Workforce Training: A Comparative Study of Universities in Colombia for the Integration of Building Information Modeling (BIM) in Academic Curricula

Abstract:

Building Information Modeling (BIM) has emerged as a transformative technology in architecture, engineering, and construction (AEC), offering numerous benefits in collaboration, efficiency, and project management. Recognizing its potential, universities worldwide incorporate BIM into their curricula to prepare students for the evolving industry demands. This paper compares workforce training methods using BIM implementation strategies in the academic curricula of five prominent (QS International, 2022) universities in Colombia, where different approaches merge to diagnose the country's advancement in workforce training regarding BIM skills and competencies, shedding light on the integration of BIM in undergraduate architecture and civil engineering programs.

Keywords: BIM Implementation, Architecture, Civil Engineering, Colombia, Academic Curricula

Methodology

This paper discusses six approaches to BIM academic implementation in Colombia by describing each approach's strategies, experiences, and results. To generate a comprehensive analysis, we compare these results with the competency sets and topics established by (Succar & Sher, 2014) for knowledge-based learning. This comparison enables the study to build a reference frame that is not only comparable between each approach but also helpful in determining which real-life competencies and capacities students are acquiring in universities in the country.

1. UNIVERSIDAD DE LOS ANDES. SCHOOL OF ARCHITECTURE AND DESIGN

Enhancing Architectural Education: Integrating BIM Implementation through Design Challenges

While the importance of BIM in professional practice is widely recognized, its integration into architecture school curricula remains an area of ongoing exploration and debate. At the School of Architecture and Design at the Universidad de los Andes, we propose integrating BIM into architectural education through the inception of its principles in the culture. To complement developing software-mastering capabilities in specific courses, we introduce a series of open quick design challenges that prompt students to use BIM software and workflows to solve architectural problems outside the classrooms. This strategy allows them to see how these tools can enhance their design abilities while providing a more hands-on and practical application of BIM concepts.

An essential part of the initiative is promoting horizontal integration among students from various disciplines and universities nationwide, mirroring real-world and multi-disciplinary projects. Additionally, the challenges align with contemporary professional tasks, focusing on themes such as BIM and sustainable design and BIM software interoperability. This approach departs from traditional BIM education, emphasizing practical problem-solving and contextualizing BIM knowledge in real-world architectural scenarios. Some of the benefits of this approach are increased student engagement, improved skill development, a deeper understanding of how BIM can address complex problems, and the identification of student disciplinary and professional interests regarding BIM implementation.

In this paper, we will report on the least and most successful design challenges. The first one focused on "BIM and sustainable design." Participants had to create a carbon budget using Autodesk Dynamo, Autodesk Revit, and Microsoft Excel. This involved algorithm development to visually represent a 3D model's compliance with preset limits for the building's carbon footprint. Components exceeding the limits turned red, those under remained green, and those on the edge turned yellow, as shown in Figure 1.

Figure 1. Student results from the first BIM and sustainable design challenge.

The second challenge focused on BIM workflows and interoperability between Autodesk Formit and Autodesk Revit. Participants had to optimize building placement for year-round sun exposure, design an energy-efficient building envelope for interior comfort, and propose a structural system aligned with the architectural vision for the façade (Figure 2). This challenge encouraged collaboration among architecture and engineering students, emphasizing the creation of multi-disciplinary design teams. The results of the student's work were assessed by project and BIM managers from a prominent construction company in Colombia, who selected two winning teams. The judges were impressed with the executed BIM workflows, which allowed numerous iterations of project alternatives to achieve optimal design solutions. They noted the valuable information generated quickly and concluded that the design challenge successfully achieved its intended outcomes.

