was worth 11.2 % of project cost, an order of magnitude more than any plausible efficiency gain. Model-based and manual take-off should therefore be treated as two independent estimates whose disagreement is diagnostic, rather than as an old method and its replacement. That reframing also guards against the opposite failure, in which unchecked automated quantities carry a modelling error straight into a tender.

Second, the walling comparison is directionally consistent with the regional literature but substantially smaller in magnitude. Savings of 15 % to 30 % are frequently quoted for compressed earth blocks against sandcrete; this study finds 25.8 % at the level of the wall rate, entirely compatible with those figures, but only 5.35 % on total construction cost. The difference is one of scope, not substance: the higher figures are computed over the envelope, whereas a client's budget covers a building in which the envelope is one component among sixteen. Reporting only the first is what produces disappointed expectations on site. Where a walling material also removes downstream operations, as interlocking CEB does with rendering, that indirect effect can outweigh the direct material saving, and only a whole-project measurement will surface it.

Third, the programme result matters as much as the cost result in this context. A 59-day reduction on a 427-day programme lowers exposure to price escalation on cement and steel, shortens the period over which site overheads accrue, and brings the asset into revenue earlier. Against this, V2 requires masons trained in a technique not yet widespread locally, and its wet compressive strength of 2.2 MPa, against 4.2 MPa for sandcrete and 8.1 MPa for fired clay, makes protection against rising damp a condition rather than a recommendation in a climate delivering 1,612 mm of rain a year at 80 % relative humidity. These are the trade-offs a single-criterion appraisal suppresses, and they motivate the multi-criteria treatment reported separately.

Several limitations qualify these results. The unit rates are those of the Yaoundé market in January 2026 and are volatile, particularly for cement and steel; a rise in the cement price would mechanically widen the advantage of V2, whose binder content is the lowest of the three. Output rates for sandcrete and fired clay masonry rest on numerous site observations, but the rate adopted for interlocking CEB rests on fewer local references and carries greater uncertainty, which directly affects the 13.8 % programme saving. Indirect costs were applied as a flat 18 % across variants, which is defensible for a comparison but does not capture the effect of the shorter programme on time-related preliminaries and therefore understates the V2 advantage. Finally, this is a single low-rise, geometrically regular case, and the take-off deviations reported here should not be generalised to complex geometry; the comparison is also confined to capital cost.

Three further qualifications govern how far the results travel. The evidence is a single building, so the numerical findings, the 233 clashes, the 85.4 % reduction in measurement time and the 5.35 % cost advantage, are properties of this case and not estimates of a population parameter; what is offered for transfer is the mechanism, namely that a walling choice acts on total cost mainly through the finishing operations it removes, and is bounded by the share of the bill it cannot reach, here 57.4 %. Second, the accuracy comparison rests on one manual measurement by one measurer, so it captures the deviation between two particular take-offs rather than the inter-measurer variability that would be needed to characterise manual measurement as a method; nor can a single control separate error in the manual route from error in the model, and the reinforcement item was resolved by diagnosis of the steel ratio rather than by a third measurement. Third, the flat 18 % indirect-cost allowance and the 5 % waste allowance were applied uniformly to all three variants, which is appropriate for isolating the effect of the infill but makes the comparison conditional on those settings.

CONCLUSION

This paper has tested how far an integrated BIM workflow can improve design-stage cost information for a real building in a market where BIM adoption remains marginal. A four-storey mixed-use building in Yaoundé was modelled in Revit, verified in Robot Structural Analysis, federated and clash-tested in Navisworks, and measured and priced in CostX, and three walling variants sharing an identical concrete frame were compared on a common basis.

The structural verification established that the frame is insensitive to the choice of infill: although wall self-weight varies by 17.7 % between the extreme variants, the additional load is under 3 % of the total base reaction and is absorbed within margins that leave the roof displacement at 32 % of its code limit. Coordination returned 233 conflicts, 44.6 % of them between architecture and structure, all cleared within four iterations; eleven arose from a one-centimetre discrepancy in wall thickness that no two-dimensional workflow would have revealed. Automated measurement agreed with an independent manual take-off within +1.8 % to +6.1 % on four of five items while cutting measurement time by 85.4 %, and the fifth exposed a unit error in the manual reinforcement measurement worth some 29.0 million FCFA, or 11.2 % of project cost. On the priced bills, the interlocking compressed earth block variant returned the lowest total cost at 245,817,921 FCFA, 5.35 % below the sandcrete reference and 157,576 FCFA per square metre, with 59 days saved on the critical path; the fired clay variant cost 0.47 % more than the reference.

Two conclusions follow for practice. Model-based measurement should be adopted not as a faster substitute for manual take-off but as a second, independent estimate whose disagreements are investigated, since in this case the diagnostic value of that redundancy exceeded the efficiency gain by an order of magnitude. And walling materials should be appraised on whole-project cost: the compressed earth block variant is 25.8 % cheaper per square metre of wall but only 5.35 % cheaper per building, because ten of sixteen work packages, representing 57.4 % of direct cost, are unaffected by the choice, while two-thirds of the saving that does arise comes from the rendering and painting that the material renders unnecessary rather than from the material itself.

Further work should extend the analysis from capital cost to whole-life cost, so that the durability implications of the wet strength of stabilised earth in a humid tropical climate are priced rather than merely noted; from a single regular low-rise building to geometrically complex cases, where the reliability of automated measurement is less well established; and from cost alone to an explicit multi-criteria appraisal weighing technical, comfort and environmental performance alongside economics. The last of these is the subject of a companion paper.

Three of those extensions bear directly on the limits of the present evidence. Replication across a portfolio of cases differing in height, structural system, geometric regularity, procurement route and city is needed before the deviations and savings reported here can be treated as more than case evidence, and would allow the relationship between geometric complexity and take-off accuracy to be estimated rather than asserted. A controlled measurement experiment, in which several quantity surveyors measure the same drawings blind to one another and to the automated output, would establish the inter-measurer variability against which model-based take-off should properly be judged. And a probabilistic treatment of the inputs, propagating the observed dispersion in supplier prices and crew output rates through the bill by simulation, would replace the point estimates of Table 9 with cost distributions and state the probability that the ranking of the three variants survives price movement.

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