CONSTRUCTION MANAGEMENT, TECHNICAL EDUCATION

# Effect of BIM-Integrated Instruction on Construction Management Competence and Innovation Skills among NCE Technical Education Students

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**Abstract**

Building Information Modelling (BIM) is central to construction innovation yet underused in Nigerian technical teacher education. This quasi-experimental study examined the effect of BIM-integrated instruction on construction management competence and innovation skills among Nigeria Certificate in Education (NCE) Technical Education students in South-East Nigeria. A pretest–posttest non-equivalent control-group design was applied to 120 NCE II and III Building and Woodwork Technology students (experimental n = 60; control n = 60) from three Colleges of Education (Technical). The experimental group received 12 weeks of Revit-based BIM instruction; the control group received conventional lecture-based instruction. The 25-item Construction Management Competence and Innovation Skills Scale (α = .94–.98) was analysed using ANCOVA; groups were equivalent at pretest. Controlling for pretest scores, the experimental group scored significantly higher on the composite (adjusted M = 84.78 vs. 55.62), $F(1, 117) = 208.05$, $p < .001$, $\eta^2_p = .64$, and on construction management competence ($\eta^2_p = .63$) and innovation skills ($\eta^2_p = .60$). Results were robust. BIM-integrated instruction is a promising model for curriculum reform in technical teacher education, pending replication with performance-based measures.

**Keywords:** Building Information Modelling; construction management; curriculum reform; innovation skills; Technical and Vocational Education and Training (TVET)

## 1 Introduction

The architecture, engineering and construction (AEC) sector is undergoing a sustained digital transformation in which Building Information Modelling (BIM) has become the organising technology for design coordination, quantity extraction, scheduling and facility lifecycle management (Eastman et al., 2018; Succar, 2009). As model-based workflows displace document-centred practice, the competencies expected of construction managers have shifted from procedural supervision towards data-driven planning, interdisciplinary coordination and the capacity to generate and test novel responses to project constraints. Global policy frameworks locate this shift within the remit of Technical and Vocational Education and Training (TVET): the UNESCO (2022) strategy for 2022–2029 identifies digital transformation and innovation capacity as central to the responsiveness of TVET systems to changing labour markets.

In Nigeria, Colleges of Education (Technical) occupy a strategic position in this agenda because they prepare Nigeria Certificate in Education (NCE) Technical teachers who subsequently instruct in technical colleges and related vocational settings. Students in Building Technology and Woodwork

Technology options therefore function as multipliers: the construction technologies they master, or fail to encounter, are transmitted to successive cohorts of learners. Preparing them for BIM-mediated construction management is consequently a matter of systemic rather than merely individual readiness.

However, empirical work has documented persistent barriers to BIM adoption in the Nigerian construction industry, including weak enforcement by private clients, limited professional body support and the absence of enabling policy (Oladiran and Ameh, 2022). Parallel studies on education attribute slow curricular uptake to inadequate infrastructure, scarce BIM-competent instructors and the absence of accreditation guidance (Babatunde and Ekundayo, 2019; Babatunde et al., 2018), and, more recently, to layered regulatory, institutional and student-level constraints in polytechnic built-environment programmes (Ebekozien et al., 2024). Internationally, a systematic review of BIM curriculum research called for more diverse research designs and settings (Abdirad and Dossick, 2016), while recent evidence identifies limited faculty training, inconsistent curricula and insufficient hands-on collaboration as continuing deficits (Papuraj et al., 2025). Learner-centred strategies such as problem-based learning have been shown to support BIM competence development (Obi et al., 2024).

Consequently, three limitations of this evidence base define the niche. First, Nigerian BIM-education studies are predominantly perception or barrier surveys rather than controlled instructional trials. Second, the populations examined are architecture, quantity surveying and polytechnic cohorts; NCE Technical Education students, who are teachers-in-training, are largely absent. Third, outcome variables are typically BIM awareness or software proficiency, whereas construction management competence and innovation skills, the higher-order outcomes BIM is expected to enable, remain under-measured. To the authors' knowledge, no controlled study has yet examined these outcomes jointly within Nigerian technical teacher education. Its novel contribution is controlled, context-specific evidence from technical teacher education in South-East Nigeria and an empirically tested instructional model for curriculum reform. This study therefore, fills this gap.

### 1.1 Statement of the problem

Technical teacher education should equip prospective teachers of Building and Woodwork Technology to plan, cost, coordinate and document construction work through model-based workflows, and to apply the innovation skills needed to adapt those workflows to local constraints (Eastman et al., 2018; UNESCO, 2022). The BIM pedagogy literature positions integrated, hands-on instruction as the means of producing such graduates (Abdirad and Dossick, 2016; Obi et al., 2024).