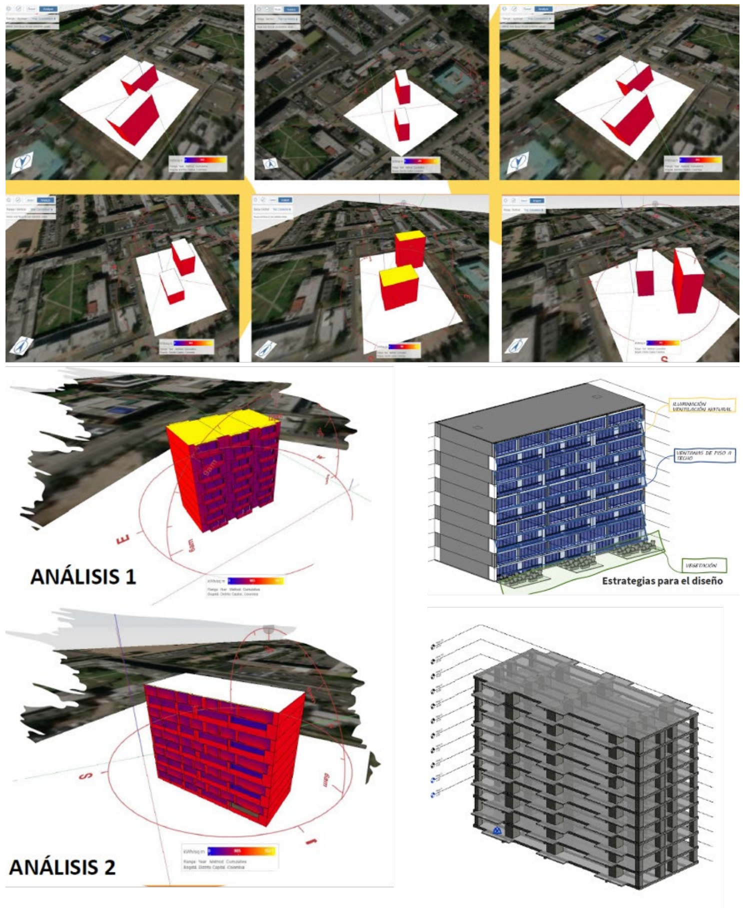


Figure 2. Student results from the second BIM and sustainable design challenge.

Results

These experiences taught us that the second challenge was more engaging for our students than the first one. We realized that most participants were interested in something other than algorithms and carbon budget since most of them dropped out and were a minority among those who completed the assignments. However, the second challenge touched on more familiar topics that were more relatable to their academic and professional paths. Therefore, we concluded that although BIM tools and procedures can be powerful and full of advantages, not all of them fit a school's culture. This notion puts us on a track to define how to align student and faculty mindsets around disciplinary competencies to insert BIM as an endemic agent within the school and not only as a part of the curricula.

2. UNIVERSIDAD JORGE TADEO LOZANO

Integrating BIM through Project Design Workshops in the Undergraduate Curriculum

This section discusses implementing Building Information Modeling (BIM) into the undergraduate architecture curriculum in Architecture and Habitat at Jorge Tadeo Lozano University of Bogotá, focusing on project design workshops. These workshops, following STEAM-type educational models (Middle East Technical University (METU) et al., 2016), provide an ideal platform for introducing BIM methodology into architectural education (Education Ministry of Colombia, 2003). The goal is to enhance architectural design skills and prepare students for using BIM in their future careers.

In these workshops, students learn how to organize various components and systems from different specialties and integrate them into architectural projects using digital information modeling, mirroring real-world architectural agency workflows with specific BIM execution plans. Action research, grounded in action reflection, is employed as a pedagogical research model, emphasizing continuous improvement through iterative cycles of planning, implementation, and evaluation (Latorre Beltrán, 2003).

These workshops were closely monitored over eight academic periods starting in 2018 to assess their impact on architectural design learning. Pedagogical planning continuously evolved, adjusting learning activities and resources to achieve objectives. A work breakdown structure (WBS) was used to organize BIM-related learning activities within the architectural design workshop. Table 1 summarizes the refined learning activities during the design planning phase.

Types of BIM Learning Activities	Design planning
Exploration activities	Organization of the strategy for collaborative work around a project
	The organizational culture of a design agency and a project team that receives a commission under the BIM methodology
Structuring activities	Adopting a BIM execution plan (BEP) for the architectural design phase.
	Understanding of fundamental BIM concepts.
	Design information management with BIM according to the ISO 19650 series

	Implementation of the BIM methodology in architectural design companies.
	Learning digital tools. Modeling software and collaborative work platforms – CDE.
Integration activities	Design thinking for the collaborative design of the project
	Collaborative work for information management
Evaluation activities	Performance measurement and use of KPIs for the design phase.

Table 1. Relations between BIM learning activities and the design planning phase

The action-research findings align with similar studies, highlighting the methodology's potential to enhance design skills and create a collaborative learning environment (Alfaro-González et al., 2019). A performance-based evaluation model, typical in architectural design workshops, assesses learning outcomes, like design quality and the BIM methodology's application (Miller et al., 2009). The workshop prioritized practical design in real-world-like conditions. Figure 3 showcases the information model of a multifamily housing project by the NOX student group in the 2023 workshop. This model integrated real-world criteria, technical data, and regulations, revealing a strong link between design quality and methodology.

