

Project-Based Learning in Virtual Environments and Cognitive Development in Architecture

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HOW TO CITE:

Ruth Dahiana Santacruz Martínez
(2026).
Project-Based Learning in Virtual
Environments and Cognitive
Development in Architecture.
International Journal of Special
Education, 41(24s), 12 - 22

ABSTRACT:

This article analyzes the impact of Project-Based Learning (PBL) in virtual environments on the development of higher cognitive processes in Architecture students at Columbia University of Paraguay during the 2025 academic year. Despite the integration of digital platforms in design and technical courses, deficiencies in techno-pedagogical mediation persist. The research adopted a concurrent mixed-methods design with a descriptive-correlational approach under a pragmatic paradigm. The population consisted of 165 students and 12 teachers. Through stratified probability sampling, a quantitative sample of 116 students was selected, while a census was applied to the teaching stratum. Data collection integrated a validated digital survey (α de Cronbach = 0.944) statistically processed with SPSS, semi-structured interviews qualitatively analyzed through coding in ATLAS.ti, and the deductive documentary analysis of operationalization matrices and teaching guides. The results demonstrated an incipient level of cognitive development (means of 1.87 to 2.51), revealing that over 50% of students perceive critical shortcomings in digital scaffolding. Triangulation highlighted a significant gap: excellent theoretical planning (4.7/5) versus deficient virtual execution (2.1/5). The implementation of the Cognitive Process Assessment Model in Virtual PBL (MEPC-ABP-V) is proposed, concluding that optimizing virtual environments requires transcending their use as mere repositories into authentic spaces for architectural ideation.

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Keywords: Project-based learning; virtual environments; cognitive processes; architecture; higher education.

1. Introduction

Higher education in architecture is undergoing a paradigmatic shift, propelled by the accelerated integration of Information and Communication Technologies (ICT) into traditional pedagogical

models. Historically, architectural training has been deeply rooted in the design studio model a physical locus of continuous interaction where learning unfolds through tactile experimentation, collaborative assessment (desk critiques), and the direct manipulation of matter and space. Within

this ecosystem, Project-Based Learning (PBL) is consolidated as the quintessential active methodology, requiring students to mobilize higher-order cognitive processes such as critical analysis, spatial synthesis, the evaluation of contextual variables, and creation to resolve complex design problems. However, the systematic migration of these processes toward Virtual Learning Environments (VLE) has drastically reconfigured teaching and learning dynamics, posing unprecedented challenges in the structuring of techno-pedagogical scaffolding and the management of students' cognitive load.

The virtualization of architectural education does not merely entail the digitization of content or the substitution of screens for paper; rather, it involves a profound alteration in how students perceive, process, and communicate three-dimensionality. The development of cognitive processes in architecture necessitates an intrinsic connection between abstract conceptualization and material feasibility. In face-to-face settings, this connection is facilitated by haptic experience: the construction of physical models, freehand drawing, and sensory exploration. By transferring PBL into a purely digital environment, extraneous cognitive load that which is generated by the interface, software tools, and the barriers of asynchronous communication increases substantially. If instructional mediation strategies are not adequately designed to mitigate this overload, students' mental resources are diverted from architectural ideation toward mere operational problem-solving, severely limiting their capacity to achieve deep levels of critical reflection.

This phenomenon manifests evidently and critically in core courses that demand a high degree of abstraction and spatial comprehension, such as Architectural Design Studio III (Taller de Arquitectura III). At this level, students must confront multidimensional design variables, including urban integration, bioclimatic response, and topography. Site analysis, for instance, demands a precise geomorphological understanding; when studying a site's characteristics and soil typologies such as clay, sandy, silty, or rocky strata the student must

deduce the structural behavior and appropriate foundational strategies. In virtuality, the inability to physically experience the site (*genius loci*) compels the instructor to orchestrate highly complex digital scaffolding, utilizing geographic information systems (GIS), 3D simulations, and digital cartography. If feedback within these virtual environments lacks immediacy and specificity, the student risks designing decontextualized architectural objects, evidencing a cognitive disconnect between the digital model and the physical reality of the site.