BIM-integrated instruction remains marginal in Nigerian technical and built-environment education. Studies report inadequate infrastructure, scarce BIM-competent instructors and absent accreditation guidance (Babatunde and Ekundayo, 2019). Baseline data from the present sample corroborate this: 60.8% of the 120 NCE students had never heard of BIM, and none attained a mean item rating of 2.50 on the 25-item competence and innovation scale before instruction. The gap matters because these students are multipliers; graduating unprepared, they will reproduce outdated practice in technical colleges and widen the distance between Nigerian TVET outputs and global construction standards.

Existing studies predominantly describe barriers and perceptions in architecture, quantity surveying and polytechnic populations. None has tested, under controlled conditions, whether BIM-integrated instruction improves construction management competence and innovation skills among NCE Technical Education students in South-East Nigeria.

### 1.2 Purpose of the study

The main purpose of this study was to investigate the effect of BIM-integrated instruction on construction management competence and innovation skills among NCE Technical Education students in South-East Nigeria. Specifically, the study sought to:

1. Determine the effect of BIM-integrated instruction on the combined construction management competence and innovation skills of NCE Technical Education students;
2. Establish the effect of BIM-integrated instruction on construction management competence of NCE Technical Education students and
3. Establish effect of BIM-integrated instruction on innovation skills, relative to conventional lecture-based instruction of NCE Technical Education students.

### 1.3 Research questions

Three research questions guided the study.

1. What is the effect of BIM-integrated instruction, relative to conventional instruction, on the combined construction management competence and innovation skills of NCE Technical Education students?
2. What is the effect of BIM-integrated instruction on construction management competence of NCE Technical Education students?
3. What is the effect of BIM-integrated instruction on innovation skills of NCE Technical Education students?

### 1.4 Hypotheses

The following null hypotheses, tested at 0.05 level of significance were formulated to further guide the study.

- **$H_{01}$:** There is no significant difference in the combined post-test scores of students taught with BIM-integrated instruction and those taught with conventional methods.
- **$H_{02}$:** The construction management competence scores of students in experimental and control groups did not differ significantly.
- **$H_{03}$:** The innovation skills scores of students in experimental and control groups did not differ significantly.

### 1.5 Significance of the study

The study matters to several constituencies. Students gain access to industry-aligned digital competencies; lecturers receive a tested instructional model; college managers, the National Board for Technical Education (NBTE) and the National Commission for Colleges of Education (NCCE) obtain evidence for revising minimum standards; funding bodies can justify investment in BIM laboratories and software licences; and researchers gain controlled evidence from an under-studied population.

## 2 Literature review

The study draws on Experiential Learning Theory (Kolb, 1984), which holds that knowledge is created through cycles of concrete experience, reflection, abstract conceptualisation and active

experimentation. BIM-integrated instruction operationalises this cycle: learners build, interrogate and revise a virtual building, observe the consequences of decisions on cost, sequence and clashes, and iterate. The Technological Pedagogical Content Knowledge (TPACK) framework (Mishra and Koehler, 2006) complements this view by emphasising that technology yields learning gains only when integrated with pedagogy and disciplinary content, a principle of particular relevance for teachers-in-training who must later teach with the technologies they learn.

### 2.1 BIM, construction management competence and innovation

BIM extends beyond three-dimensional modelling to a coordinated process of information creation and exchange across the project lifecycle (Succar, 2009; Eastman et al., 2018). For construction management, this implies competencies in model-based quantity take-off, cost planning, sequencing, clash detection and collaborative documentation. In higher education, reviews show that BIM curriculum design is shaped by trade-offs among enrolment, mandatory versus optional use, tutoring methods, industry engagement and assessment (Abdirad and Dossick, 2016), and that deficits in faculty training, curricular consistency and applied collaboration continue to limit graduate readiness in construction project management (Papuraj et al., 2025). Evidence on instructional effectiveness is encouraging but thin: problem-based learning in an undergraduate BIM module was associated with cognitive and affective knowledge acquisition and with transferable analytical, communication and collaboration skills among 53 students (Obi et al., 2024). Innovation skills, conceptualised as the capacity to associate ideas, question assumptions, observe, experiment and network (Dyer et al., 2011), are theoretically linked to BIM because parametric modelling lowers the cost of experimentation, yet this link has seldom been tested experimentally.

### 2.2 BIM education in Nigeria

Nigerian studies converge on a picture of awareness without integration. Babatunde et al. (2018) reported that academics and quantity surveying students regarded BIM benefits as important, while Babatunde and Ekundayo (2019) identified the barriers that impede its incorporation into the curriculum. Industry-side research reached a parallel conclusion, finding that adoption challenges centre on weak enforcement, limited professional support and policy vacuums (Oladiran and Ameh, 2022). Closest to the present population, Ebekozien et al. (2024) examined BIM implementation via Revit for polytechnic built-environment undergraduates, a middle-level workforce cohort, and found that the issues were clustered under government, institutional and student domains. These studies are informative but observational: none estimates the effect of a defined BIM instructional treatment on measured competence outcomes.