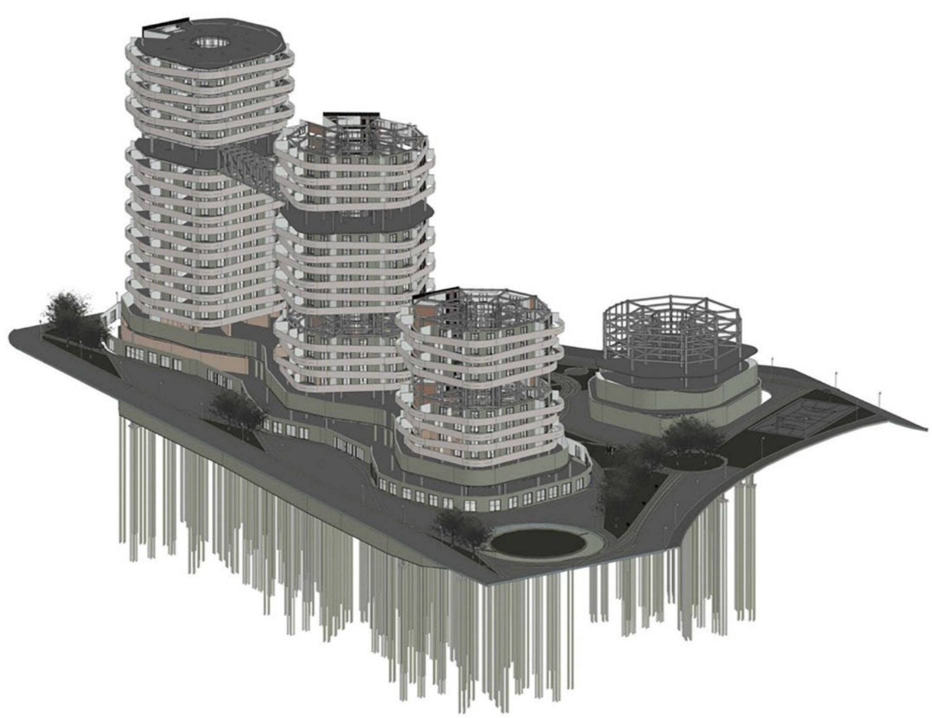


Figure 3. Information model of the multifamily housing project developed by the NOX student group.

Results

BIM brings innovation to traditional project design workshops, promoting collaboration and early engagement in design information management. The methodology offers a structured approach to information management, enhancing critical data integration for design decisions. Through action research and student evaluations, the study highlights the importance of focusing on human aspects of BIM, emphasizing the training and adaptation of individuals for successful implementation. The workshop's implementation reveals initial resistance to collaborative work. It underscores the need to address ingrained perceptions of architecture as a solitary endeavor, fostering trust, teamwork, and effective communication among colleagues.

3. PONTIFICIA UNIVERSIDAD JAVERIANA (PUJ)

Leveraging BIM and campus infrastructure transformation for construction education

PUJ has harnessed its state-of-the-art campus infrastructure to innovate construction education (CE) by embracing BIM as both a project management methodology and a transformative learning tool. The ever-increasing BIM implementation at the Construction Office in campus buildings is used to explore new technologies and methods for teaching and learning about construction. The convergence of physical campus transformation and academic exploration has sparked significant opportunities, particularly within the Schools of Architecture, Design, and Engineering.

A novel approach to monitoring construction site activities has been a critical highlight by implementing stereoscopic panoramic views from the School of Engineering Labs BIM model, where Architecture students have gained invaluable insights into tracking construction progress, as seen in Figure 4. Compared with traditional Gantt chart-based monitoring, this method has allowed students to appreciate the real-time state of various construction elements. This inversion of the typical learning process, where students first see the result and then dissect the process, has provided a fresh perspective, bridging the gap between theory and practice.

Figure 4. On-site control technologies

Civil engineering students had sessions with the BIM model of the School of Engineering Labs at the CAVE (Cave Automatic Virtual Environment), an immersive VR environment to visualize and control 3D models, shown in Figure 5. Students visualize the new building (in construction at that time) in 3D real scale, verifying specific elements and systems such as the structure, and displaying a series of significant design aspects that were not evident even at the modeling stage on a computer. Additionally, students visualize their models at the construction simulation stage, exploring new ways to control scheduling in construction works.

