



Strategies and Virtual Tools for Teaching Building Construction to Civil Engineering Undergraduates: A Case Study

Estrategias y herramientas virtuales para la enseñanza de Construcción de Edificaciones en el programa de ingeniería civil: Un estudio de caso

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HIGHLIGHTS

- BIM methodology and its application possibilities in virtual settings are described.
- Promote strategies and tools to facilitate the acquisition of competencies and soft skills by students.
- Apply technologies and virtual tools to acquire employability.

TITULARES

- Se describe la metodología BIM y sus posibilidades de aplicación en entornos virtuales.
 - Promover estrategias y herramientas para facilitar la adquisición de competencias y habilidades blandas por parte de los estudiantes.
 - Aplicar tecnologías y herramientas virtuales para adquirir empleabilidad.
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RESUMEN

El objetivo de este trabajo es mostrar las técnicas efectivas empleadas para enseñar construcción de edificaciones en el tercer año de un programa de la carrera de ingeniería civil de la Pontificia Universidad Católica del Perú. Este enfoque implicó integrar plataformas virtuales y software para realizar videoconferencias y laboratorios en las que se utilizan herramientas como Building Information Modeling (BIM) y Lean Construction, entre otras. Esta metodología balanceada sirve como un modelo exitoso para impartir conocimientos sobre la construcción de edificaciones. Las visitas a obra se simularon mediante recorridos virtuales creados con la tecnología scanner laser, fotogrametría y BIM. Los gemelos digitales generados se colocaron en plataformas en línea y los estudiantes recorrieron interactivamente el proyecto de construcción. Adicionalmente, los estudiantes desarrollaron planos de layout utilizando modelos BIM 3D y 4D. Durante la asignatura también se instruyó a los alumnos en el análisis de precios unitarios y en las mediciones de las actividades de obra a través de la metodología BIM con software 5D, teniendo como resultado el desarrollo de los presupuestos. La efectividad de esta metodología se evidencia en la alta calidad de los trabajos académicos, evaluaciones y encuestas realizadas a los estudiantes. Esta propuesta también ganó el Premio a la Innovación y Mejores Prácticas en Docencia convocado por la Pontificia Universidad Católica del Perú, concurso en donde un jurado internacional de expertos especializados en innovación docente evaluó el desarrollo de competencias genéricas y habilidades colaborativas generadas, destacando la claridad, alineación curricular y el carácter sostenible y transferible de la innovación implementada.

Palabras clave: Enseñanza; Aprendizaje; Construction 4.0; Gestión de la Construcción; Building Information Modeling; Lean Construction

ABSTRACT

The objective of this report is to showcase the effective techniques employed to teach building construction in a third-year civil engineering program at Pontifical Catholic University of Peru. This approach involves integrating virtual platforms and software for video conferences and laboratories, while utilizing tools like Building Information Modeling and Lean construction, among other systems. This balanced methodology serves as a successful model for imparting knowledge on building construction. Construction site visits were simulated by virtual tours created using scanner laser technology, photogrammetry, and BIM. The generated digital twins were placed on online platforms. Students interactively toured the construction project with input from professionals managing the project. Additionally, students developed layout plans using 3D and 4D BIM models. The course, however, instructed on generating and analyzing unit prices and conducting quantity surveys of

activities through the BIM methodology with 5D software, resulting in the development of project budgets. The effectiveness of this methodology is evident in the high-quality papers, evaluations, and student surveys. This proposal also won the Award for Innovation and Best Practices in Teaching 2022 organized by the Pontificia Universidad Católica del Perú, where an international jury of experts in teaching innovation evaluated the development of generic competencies and collaborative skills generated in students, highlighting the clarity, curricular alignment and the sustainable and transferable nature of the innovation implemented.

Keywords: *Teaching; Learning; Construction 4.0; Construction Management; Building Information Modeling; Lean Construction*

1. INTRODUCTION

At the beginning of 2020, the Covid-19 pandemic arose in a great number of countries. At that time, the Peruvian Government demanded universities to teach virtual classes [1]. Redesigning courses that include construction site visits posed a challenge for the faculty staff. A need to execute an integrated vision of online education that incorporates current technology in support of teaching and learning had already been identified [2].

Years before the pandemic, the education sector had been offering face-to-face, online/virtual and blended learning (BL) teaching and learning modalities. BL is an educational modality that combines face-to-face and online/virtual teaching, creating an educational environment with multiple forms of communication in which technology plays an essential role [3]. A BL environment facilitates students' social participation, creates a unified community, and enhances collaboration [3].