### 2.3 Synthesis and research gap

The literature establishes that BIM competence is a global curricular priority, that Nigerian institutions face substantial implementation barriers, and that learner-centred BIM pedagogies can build transferable skills. It does not establish whether BIM-integrated instruction improves construction management competence and innovation skills among NCE Technical Education students, a population whose graduates transmit skills to technical colleges. By testing this effect quasi-experimentally in South-East Nigeria, the present study fills that gap.

## 3 Method

A quasi-experimental design with pretest-posttest non-equivalent control group was adopted (Shadish et al., 2002) because random assignment of individuals was infeasible within intact, timetabled classes. Instructional approach: (BIM-integrated vs. conventional) was the independent variable, post-test scores the dependent variables, and pre-test scores the covariate. The study was conducted in the 2025/2026 academic session.

Three Colleges of Education (Technical) in South-East Nigeria were purposively selected because each had a Technical Drawing/AutoCAD drawing studio, with CAD facilities. All 120 eligible NCE II ($n$ = 73) and NCE III ($n$ = 47) students in Building Technology ($n$ = 78) and Woodwork Technology ($n$ = 42) were included. Within each institution, intact classes were allocated to the experimental ($n$ = 60) or control ($n$ = 60) condition, so both conditions were represented in every institution. A sample of 120 affords approximately 0.80 power to detect a medium effect ($f$ = 0.25) after covariate adjustment. Ethical clearance was obtained from the institutions' research ethics committees, and all participants gave informed consent.

The experimental group received 12 weeks of BIM-integrated instruction using Autodesk Revit 2026 in a computer laboratory. Content followed a progressive sequence: orientation to BIM concepts and the modelling environment; parametric modelling of a small building from supplied drawings; extraction of schedules and quantities for cost estimation; construction sequencing and clash detection; and a culminating team-based problem task requiring learners to propose and justify a design or process improvement. Instruction was experiential and problem-based (Kolb, 1984; Obi et al., 2024). The control group covered the same construction management syllabus through lectures, board illustration and manual or two-dimensional drafting, with identical contact hours. Researchers and trained research assistants delivered instruction in both groups, and treatment fidelity was monitored through lesson-observation checklists and attendance logs.

Data were collected with the Construction Management Competence and Innovation Skills Scale (CMCISS), a researcher-developed 25-item, four-point instrument scored as a composite (25-100). It comprises construction management competence (15 items: quantity extraction and costing, sequencing and scheduling, clash detection, documentation, resource planning, and site coordination and quality monitoring; range 15-60) and innovation skills (10 items: associating, questioning, observing, experimenting and networking, two items each; Dyer et al., 2011; range 10-40). Three experts in Building Technology, Technical Education, and Measurement and Evaluation established face and content validity. A pilot test with 33 students outside the study sample yielded Cronbach's α of .95 (pre-test) and .97 (post-test) for the full scale, and .87 and .95 for the two subscales. In the study sample, composite α was .94 at pre-test and .98 at post-test; subscale values ranged from .84 to .97. The pre-test form also recorded institution, programme, NCE level, gender, prior BIM experience and laptop access; the post-test form recorded lessons attended. The same instrument served as pre-test and post-test.

The pre-test was administered in the week before the intervention and the post-test in the week after its completion, under standardised conditions. Data were analysed in Python. Group characteristics were compared with Pearson chi-square tests. Descriptive statistics answered the research questions, and one-way ANCOVA with pre-test score as covariate tested the hypotheses at α = 0.05 level of significance. Pre-test equivalence (independent-samples $t$ test), normality (Shapiro-Wilk), homogeneity of variance (Levene), linearity and homogeneity of regression slopes were examined first (Tabachnick and Fidell, 2019), and within-group change was tested with paired-samples $t$ tests. Be-

cause normality and equal-variance assumptions were not fully met, Welch *t* tests, Mann-Whitney *U* tests and ANCOVA models with additional covariates (laptop access, lesson attendance, and institution) served as sensitivity analyses. Effect sizes were reported as partial eta squared ($\eta^2_p$) and Cohen's *d* (Cohen, 1988) with 95% confidence intervals.

## 4 Results

This section presents the findings in the following order: participant characteristics and instrument reliability; pre-test equivalence of the groups and the ANCOVA assumption checks; the results for each of the three research questions and their corresponding hypotheses; within-group change from pre-test to post-test; and sensitivity analyses. Responses were obtained from all 120 participants (experimental $n = 60$; control $n = 60$) at both administrations, and there were no missing values.