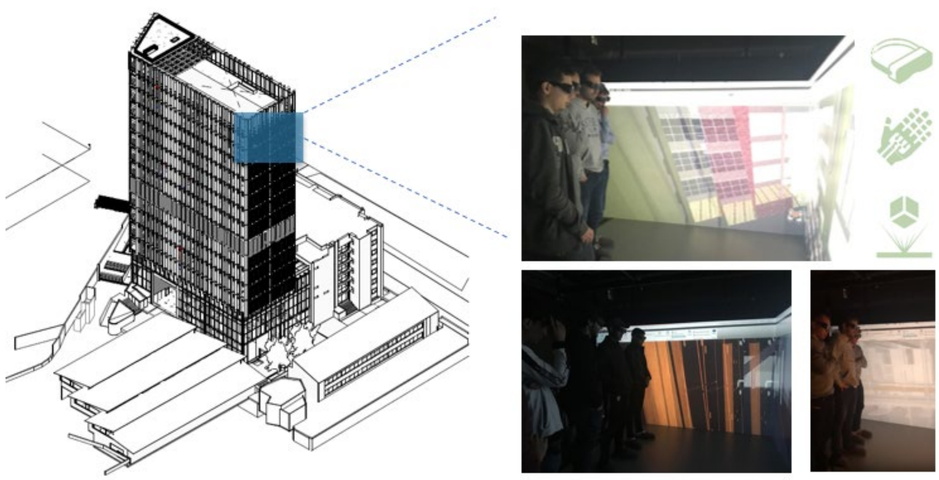


Figure 5. BIM construction models in VR

One of the most promising experiences of using construction on campus for education is Campus Javeriana (Figure 6), a mobile app offering a gallery of audiovisual and interactive media, bringing the education community closer to construction processes knowledge. Buildings of the University Campus in constant transformation are used as regular input and source of educational material, becoming a learning laboratory in constant construction (from both the perspective of infrastructure and knowledge) and bringing the user closer to straightforward knowledge adapted to new generations. The first experiences showed increased construction learning for architecture students from three specific courses (results are currently under publication), generating an interest to explore innovative technologies from professors and students.

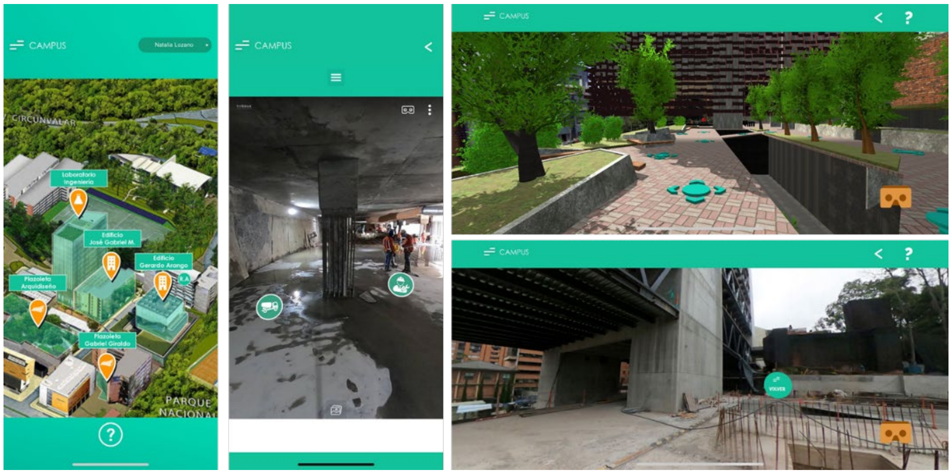


Figure 6. Campus Javeriana app (Cuberos et al., 2021)

Results

The three experiences described shape the general intention of the construction professors from the PUJ: to leverage campus construction transformation in the classroom. The initial results have been positive because an increasing interest in exploring new technologies in architecture and civil engineering curricula has manifested. Connecting real campus construction experiences and processes to students and classes proved effective, and harnessing lessons learned from academia and the professional field to improve construction education is mutually beneficial.

4. UNIVERSIDAD NACIONAL (UNAL) - MANIZALES

Uses of superstructure models

The civil engineering department at UNAL-Manizales is developing a BIM strategy to align the academic curriculum with the digitization of construction. Key objectives include implementing OpenBIM, integrating the curriculum, and fostering multi-disciplinary interaction within the faculty. The strategy begins with the elective course "Modeling of Information for Construction," which serves as an introduction to BIM and a precursor to advanced courses like "OpenBIM-Modeling and Multi-disciplinary Management" and the specialization in "BIM-Management."

The course "Modeling Information for Construction" focuses on collaborative work to build the superstructure BIM model of the Technological Park in Caldas, Colombia (Figure 7). Students assume roles as coordinators and modelers, working within an information management system. The project is divided into zones, with each student responsible for modeling one. The model serves four primary purposes: constructive sequence analysis, clash detection, virtual and augmented reality visualization, and material take-off.