Similarly, the challenge of virtualization profoundly impacts technical core subjects, such as Construction Procedures and Materials Technology B (Tecnología de Procedimientos Constructivos y Materiales B). Mastery of tectonics and comprehension of the physicochemical behavior of materials are inescapable pillars for any viable architectural resolution. In the contemporary approach to construction systems, which prioritizes the study of high-precision and industrialized components, the student must internalize the mechanical properties, resistance, and assembly methods of synthetic and industrial materials, such as reinforced concrete, steel structures, high-density polymers, tensile membranes, structural glass, and various contemporary composites. Learning to detail the juncture between a steel profile and a synthetic enclosure requires a constructive understanding that, in the physical classroom, is supported by site visits, laboratory samples, or the assembly of full-scale prototypes. When virtualizing this learning, the transition from heavy, physical materiality to a weightless, digital representation (such as an AutoCAD block or a Revit component) can engender superficial knowledge. The student may succeed in visually representing the construction detail via software, yet fail to cognitively assimilate the structural logic, assembly tolerances, or thermodynamic behavior of these industrialized materials, constituting a failure in the consolidation of meaningful learning.

In the specific context of higher education in Paraguay, and particularly within the Architecture program at Universidad Columbia, this scenario

has exposed structural vulnerabilities in the academic trajectory. Recent metrics and academic cycle evaluations evidence that, despite notable institutional efforts to design rigorous operational matrices and exhaustive didactic guides, a significant gap persists in the execution of virtual mediation. Virtual Learning Environments run the risk of underutilization, operating in many instances as static information repositories (PDFs, regulations, assignments) rather than constituting true ecosystems for ideation, debate, and iterative feedback. This dissonance between ideal theoretical planning and virtualized praxis directly impacts student motivation and their perception of self-efficacy factors strongly correlated with the development of design competencies.

The lack of evaluation models specifically designed to measure and accompany the evolution of critical thinking within virtualized PBL exacerbates the situation. Traditional evaluation, focused on grading the final product (the blueprint, the render, the technical dossier), proves insufficient to make visible the heuristic processes, creative crises, and reasoned decision-making that the student experiences during the design phase. Consequently, an imperative need arises to empirically investigate how these variables interact within the current ecosystem.

The fundamental purpose of this article is to describe and deeply analyze the perceived relationship between the implementation of Project-Based Learning in virtual environments and the development of cognitive processes among architecture students at Universidad Columbia during the year 2025. Through diagnosing weaknesses in current technological mediation and contrasting documentary planning with student perception, this study seeks to establish the empirical foundations for validating a process-oriented evaluation model. Said model aims to transform the virtual environment from a barrier that increases cognitive load into an active facilitator that enhances critical thinking and constructive excellence in future architecture professionals.

2. Methodology

Research Approach and Design

This study was framed within a pragmatic paradigm, which posits that educational reality is complex, dynamic, and multidimensional, thereby requiring multiple analytical perspectives for a comprehensive understanding. To address the object of study, a concurrent mixed-methods design (QUAL-QUAN) was implemented, adopting a descriptive-correlational and cross-sectional scope. The adoption of a concurrent triangulation design enabled the simultaneous collection, analysis, and integration of quantitative and qualitative data during a single research phase conducted throughout the 2025 academic year. The descriptive component aimed to detail the characteristics of the digital scaffolding and the levels of cognitive development achieved, whereas the correlational component sought to ascertain the degree of statistical relationship between the implementation of Project-Based Learning (PBL) within the virtual platform and students' self-perceived higher-order cognitive skills.

Population and Sample

The spatial context of the research was the Architecture program at Universidad Columbia, Asunción Campus, Paraguay. The target population comprised two fundamental strata of the educational ecosystem: 165 students actively enrolled in design studio and technical courses during 2025, and a faculty body consisting of 12 professors responsible for these courses.

For the quantitative approach, a probabilistic sample of 116 students was determined, calculated with a 95% confidence level and a 5% margin of error. Selection was executed via stratified random sampling with proportional allocation, ensuring equitable representation across the various academic levels of the degree program. Conversely, for the qualitative approach focused on the faculty, no restrictive sampling techniques were applied; instead, a complete population census was conducted, incorporating all 12 professors to guarantee

theoretical saturation regarding techno-pedagogical mediation.

Data Collection Techniques and Instruments

To ensure construct validity and analytical depth, three data collection instruments were designed and administered, operationalizing the study's independent and dependent variables:

Digital Survey (Quantitative): A structured questionnaire administered to students was hosted on the Google Forms platform. The instrument comprised 35 items evaluated using a five-point Likert scale (ranging from 1 = "Never" to 5 = "Always"). The dimensions evaluated included perception of interactive digital scaffolding, quality of formative feedback, and self-perception of critical thinking and problem-solving development. The instrument underwent content validation by a panel of five experts in architectural pedagogy. Subsequently, internal consistency reliability was computed using **Cronbach's α** coefficient, yielding a highly reliable value of **Cronbach's $\alpha = 0.944$** , thereby establishing the stability and precision of the metrics obtained.