### 4.1 Participant characteristics, reliability and preliminary analysis

**Table 1.** Characteristics of participants by instructional group (N = 120).

| Characteristic | Experimental *n* (%) | Conventional *n* (%) | Comparison |
|---|---|---|---|
| *Institution* | | | |
| College I | 28 (46.7) | 30 (50.0) | $p > .05$ |
| College II | 26 (43.3) | 20 (33.3) | |
| College III | 6 (10.0) | 10 (16.7) | |
| *Programme* | | | |
| Building Technology | 38 (63.3) | 40 (66.7) | $p > .05$ |
| Woodwork Technology | 22 (36.7) | 20 (33.3) | |
| *NCE level* | | | |
| NCE II | 35 (58.3) | 38 (63.3) | $p > .05$ |
| NCE III | 25 (41.7) | 22 (36.7) | |
| *Gender* | | | |
| Male | 36 (60.0) | 36 (60.0) | $p > .05$ |
| Female | 24 (40.0) | 24 (40.0) | |
| *Prior BIM experience* | | | |
| Never heard of it | 33 (55.0) | 40 (66.7) | $p > .05$ |
| Heard of it, never used it | 19 (31.7) | 14 (23.3) | |
| Used it a little | 8 (13.3) | 6 (10.0) | |
| Personal laptop/computer access | | | |
| Yes | 47 (78.3) | 31 (51.7) | $\chi^2(1) = 9.38$, $p = .002$ |
| No | 13 (21.7) | 29 (48.3) | |
| Lessons attended (of six weeks) | | | |
| All six weeks | 38 (63.3) | 43 (71.7) | $p > .05$ |
| Most of the weeks | 22 (36.7) | 17 (28.3) | |

*Note.* Group comparisons are Pearson chi-square tests. Institutions are anonymised as Colleges I-III. Three participants who ticked both "Heard of it, never used it" and "Used it a little" were classified as "Used it a little."

Table 1 shows that participants were drawn from three institutions, two programmes and two NCE levels, with both instructional groups represented in every institution. The groups did not differ significantly in institution, programme, NCE level, gender, prior BIM experience or number of lessons attended (all $p > 0.05$). They differed in access to a personal laptop or computer, $\chi^2$ (1) = 9.38, $p$ = 0.002: 47 of 60 experimental participants (78.3%) and 31 of 60 control participants (51.7%) reported access.

**Table 2.** Pre-test equivalence of groups and ANCOVA assumption checks.

| Check | Composite | Construction management competence | Innovation skills |
|---|---|---|---|
| Pre-test equivalence, $t(118)$ | 1.47, $p = .143$ | 1.78, $p = .078$ | 1.12, $p = .266$ |
| Pre-test difference, Cohen's $d$ | 0.27 | 0.32 | 0.20 |
| Shapiro–Wilk, experimental pre-test | $W = .91$, $p < .001$ | $W = .94$, $p = .003$ | $W = .89$, $p < .001$ |
| Shapiro–Wilk, control pre-test | $W = .81$, $p < .001$ | $W = .86$, $p < .001$ | $W = .82$, $p < .001$ |
| Shapiro–Wilk, experimental post-test | $W = .78$, $p < .001$ | $W = .80$, $p < .001$ | $W = .86$, $p < .001$ |
| Shapiro–Wilk, control post-test | $W = .75$, $p < .001$ | $W = .83$, $p < .001$ | $W = .87$, $p < .001$ |
| Shapiro–Wilk, ANCOVA residuals | $W = .95$, $p < .001$ | $W = .96$, $p = .001$ | $W = .95$, $p < .001$ |
| Levene, pre-test, $df = 1, 118$ | $F = 1.61$, $p = .207$ | $F = 2.13$, $p = .147$ | $F = 0.63$, $p = .431$ |
| Levene, post-test, $df = 1, 118$ | $F = 0.54$, $p = .465$ | $F = 0.41$, $p = .525$ | $F = 11.06$, $p = .001$ |
| Levene, ANCOVA residuals, $df = 1, 118$ | $F = 0.42$, $p = .521$ | $F = 0.42$, $p = .519$ | $F = 8.98$, $p = .003$ |
| Homogeneity of regression slopes, $F(1, 116)$ | 1.15, $p = .286$ | 0.21, $p = .645$ | 1.98, $p = .162$ |
| Pre-test–post-test correlation, $r$ ($N = 120$) | .13, $p = .157$ | .13, $p = .151$ | .13, $p = .158$ |

*Note.* Pre-test equivalence was tested with independent-samples $t$ tests (equal variances assumed; experimental $n = 60$, control $n = 60$). Shapiro-Wilk $n = 60$ per group (residuals $n = 120$).