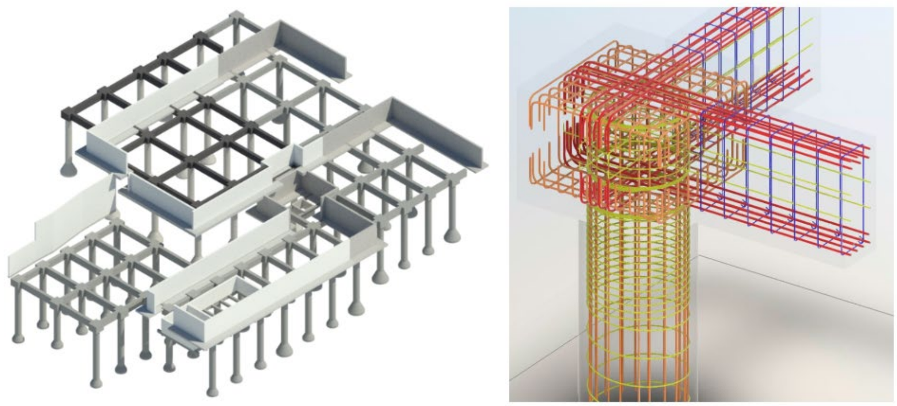


Figure 7. Student work. Superstructure and reinforcement steel.

Constructive sequence analysis is employed to understand the superstructure's construction phases, including earthworks, caissons, foundation beams, retaining walls, and slabs (Figure 8). Coordination involves dividing the superstructure into four zones, each assigned to a student modeler (Figure 9). Under the coordinator's guidance, a federated model is generated with visual and automatic quality control for clash detection.

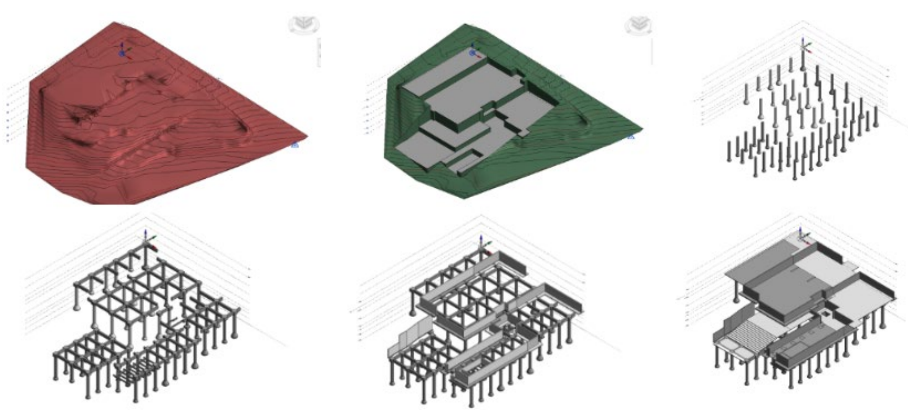


Figure 8. Student work. Construction Phases

Figure 9. Student work. File management

In the STEM lab, students use virtual and augmented reality glasses for project visualization exercises. They also use CYPE's BIM SERVER CENTER platform on their mobile phones to examine specific elements, such as complex junctions (Figure 10).

Figure 10. Virtual and augmented reality.

A marking system is implemented to classify and group elements for quantity extraction. The coordinator manages a shared file, which modelers refine in detail (Table 2).

PHASES	**MARKING**			**TYPE**	
Existing	TOPOGRAPHY	Terrain leveling		**FOUNDATION BEAMS**	**CAISSONS**
Terrain leveling		N-0.70		VC-3	CA-1
Caissons		N-4.06		VC-C	CA-2
Foundations		N-.696		VC-2	CA-3
Retaining Walls		N-10.57 Secretary		VC-C”	CA-4
Floor Slab		N-10.57 Auditorium		VC-1’	
Rebar		N-8.36		VC-1”	
Structure		N-13.11		VC-A’	
Architecture	STRUCTURE (Foundations and Floor Slab	N+1.00		VC-A	
		N-3.76		VC-2’	
		N-3.76		VC-B	
		N-6.96		VC-B’	
		N-10.57 Secretary		VCT	
		N-10.57 Auditorium		VC-1	
		N-8.36		VC-C’	
		N-13.11		VC-5’	
	WALLS	MC-6	N-3.76	VCF-1	
		Wall Foundation MC-6		VC-CC	
		MC-4	N-7.36	VC-4	
		Wall Foundation MC-4		VC-D	
		MC-1	N-10.57		
		Wall Foundation MC-1			
		MC-3	N-10.57		
		Wall Foundation MC-3			
		MC-4A	Auditorium		
		Foundation Beam MC-4A			
		MT-1	Water Tank		
		Negative elevator pit walls	Elevator		

Table 2. Student work. Information management.