Semi-Structured Interview (Qualitative): An interview guide was developed for the faculty census. Open-ended questions explored teaching experiences in the virtualization of PBL, obstacles in communicating complex construction logics, and strategies employed to evaluate the heuristic process of architectural design. Sessions were audio-recorded with participants' informed consent and subsequently transcribed verbatim.

Deductive Document Analysis: An evaluation matrix was constructed to examine official course documentation (syllabi, practical assignment guidelines, and assessment rubrics). This analysis evaluated the level of theoretical planning of cognitive processes using a 1–5 rating scale, allowing for a contrast between documented pedagogical intent and actual execution within the virtual environment.

Data Analysis Procedure

Data processing followed a rigorous protocol of initial separation followed by hermeneutic

integration. Quantitative data extracted from the surveys were coded, tabulated, and exported to IBM SPSS (Statistical Package for the Social Sciences). In the first phase, descriptive statistics were used to calculate absolute frequencies, percentages, measures of central tendency (means), and measures of dispersion (standard deviations). In the second phase, non-parametric inferential statistics (Spearman's rank correlation coefficient, given the ordinal nature of the variables) were applied to test the study's hypotheses and determine the statistical significance of the correlations among variables.

Concurrently, the qualitative corpus derived from the interviews was imported into ATLAS.ti software. Open and axial coding was performed to identify units of meaning, which were subsequently grouped into code families and semantic networks. This process generated a total of 180 coded quotations, delineating emergent categories such as "VLE Bureaucratization" and "Evaluative Dissonance."

Finally, methodological triangulation (meta-inference) was conducted by cross-referencing the SPSS statistical matrices with ATLAS.ti semantic networks and the documentary analysis means. This allowed for contrasting the excellence of theoretical planning (documents) against perceived deficiencies (surveys) and techno-pedagogical justifications (interviews).

Ethical Considerations

The overarching development of this research was conducted in strict compliance with international ethical guidelines for research involving human subjects and the protocols established by Universidad Columbia. Participant autonomy was safeguarded through the execution of digital informed consent forms by all participants. Furthermore, absolute anonymity and confidentiality were ensured throughout data processing by decoupling individual identities from responses and transcripts. The formal structuring of the manuscript, including citation style, bibliographical references, and the presentation of tables and figures, strictly adhered to the guidelines of the 7th edition of the Publication Manual of the American

Psychological Association (APA), thereby ensuring academic rigor and editorial integrity.

3. Results

The research findings are structured around three fundamental axes derived from methodological triangulation: the descriptive statistical analysis of student perceptions, the qualitative categorization of the faculty cohort, and the correlational testing of the study variables.

The processing of quantitative data obtained from the sample of 116 students, analyzed via SPSS software, revealed a significant deficit in the development of higher-order cognitive processes mediated by the Virtual Learning Environment (VLE). The overall means across the evaluated dimensions fell within a critically low range, spanning between $M = 1.87$ and $M = 2.51$ (on a 1–5 scale). These descriptive statistics are detailed below in Table 1.

Table 1: Measures of Central Tendency and Dispersion for the Dimensions Evaluated in the Virtual Learning Environment (VLE)

Dimension evaluated	N	Medium (M)	Standard Deviation (SD)	Minimum	Maximum
Interactive digital scaffolding	116	1.87	0.82	1.00	4.00
Formative and continuous feedback	116	2.15	0.91	1.00	5.00
Self-perception of critical thinking	116	2.51	0.78	1.00	4.00
Solving design problems	116	2.30	0.85	1.00	5.00

Note. Data obtained from the digital survey administered to students of the Architecture program (Universidad Columbia, 2025 academic year). The rating scale ranges from 1 (Never) to 5 (Always).

Upon disaggregating the responses, 54% of participants selected the option "Never" for items regarding the receipt of continuous formative feedback from faculty during the design ideation phase. Likewise, 61% reported structural deficiencies in the interactive digital scaffolding provided on the institutional platform.

These cognitive deficits manifested most acutely in subjects of high technical and spatial complexity. For instance, students reported elevated levels of cognitive overload when attempting to resolve exercises in Architectural Design Studio III (Taller de Arquitectura III), specifically during the topographic and geomorphological site analysis wherein they were required to deduce foundation strategies for complex soil classifications (excluding basic typologies such as humic soil). Similarly, in the

course Construction Procedures and Materials Technology B (Tecnología de Procedimientos Constructivos y Materiales B), the comprehension of construction systems based on synthetic and industrialized materials having advanced beyond the study of organic or traditional materials such as timber, thatch, bamboo, and cork yielded the lowest assimilation means ($M = 1.87$), demonstrating that the mere virtual representation of these components failed to translate their tectonic and structural logic.