Table 2 presents the pre-test equivalence tests and the ANCOVA assumption checks. Pre-test scores did not differ significantly between the groups on the composite scale (experimental $M = 38.02$, $SD = 8.99$; control $M = 35.67$, $SD = 8.46$), $t$ (118) = 1.47, $p = .143$, $d = 0.27$, or on either subscale (construction management competence: $p = 0.078$; innovation skills: $p = 0.266$). Shapiro-Wilk tests indicated departures from normality in pre-test and post-test scores within both groups and in the ANCOVA residuals (all $p < .01$). Variances were homogeneous across groups for the composite scale and the construction management competence subscale, but not for the innovation-skills post-test scores, $F$ (1, 118) = 11.06, $p = 0.001$. The assumption of homogeneous regression slopes was met for all three

outcomes (all $p > .05$), and the pre-test-post-test correlation was weak (composite $r = 0.13$, $p = 0.157$). Because of the departures from normality and, for innovation skills, unequal variances, the ANCOVA results were supplemented with Welch $t$ tests and Mann-Whitney $U$ tests (Table 6).

### 4.2 Research question 1 and hypothesis 1: composite construction management competence and innovation skills

**Table 3.** Pre-test, post-test, gain and adjusted post-test scores of the experimental and control groups.

| Group | *n* | Pre-test *M* (*SD*) | Post-test *M* (*SD*) | Gain *M* (*SD*) | Adjusted post-test *M* (*SE*) | Post-test mean item rating |
|---|---|---|---|---|---|---|
| Composite score (25 items; range 25-100) | | | | | | |
| BIM-integrated (experimental) | 60 | 38.02 (8.99) | 84.83 (12.06) | 46.82 (14.14) | 84.78 (1.42) | 3.39 |
| Conventional (control) | 60 | 35.67 (8.46) | 55.57 (9.67) | 19.90 (13.32) | 55.62 (1.42) | 2.22 |
| Construction management competence (15 items; range 15-60) | | | | | | |
| BIM-integrated (experimental) | 60 | 22.32 (4.38) | 50.50 (6.89) | 28.18 (7.99) | 50.49 (0.90) | 3.37 |
| Conventional (control) | 60 | 20.97 (3.93) | 32.48 (6.91) | 11.52 (8.09) | 32.49 (0.90) | 2.17 |
| Innovation skills (10 items; range 10-40) | | | | | | |
| BIM-integrated (experimental) | 60 | 15.70 (4.96) | 34.33 (5.50) | 18.63 (6.74) | 34.30 (0.59) | 3.43 |
| Conventional (control) | 60 | 14.70 (4.84) | 23.08 (3.42) | 8.38 (6.12) | 23.12 (0.59) | 2.31 |

*Note.* Adjusted means are estimated marginal means at the grand-mean pre-test score (composite = 36.84; construction management competence = 21.64; innovation skills = 15.20). Mean item rating = post-test mean score divided by number of items (response scale 1-4).

Table 3 and Figure 1 present the descriptive statistics. At post-test, the experimental group obtained a mean composite score of 84.83 ($SD = 12.06$) and the control group 55.57 ($SD = 9.67$), a difference of 29.27 points (95% CI [25.31, 33.22]). The experimental mean was 52.7% higher than the control mean. Expressed as mean item ratings on the four-point scale, the post-test values were 3.39 and 2.22, respectively. A mean item rating of 2.50 or above was recorded for 90.0% of experimental participants and 25.0% of control participants at post-test, compared with 0.0% and 0.0% at pre-test.