Results

Students recognized BIM's benefits, particularly in terms of time reduction, motivating their adoption of this methodology. However, coordination was the most challenging aspect due to communication issues and file management gaps, which disrupted the modeling process. Students want to collaborate with other disciplines and programs to enable multi-disciplinary cooperation. They also desire to explore alternative software solutions to expand their capabilities for various activities and promote OpenBIM implementation.

5. UNIVERSIDAD DE LOS ANDES - SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

BIM-Enhanced Engineering Education: Nurturing Collaboration and Sustainability

The Department of Civil and Environmental Engineering at Universidad de los Andes has recognized BIM's transformative potential in promoting multi-disciplinary collaboration and addressing sustainable project objectives. In our undergraduate civil engineering ABET-certified program, the capstone class leverages BIM and introduces students to designing large projects encompassing various civil engineering disciplines: geotechnical, road infrastructure, structural, transportation, water resources, and construction. Within this class, students embrace distinct roles within project delivery teams, fostering self-coordination to meet deadlines effectively. With group sizes of 12 to 15, enhanced communication skills and project management techniques are nurtured—vital attributes for collaborative project delivery.

Our pedagogical approach is anchored in project-based learning, guided by facilitator instructors who introduce core curriculum elements and assist students in framing complex problems. This approach thrives on active student involvement. Each semester commences with students choosing one of three project options, fostering project ownership and self-directed learning. A summary of projects from the past four semesters is available in Table 3.

Semester	Capstone project design	# of students	# of groups	Average # of students/group
2021-2	Immigrant service building	61	5	12.2
2022-1	Recreational building	68	5	13.0
2022-2	Airport passenger terminal	75	5	15.0
2023-1	Metro underground station	37	3	12.3

Table 3. Summary of student capstone projects during the past four semesters

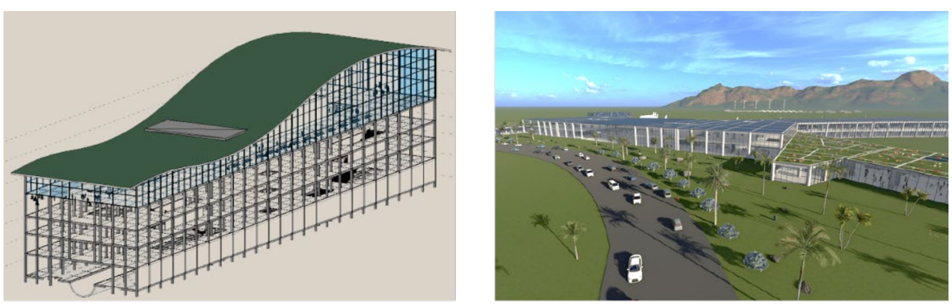
Throughout the term, students delve into the virtual design and construction (VDC) methodology, emphasizing multi-disciplinary models to achieve clear business and project objectives (Kunz & Fischer, 2020). In line with the VDC approach, students define project objectives spanning social, environmental, and economic sustainability. They then design projects that align with these objectives and each discipline's distinct technical requisites.

Students shift from conventional discipline-centric methods to an integrated, multi-disciplinary framework by establishing overarching project objectives early. In this setting, decisions within one discipline reverberate across others, guiding the achievement of overarching project objectives.

Each student group crafts a BIM Execution Plan, outlining objectives, discipline-specific scopes, milestones, and roles. Project teams work within an integrated Common Data Environment (CDE) and utilize Integrated Concurrent Engineering (ICE) to assess progress toward specific objectives. Throughout the term, teams evolve designs from conceptual to design development stages. Significantly, the class emphasizes BIM as a collaborative tool, with a reduced emphasis on modeling and software training skills. Figure 12 shows snapshots of the student's designs.

Results

While students appreciate BIM's collaborative value, they note challenges working within large, multi-disciplinary teams. Instances of missed deadlines affecting team performance mirror real-world scenarios. Addressing these is an intrinsic class component. To mitigate this, planning documents were introduced. Students draft pull schedules, set due dates and responsibilities, enhancing comprehension of interdependencies, and promoting mutual accountability.



(a) (b)

Figure 11. Examples of student capstone project deliverables: a) Metro station from 2023-1 Group 3, b) Airport from 2022-2 Group 5

The capstone course equips students with technical BIM skills and crucial qualities such as teamwork, problem-solving, and accountability—vital in contemporary professional settings. The fusion of BIM, project-based learning, and interdisciplinary collaboration creates a powerful educational model, effectively equipping engineering students to confront real-world collaborative challenges.

VI. UNIVERSIDAD SANTO TOMÁS - CIVIL ENGINEERING

BIM implementation strategy in the Civil Engineering curriculum

The strategy to implement BIM is divided into three stages, according to the difficulty level of career modules within the civil engineering curriculum, as shown in Table 4.