Furthermore, to examine the nature of this relationship in greater depth, regression and correlation analyses enabled the modeling of the direct impact exerted by technological mediation on higher-order cognitive skills. The distribution of scores obtained from the sample of 116 students confirms an ascending linear trend: higher quality and interactivity in the scaffolding provided by the VLE correspond to higher self-perception and effective performance in resolving complex design problems. This dynamic is illustrated in the following figure.

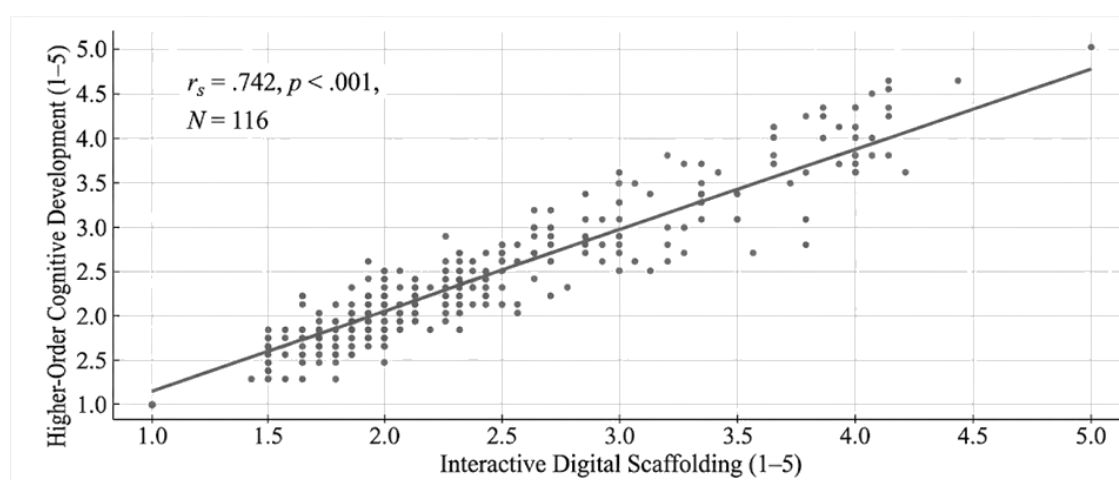


Figure 2: Scatter Plot and Trend line of the Correlation between Interactive Digital Scaffolding and Higher-Order Cognitive Development

Note. $r_s = .742, p < .001, N = 116$. The linear trend line demonstrates a positive and statistically significant correlation. Asterisks and data points denote the concentration of student response frequencies, demonstrating that low scores in digital scaffolding (ranging from 1.0 to 2.0) consistently co-occur with limited cognitive development.

As observed in Figure 2, the concentration of student ratings clusters markedly in the lower-left quadrant, reflecting that inadequate feedback and the absence of interactive tools constrain perceived cognitive scores to a critical range ($M = 1.87$ to 2.51). This numerical evidence strongly corroborates the preceding qualitative findings,

affirming that the assessment gap is not an isolated perceptual issue, but rather a direct consequence of current techno-pedagogical inefficiencies within the institutional virtual environment.

Concurrently, qualitative processing of the faculty census ($n = 12$) using ATLAS.ti software facilitated the consolidation of a robust semantic network comprising 180 coded quotations. From this analysis, two primary macro-categories emerged: "VLE Bureaucratization" and "Evaluative Dissonance." The configuration of the latter, along with its linkages to discursive codes, is depicted in Figure 1.