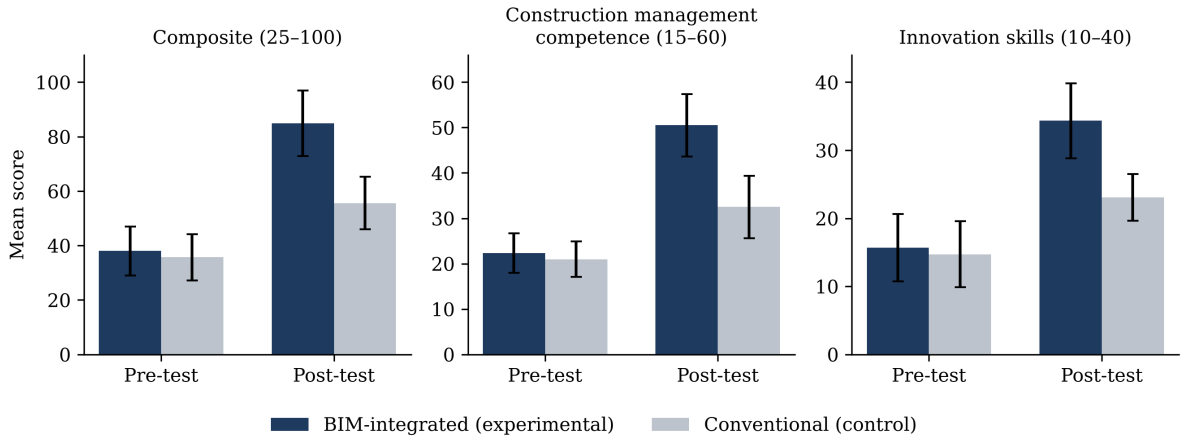



**Figure 1.** Mean pre-test and post-test scores of the experimental and control groups. Bars show group means; error bars show ±1 SD. Panels show the composite score and the two subscales (n = 60 per group).

**Table 4.** ANCOVA of post-test scores by instructional approach, controlling for pre-test scores.

| Source | *SS* | *df* | *MS* | *F* | *p* | $\eta^2_p$ |
|---|---|---|---|---|---|---|
| ***A. Composite score*** | | | | | | |
| Pre-test (covariate) | 19.47 | 1 | 19.47 | 0.16 | .688 | .001 |
| Instructional approach | 25043.33 | 1 | 25043.33 | 208.05 | < .001 | .64 |
| Error | 14083.60 | 117 | 120.37 | | | |
| B. Construction management competence | | | | | | |
| Pre-test (covariate) | 0.17 | 1 | 0.17 | 0.00 | .953 | .000 |
| Instructional approach | 9471.34 | 1 | 9471.34 | 197.19 | < .001 | .63 |
| Error | 5619.82 | 117 | 48.03 | | | |
| ***C. Innovation skills*** | | | | | | |
| Pre-test (covariate) | 15.93 | 1 | 15.93 | 0.76 | .386 | .006 |
| Instructional approach | 3707.22 | 1 | 3707.22 | 176.32 | < .001 | .60 |
| Error | 2459.99 | 117 | 21.03 | | | |

*Note.* $\eta^2_p$ = partial eta squared = *SS*effect / (*SS*effect + *SS*error). Model $R^2$ = .65 (composite), .63 (construction management competence), .61 (innovation skills).

The ANCOVA results are shown in Table 4. After adjustment for pre-test scores, instructional approach had a statistically significant effect on composite post-test scores, $F(1, 117) = 208.05$, $p < 0.001$, $\eta^2_p = 0.64$. The adjusted post-test means were 84.78 ($SE$ = 1.42) for the experimental group and 55.62 ($SE$ = 1.42) for the control group, an adjusted difference of 29.16 points ($SE$ = 2.02). The unadjusted standardised mean difference was $d$ = 2.68 (95% CI [2.18, 3.17]). The pre-test covariate was not a significant predictor of post-test scores, $F(1, 117) = 0.16$, $p$ = .688. Hypothesis 1 was therefore rejected.

### 4.3 Research question 2 and hypothesis 2: construction management competence

On the construction management competence subscale, the experimental group scored higher at post-test ($M$ = 50.50, $SD$ = 6.89) than the control group ($M$ = 32.48, $SD$ = 6.91), a difference of 18.02

points (95% CI [15.52, 20.51]) and a mean 55.5% higher in the experimental group. Pre-test means were 22.32 ($SD$ = 4.38) and 20.97 ($SD$ = 3.93), respectively. Controlling for pre-test scores, the effect of instructional approach was significant, $F(1, 117) = 197.19$, $p < 0.001$, $\eta^2_p = 0.63$; the adjusted means were 50.49 and 32.49 (Table 4, Panel B), and $d = 2.61$. Hypothesis 2 was therefore rejected.

### 4.4 Research question 3 and hypothesis 3: innovation skills

On the innovation-skills subscale, the experimental group scored higher at post-test ($M$ = 34.33, $SD$ = 5.50) than the control group ($M$ = 23.08, $SD$ = 3.42), a difference of 11.25 points (95% CI [9.59, 12.91], Welch-based) and a mean 48.7% higher in the experimental group. Pre-test means were 15.70 ($SD$ = 4.96) and 14.70 ($SD$ = 4.84), respectively. Controlling for pre-test scores, the effect of instructional approach was significant, $F(1, 117) = 176.32$, $p < 0.001$, $\eta^2_p = 0.60$; the adjusted means were 34.30 and 23.12 (Table 4, Panel C), and $d = 2.46$. Hypothesis 3 was therefore rejected.