STAGE 1 INTRODUCTORY COURSES		**STAGE 2 INTERMEDIATE COURSES**		**STAGE 3 ADVANCED COURSES**	
COURSE	**BIM USES**	**COURSE**	**BIM USES**	**COURSE**	**BIM USES**
- Construction Drawings and Detailing	- Construction System Design - - Digital Fabrication	- Construction Management: Cost management and control	- Phase Planning - (4D Modeling) - 3D Control Planning - Cost Estimation	- Infrastructure Integrative Project (Highway Design) - Building Integrative Project	- 3D Coordination - 3D Control and Planning - Design Reviews

Table 4. Implementation Stages

In Stage 1, introductory courses present the students with the representation of design and construction elements using a 3D modeling process to eliminate the gap in the skill development process in first-year students and, therefore, build practical capacities for the following modules. (Figure 12)

Figure 12. 3D Modeling session

In intermediate courses in Stage 2, students focus on creating technical information for the planning, design, construction, and operation phases of AEC projects. The documentation is created and managed through 3D BIM modeling software and Common Data Environments. For now, the implementation focuses on Construction Management, emphasizing delivering Cost Management and Control information for decision-making, as shown in Figure 13, where students develop scheduling and budgeting diagrams using specialized software, such as Synchro 4D Pro, for scheduling and planning, and Presto for budget creation.

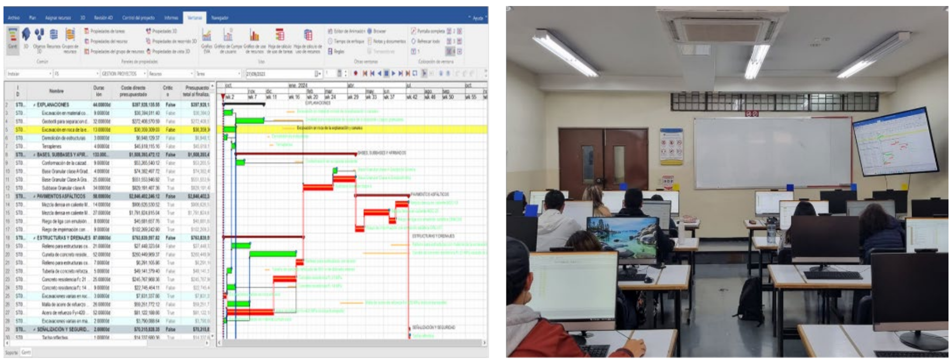


Figure 13. 4D and 5D session

In Stage 3, we guide students to take on complex construction projects and analyze coordination issues in the design and construction stages. Students in these exercises acquire different roles as designers, contractors, and project managers. Acting as their roles, students must develop integrated strategies to deliver coordinated building and infrastructure BIM models as an option to culminate their studies.

Results

BIM implementation at the school is relatively new and has to undergo a meticulous analysis as it evolves. For now, the results documented in student work are promising. Students have seen BIM's potential application in their professional careers and seek to add BIM as a minor to their engineering emphasis.

CONCLUSIONS AND DISCUSSION

BIM implementation in academic curriculums in Colombia proves to be a challenge that surpasses the mastering of software, requiring the development of specialized competencies that enable the setup of high-performance teams based on individual skills and talents working and making decisions as a unit to understand the importance of co-responsibility and social skills, among other aspects. Since the different approaches documented in this report vary in strategic goals and results for each school and seeking to generate a diagnosis of the state of BIM development in the Colombian academic stage, we developed the following Table to synthesize and associate each strategy to the competencies to promote BIM learning at educational institutions (Succar & Sher, 2014). Table 5 shows a colorcoded system that differentiates each competency according to Succar & Sher's classification for a clear understanding of what each academic strategy is achieving.