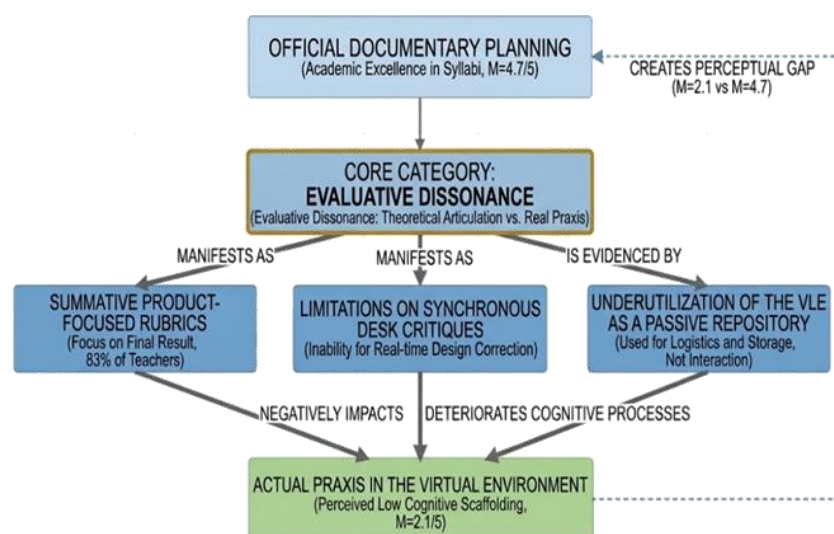


Figure 1: Main Semantic Network Derived from Qualitative Analysis in ATLAS.ti, Illustrating the Core Category "Evaluative Dissonance"

Note. The figure illustrates the hermeneutic tension between the high documentary pedagogical intent and the operational reduction of the virtual environment to a mere instrument for final grading, derived from the 180 coded quotations from semi-structured faculty interviews.

The transcripts revealed that faculty predominantly perceive the digital platform as an administrative management tool and file repository rather than a locus for heuristic exchange. Eighty-three percent of interviewed professors admitted to using traditional rubrics focused on grading final deliverables (digital drawings or renders), thereby obscuring iterative cognitive processes such as trial and error that are fundamental to Project-Based Learning (PBL). Faculty indicated that the current virtual interface severely restricts their capacity to conduct synchronous "desk critiques" (críticas de tablero), hindering the real-time remediation of spatial conceptualization errors.

Deductive document analysis of operationalization matrices, syllabi, and instructional guides yielded contrasting results. The assessment of theoretical planning for cognitive processes within official documents achieved an average score of excellence ($M = 4.7$ out of 5.0). Course syllabi explicitly mandate the promotion of critical thinking, the analysis of contextual variables, and technological innovation.

However, triangulating this data with the actual execution of virtual scaffolding as perceived by students ($M = 2.1$) confirmed the existence of a profound structural gap. This dissonance demonstrates that although curricular design and PBL instructional guides are formulated with academic and scientific rigor, their transposition to the virtual environment undergoes a techno-pedagogical degradation that negates their cognitive benefits. To determine the relationship between virtual PBL implementation and the development of cognitive processes among architecture students, Spearman's rank correlation coefficient (r_s), a non-parametric test suitable for ordinal-level variables, was calculated.

The results yielded a Spearman correlation coefficient of $r_s = .742$, with a significance level of $p < .001$. Because the p-value is less than the designated alpha level (Cronbach's $\alpha = .05$), the null hypothesis (H_0) is rejected and the alternative hypothesis (H_1) is accepted. It is empirically concluded that a strong, positive, and statistically significant correlation exists between the quality of scaffolding dynamics and interactivity within the virtual environment and students' self-perceptions regarding the development of their higher-order design cognition skills.

4. Discussion

The primary objective of this study was to analyze the relationship between the implementation of Project-Based Learning (PBL) in virtual environments and the development of cognitive processes among architecture students. Quantitative and inferential findings permitted the rejection of the null hypothesis, demonstrating a strong, positive, and statistically highly significant correlation ($r_s = .742$, $p < .001$) between digital scaffolding dynamics and students' self-perceived development of higher-order cognitive skills. As illustrated in the scatter plot in Figure 2, the concentrated score distribution empirically corroborates this ascending linear trend: technology, when devoid of interactive pedagogical intent, cannot independently guarantee the didactic transposition from the face-to-face design studio to the virtual space.

Contrasting the critically low cognitive development means perceived by students ($M = 1.87$ to 2.51) with the high indices of excellence identified in the official document planning analysis ($M = 4.7$) reveals a structural dissonance within the institutional educational ecosystem. This perceptual gap—centrally conceptualized in the semantic network of Figure 1—confirms that while syllabi and curricular frameworks exhibit optimal techno-pedagogical design in theory, they undergo severe degradation during practical execution within the Virtual Learning Environment (VLE). Qualitative faculty interviews corroborate this finding,

demonstrating that the virtual platform succumbs to a process of "bureaucratization," functioning primarily as an asynchronous repository for submitting final deliverables and downloading regulations rather than operating as a genuine workshop for co-creation and iterative critique.