### 4.5 Within-group change from pre-test to post-test

**Table 5.** Within-group change from pre-test to post-test and between-group comparison of gain scores.

| Group | Gain *M* (*SD*) | *df* | *t* | *p* | *dz* |
|---|---|---|---|---|---|
| ***Composite score*** | | | | | |
| BIM-integrated (experimental) | 46.82 (14.14) | 59 | 25.65 | < .001 | 3.31 |
| Conventional (control) | 19.90 (13.32) | 59 | 11.57 | < .001 | 1.49 |
| Difference in gain (experimental – control) | 26.92 | 118 | 10.73 | < .001 | |
| Construction management competence | | | | | |
| BIM-integrated (experimental) | 28.18 (7.99) | 59 | 27.32 | < .001 | 3.53 |
| Conventional (control) | 11.52 (8.09) | 59 | 11.03 | < .001 | 1.42 |
| Difference in gain (experimental – control) | 16.67 | 118 | 11.36 | < .001 | |
| ***Innovation skills*** | | | | | |
| BIM-integrated (experimental) | 18.63 (6.74) | 59 | 21.42 | < .001 | 2.77 |
| Conventional (control) | 8.38 (6.12) | 59 | 10.61 | < .001 | 1.37 |
| Difference in gain (experimental – control) | 10.25 | 118 | 8.72 | < .001 | |

*Note.* Within-group tests are paired-samples $t$ tests ($dz$ = mean gain / $SD$ of gain). The between-group comparison is an independent-samples $t$ test on gain scores (equal variances assumed).

Table 5 shows that both groups obtained significantly higher scores at post-test than at pre-test on the composite scale and on both subscales (all $p < 0.001$). The mean composite gain was 46.82 points ($SD$ = 14.14; $dz$ = 3.31) in the experimental group and 19.90 points ($SD$ = 13.32; $dz$ = 1.49) in the control group. The gain was larger in the experimental group by 26.92 points, $t(118) = 10.73$, $p < 0.001$. Larger gains in the experimental group were also found for construction management competence (28.18 versus 11.52 points) and innovation skills (18.63 versus 8.38 points).

### 4.6 Sensitivity and supplementary analyses

**Table 6.** Sensitivity analyses of the post-test group difference.

| Analysis | Composite | Construction management competence | Innovation skills |
|---|---|---|---|
| Welch *t* test, post-test | $t(112.7) = 14.66$, $p < .001$ | $t(118.0) = 14.30$, $p < .001$ | $t(98.7) = 13.45$, $p < .001$ |
| Mean difference [95% CI] | 29.27 [25.31, 33.22] | 18.02 [15.52, 20.51] | 11.25 [9.59, 12.91] |
| Cohen's *d* [95% CI] | 2.68 [2.18, 3.17] | 2.61 [2.12, 3.10] | 2.46 [1.98, 2.93] |
| Mann–Whitney *U*, post-test | $U = 3413.0$, $p < .001$, *r*rb = .90 | $U = 3412.5$, $p < .001$, *r*rb = .90 | $U = 3364.0$, $p < .001$, *r*rb = .87 |
| Mann–Whitney *U*, gain scores | $U = 3290.0$, $p < .001$ | $U = 3326.5$, $p < .001$ | $U = 3129.5$, $p < .001$ |
| ANCOVA adding laptop access | $F(1, 116) = 188.27$, $p < .001$, $\eta^2_p = .62$ | $F(1, 116) = 181.44$, $p < .001$, $\eta^2_p = .61$ | $F(1, 116) = 156.13$, $p < .001$, $\eta^2_p = .57$ |
| ANCOVA adding institution | $F(1, 115) = 203.22$, $p < .001$, $\eta^2_p = .64$ | $F(1, 115) = 195.80$, $p < .001$, $\eta^2_p = .63$ | $F(1, 115) = 170.15$, $p < .001$, $\eta^2_p = .60$ |
| ANCOVA adding laptop access, attendance and institution | $F(1, 113) = 183.73$, $p < .001$, $\eta^2_p = .62$ | $F(1, 113) = 179.21$, $p < .001$, $\eta^2_p = .61$ | $F(1, 113) = 151.52$, $p < .001$, $\eta^2_p = .57$ |

*Note.* Positive values favour the experimental group. *r*rb = rank-biserial correlation. All ANCOVA models include the pre-test score and instructional approach plus the additional covariates named; group effects are the adjusted effect of instructional approach. Welch *df* are fractional because equal variances are not assumed.

The results of the sensitivity analyses are summarised in Table 6. The group difference at post-test was significant in the Welch *t* tests and in the Mann-Whitney *U* tests for the composite scale and both subscales (all $p < 0.001$), with rank-biserial correlations of 0.90 (composite), 0.90 (construction management competence) and 0.87 (innovation skills). Group differences in gain scores were also significant in Mann–Whitney tests (all $p < 0.001$). The effect of instructional approach remained significant (all $p < 0.001$) when laptop access, institution, or laptop access, lesson attendance and institution together were added to the ANCOVA models, with partial eta squared values for the composite scale ranging from 0.62 to 0.64. At the item level, post-test means were higher in the experimental group on all 25 items (Bonferroni-adjusted $p < 0.001$ for each item), with Cohen's *d* values ranging from 1.17 to 2.32.