University - program	Strategy	Tools	General results / Lessons learned	Associated individual competency (Succar & Sher, 2014)
Universidad de los Andes - School of Architecture and Design	Embed BIM into the School's culture through	Modeling tools BIM software interoperability protocols Collaborative processes for addressing design challenges.	Design Challenges are a functional strategy to define student interests around BIM workflows and tools. This enables the development of curricular content that has a better chance of being approved by the to the school's culture rather than impose outside criteria.	1. Define the strategic objectives to be achieved from implementing model-based workflows. (Managerial set - Strategic Planning) 2. Organize initiatives to encourage staff to adopt BIM software tools and workflows within the organization. (Administration set - Policies and Procedures) 3. Develop model ownership protocols with other project participants at the start of BIM projects. (Functional set - Collaboration)
Universidad Jorge Tadeo Lozano - School of Architecture	The project design workshop	Modeling tools Materials databases classification systems programming tools Pedagogical planning from research-action processes Strengthening soft skills through conflict management. Training exercises and adaptation of people to the methodology and digital tools.	Innovation in workflows Encourages collaborative work. Think from an early age about design information management. Integrate more and better information for decision-making in design	1. Define the strategic objectives to be achieved from implementing model-based workflows. (Managerial set - Strategic Planning) 2. Use a content management system to manage information storage and sharing. (Functional set - Team and Workflow Management) 3. Develop model ownership protocols with other project participants at the start of BIM projects. (Functional set - Collaboration) 4. Identify the responsibilities of a BIM manager, a model manager, and similar BIM roles. (Managerial set - Organizational Management)
Pontificia Universidad Javeriana - Schools of Architecture and Civil Engineering	Monitoring construction site activities	BIM models and stereoscopic panoramic views	Increasing interest to explore new technologies in CE	1. Define the strategic objectives to be achieved from implementing model-based workflows. (Managerial set - Strategic Planning) 2. Generate an overall mission statement covering BIM implementation within an organization. (Managerial set - Leadership)
	Contrasting design versus reality	BIM models and CAVE environment for 3D 1:1 scale visualization	Harnessing lessons learned from both sides (academia and	

			professional field) to improve CE	3. Use a content management system to manage information storage and sharing. (Functional set - Team and Workflow Management) 4. Organize initiatives to encourage staff to adopt BIM software tools and workflows within the organization. (Administration set -Policies and Procedures) 5. Establish the necessary metrics to measure the financial performance of BIM projects. (Administration set - Finance and Accounting) 6. Identify the responsibilities of a BIM manager, a model manager, and similar BIM roles. (Administration set - Human Resource Management)
	Leveraging construction on campus for CE	Mobile app using BIM models (VR and AR)	Connecting real campus construction experiences and processes to students and academic community in general	
Universidad Nacional (UNal) - Manizales	Superstructure Model uses	BIM models Information management VR and AR	Understand the construction sequence. Practice team modeling and collaborative workflow Generate integrated information	1. Define the strategic objectives to be achieved from implementing model-based workflows. (Managerial set - Strategic Planning) 2. Use a content management system to manage information storage and sharing. (Functional set - Team and Workflow Management) 3. Identify the responsibilities of a BIM manager, a model manager, and similar BIM roles. (Managerial set - Organizational Management) 4. Organize initiatives to encourage staff to adopt BIM software tools and workflows within the organization. (Administration set - Policies and Procedures)
Universidad de los Andes - School of Civil Engineering	BIM as an enabler for multidisciplinary design	Project-based learning VDC methodology Collaborative workflows Use of BEP and CDE	Projects that comprehensively integrate sustainability criteria in a multidisciplinary approach	1. Define the strategic objectives to be achieved from implementing model-based workflows. (Managerial set - Strategic Planning) 2. Organize initiatives to encourage staff to adopt BIM software tools and workflows within the organization. (Administration set) - Policies and Procedures) 3. Identify the responsibilities of a BIM manager, a model manager, and similar BIM roles. (Managerial set - Organizational Management) 4. Act as a project team's BIM facilitator while delivering collaborative BIM projects. (Functional set - Facilitation) 5. Use a content management system to manage information storage and sharing. (Functional set - Team and Workflow Management)

Universidad Santo Tomas - Civ Eng	Manage construction project information through three-dimensional databases	BIM databases Project Management Information System	Decision making Control costs Understand design and construction processes	1. Define the strategic objectives to be achieved from implementing model-based workflows. (Managerial set - Strategic Planning) 2. Use a content management system to manage information storage and sharing. (Functional set - Team and Workflow Management) 3. Identify the responsibilities of a BIM manager, a model manager, and similar BIM roles(Managerial set - Organizational Management) 4. Establish the necessary metrics to measure the financial performance of BIM projects. (Administration set - Finance and Accounting)

Table 5. Synthesis and comparison of strategies with competencies to promote BIM learning at educational institutions using Succar & Sher's classification.

The overall diagnosis for BIM education in Colombia's leading architecture and engineering programs (QS International, 2022) shows a specific emphasis on cultivating competencies related mainly to managerial and functional skills (Succar & Sher, 2014) since those competency sets are more broadly used in the different academic initiatives, especially in topics related to Strategic Planning and Team and Workflow Management. Notably, the strategies used by Pontificia Universidad Javeriana stand out because it is the only program focusing on developing individual administrative skills-related capacities. Furthermore, all programs aim to develop specific leadership skills (Succar & Sher, 2014) in their students through cultural inception, conflict management, activity monitoring, and procedure design.

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