The impact of this shortcoming is particularly critical in disciplines that structure the future professional's tectonic and spatial reasoning. In architectural PBL, students must assimilate not only spatial aesthetics but also constructive viability and site integration. As demonstrated by the findings, when students attempt the conceptualization of modern, industrialized construction systems reliant on synthetic components, steel profiles, or polymers, the lack of synchronous formative feedback within 3D modeling environments prevents them from internalizing the underlying structural logic. Similarly, complex analytical processes such as foundation design across demanding soil typologies (e.g., silty or clay strata) are reduced to mere graphical exercises when instructors lack virtual tools to scaffold students' step-by-step deductive reasoning. Consequently, assessment becomes predominantly summative, penalizing errors in the final product (the architectural drawing) while failing to evaluate heuristic effort and decision-making during the ideation phase.

This phenomenon can be elucidated through Cognitive Load Theory. Lacking interactive digital scaffolding—such as real-time collaborative simulations or virtual desk-critique forums—students deplete their working memory resources attempting to navigate the operational demands of the software and platform. This diverts processing capacity away from the higher-order cognitive skills essential for critical architectural design.

To address this issue, and as a core contribution of this research, this study establishes the imperative need to implement the Cognitive Process Assessment Model in Virtual PBL (MEPC-ABP-V). This theoretical-practical framework proposes shifting the evaluative paradigm within virtual architecture classrooms from an orientation focused on the final

"deliverable" to a continuous assessment of the "design process." The MEPC-ABP-V rests upon three fundamental pillars: (a) the integration of dynamic rubrics that assess trial and error alongside design rationale within synchronous forums; (b) faculty development in techno-pedagogical mediation strategies to reverse VLE bureaucratization; and (c) the utilization of virtual environments for iterative construction simulations, where immediate feedback acts as genuine cognitive scaffolding.

It is essential to acknowledge the limitations of this study. Given its cross-sectional design and scope restricted to a single higher education institution during the 2025 academic year, the generalization of these findings to other geographical contexts or academic disciplines should be approached with caution. Future research avenues should prioritize longitudinal studies that empirically implement the MEPC-ABP-V model across the entire degree program, measuring its direct impact on student retention rates and the technical quality of capstone or undergraduate thesis projects (Trabajos de Fin de Grado - TFG).

The virtualization of architectural education demands far more than the mere adoption of computational tools; it necessitates a profound deconstruction of instructional assessment practices. If virtual environments can transcend their current function as logistical repositories to become dialogic ecosystems of cognitive scaffolding, Project-Based Learning will be empowered to unlock its full potential to cultivate critical, resilient, and technically competent architects capable of addressing the complex challenges of the contemporary built environment.

5. Conclusion

The research culminates by empirically reaffirming that the efficacy of Project-Based Learning (PBL) in architectural education does not inherently reside in the adoption of computational tools, but rather in the quality of the techno-pedagogical mediation that structures these resources. The study demonstrated a positive, strong, and statistically significant

relationship between the interactivity of scaffolding within Virtual Learning Environments (VLE) and the development of higher-order cognitive processes among students.

A pronounced dissonance became evident between documentary curricular planning which exhibits levels of excellence and technical rigor and its practical execution in virtual settings. Digital platforms, when utilized predominantly as asynchronous repositories for assignment submissions and instruments of summative assessment, generate extrinsic cognitive load. This techno-pedagogical disconnect hinders deep learning, preventing future architects from successfully internalizing complex design variables, such as the tectonic behavior of synthetic industrialized systems or the analytical deduction of foundations from rigorous topographic profiles.

To reverse the current bureaucratization of the virtual environment and consolidate a genuine digital design studio, it is concluded that a transition toward a formative, iterative, and process-oriented assessment paradigm is imperative. The proposal and integration of the

Cognitive Process Assessment Model in Virtual PBL (MEPC-ABP-V) constitutes the methodological response to this critical need. Its implementation will enable the transformation of the digital interface into effective cognitive scaffolding, wherein the submission of a rigid final product yields to the valuation of the heuristic process, continuous dialogic critique, and the rationale behind spatial decisions.

Ultimately, the pedagogical optimization of these virtual environments will not only improve technical assimilation metrics in design subjects, but will also strengthen the holistic development of the student body. Transcending virtuality as a mere administrative tool to establish a locus of co-creation is indispensable for graduating professionals equipped with the critical thinking and innovative capacity demanded by contemporary architectural practice.

6. Author Declaration

- Confirm originality of work

The author confirms the originality of the work.

- State no conflicts of interest

The author declares no conflict of interest.

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