## 5 Discussion

The principal finding is that BIM-integrated instruction produced substantially higher combined construction management competence and innovation-skills scores than conventional instruction (adjusted means 84.78 versus 55.62), a difference that survived covariate adjustment and was upheld in non-parametric and covariate-extended sensitivity analyses. The advantage was evident for both construction management competence ($\eta^2_p = 0.63$) and innovation skills ($\eta^2_p = 0\ .60$). This result is consistent with the learner-centred BIM pedagogy literature, in which problem-based and project-oriented approaches foster transferable analytical, collaborative and disciplinary skills (Obi et al., 2024), and it extends that evidence from built-environment undergraduates in a UK context to NCE teachers-in-training in South-East Nigeria. It also speaks to the concern, voiced in systematic reviews, that BIM curriculum research relies too heavily on descriptive designs (Abdirad and Dossick, 2016), by supplying a controlled comparison. Where Nigerian studies have documented what prevents BIM

from entering curricula (Babatunde and Ekundayo, 2019; Ebekozien et al., 2024), the present findings indicate what is forgone: when a structured BIM treatment is delivered, even over six weeks, measurable gains are attainable in a resource-constrained setting.

The mechanism is plausibly experiential. Modelling a building, extracting quantities and detecting clashes compress the cycle of experience, reflection and experimentation described by Kolb (1984), and parametric tools reduce the cost of testing alternatives, which is the behavioural core of innovation (Dyer et al., 2011). The magnitude of the effect ($\eta^2_p = 0.64$; $d = 2.68$) is, however, considerably larger than typical in educational interventions and should be interpreted with caution. Plausible contributors include the novelty of the treatment, alignment between instructional content and the outcome measure, the use of a researcher-developed instrument, and unmeasured instructor effects inherent in non-equivalent designs. Two features of the data also qualify interpretation. First, the control group improved significantly from pre-test to post-test (mean composite gain = 19.90 points), so part of the observed change in both groups may reflect repeated administration of the same instrument, maturation or the effects of regular instruction; the experimental group's additional gain of 26.92 points is the quantity attributable to the treatment under the design. Second, pre-test scores were only weakly related to post-test scores ($r = 0.13$), so covariate adjustment changed the estimates very little (raw difference 29.27 versus adjusted difference 29.16).

### 5.1 Theoretical and practical implications

Theoretically, the findings support the applicability of experiential learning and TPACK-informed integration to BIM instruction in TVET teacher education, and suggest that digital modelling environments can function as vehicles for higher-order outcomes such as innovation, not merely software proficiency. Practically, they provide a 12-week, replicable module that colleges can embed within existing building and construction management courses without wholesale curriculum restructuring, and an evidence base for regulators and funders to prioritise BIM laboratories, licences and instructor training.

### 5.2 Limitations and future research

Several limitations qualify the conclusions. Non-random assignment leaves residual selection and instructor confounds, and the groups differed in access to a personal laptop or computer, although adjusting for this did not alter the results. The CMCISS is a self-report scale in which respondents rate their own ability ("I can …"), so the scores indicate self-perceived competence and innovation behaviour rather than observed performance. The score distributions departed from normality, and the intervention was brief with no delayed post-test to assess retention. The sample was confined to three institutions in one geopolitical zone. Future studies should employ cluster-randomised designs, longer interventions with delayed follow-up, performance-based and portfolio assessment of actual BIM deliverables, multi-zone samples, and mediation analyses testing whether collaboration, self-efficacy or technology acceptance explains the observed gains. Replication with other TVET options and with pre-service teachers' subsequent classroom practice would extend generalisability.

## 6 Conclusion

BIM-integrated instruction significantly improved the self-rated construction management competence and innovation skills of NCE Technical Education students relative to conventional lecture-based instruction, with a very large adjusted effect. The study thus supplies controlled, context-specific

evidence that BIM integration is a promising pathway for aligning Nigerian technical teacher education with global construction technology standards, pending replication with performance-based measures.

## 7 Recommendations

Based on the findings, the following recommendations were made:

1. The NCCE should incorporate BIM-integrated instruction into the minimum standards for NCE Technical programmes in Building and Woodwork Technology;
2. Curriculum developers should adopt project and problem-based BIM tasks that explicitly target innovation skills; and colleges should establish industry-institution partnerships to supply authentic project data and internships; and
3. The instructional model validated here should be piloted across other Colleges of Education (Technical) and monitored with performance-based assessment.

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