In addition, a study developed before the health emergency concluded that dropout rates for virtual students are significantly higher than for face-to-face students. There is evidence that isolation, technological challenges, academic expectations, and personal pressures on students contribute significantly to dropout [4]. However, there is also evidence that online "teacher presence" and a supportive and

engaging environment designed for online teaching and learning can help mitigate these difficulties and lead to higher student retention [4].

The health crisis expedited progress in necessary technological advancements for online teaching and learning. An extensive examination recommended 12 principles and practical suggestions that can seamlessly integrate into remote education and be swiftly optimized during similar emergencies [5]. Refer to Table 1 for the unique code assigned to each tip. The lessons learned could benefit future integration of educational technology with institutional infrastructure [5].

CODE	TIP
T01	Anticipate and move through the change management stages
T02	Use the current Learning Management System
T03	Modality – Optimize the potential of online lectures
T04	Modality – Optimize online small groups using intentional design
T05	Modality – Optimize the potential of asynchronous online tutorials
T06	Modality – Optimize the potential of online videos
T07	Modality – Optimize the potential of social media
T08	Modality – Optimize the potential of online reflection
T09	If you can't teach the whole task, start with part-task online training
T10	Simplify the massive online world for learners
T11	Encourage and support co-creation of online resources and activities
T12	Demonstrate the value for practitioners and academics of the shift to online learning

The critical success factors for e-learning during the health emergency were: (i) technology management, (ii) management support, (iii) increased student awareness of the use of e-learning systems, and (iv) a high level of information technology demand from faculty, students, and universities [6]. It was also found that BL was the most appropriate learning

system during the emergency, while technology readiness played a critical role in facilitating the educational process [6].

The sense of isolation experienced by students in the early stages of the pandemic can be mitigated by combining face-to-face teaching with high-quality online learning and high levels of student interaction. This will help ensure that the student experience remains a critical feature that enhances higher education [7]. The materials and strategies generated for distance learning after COVID-19 will be only the second part of the process. First, we need to ensure that our students have the minimum infrastructure to access the planned online activities [7].

In addition, the following recommendations are considered and identified as some of the best practices: (1) teacher support network to minimize the need for training and support; (2) having an institutional policy to develop virtual and distance education; (3) a systematic training program for teachers as well as digital orientation for students [8].

The quick evolution of technology has made a favorable impact on various productive and service sectors, such as education and engineering. The implementation of current and emerging technologies alongside innovative pedagogical procedures and best practices is referred to as Education 4.0 [9]. For the design of new educational innovation projects, four core components of Education 4.0 are proposed: Competencies, Learning Methods, Information and Communication Technologies, and Infrastructure. Furthermore, innovative online and physical infrastructures have been developed to meet current requirements [9]. Table 2 displays the core components, each assigned a code for identification purposes.

CODE	CORE COMPONENTS OF EDUCATION 4.0
C01	Competencies
C02	Learning Methods
C03	Information and Communication Technologies
C04	Infrastructure

For these reasons, it is necessary to include all recommended tips and components in the design of our online activities until we are authorized to resume face-to-face classes. In such a scenario, the activity could be adapted to the Blended Learning model [10].

Meanwhile, the construction industry faces challenges related to utilizing collaborative platforms, accessing computer labs remotely, and obtaining the necessary software for coursework on students' personal computers [11]. Previous experiences have demonstrated the successful use of BIM technology for addressing challenges in this complex context in real project settings [12]. However, integration with the various management systems tools available in the construction phase is currently lacking [13, 14].

The objective of this article is to present successful teaching strategies employed in a third-year civil engineering program at the Pontifical Catholic University of Peru for the course Building Construction, now known as "Economic Evaluation of Building Projects" during the pandemic.

2. SUBJECT DESCRIPTION

Before the health emergency, the teaching and learning approaches were in-person and incorporated classes, labs, and construction site visits to observe and analyze construction processes, including unit costs. Starting in 2019, the curriculum integrated research findings from the GETEC research group, highlighting the utilization of tools and technologies within construction projects. However, with the onset of

the pandemic, all classes, laboratories, and evaluations transitioned to strictly virtual settings [15]. Therefore, a methodology had to be developed utilizing tools and technologies to facilitate the acquisition of competencies and soft skills by students. Such skills were also valued by the industry, thus increasing their employability. Thus, a versatile amalgamation of construction management tools was suggested, which were combined to enable efficient operation by a work team, following Lean systems [16,17,18], Project Management Institute [19], Building Information Modeling (BIM) [20,21], and Construction Contract Management [22,23].

3. TECHNOLOGIES

Construction 4.0 is a confluence of trends and technologies that are changing the way a project is designed, built, and operated [24]. Construction 4.0 can be defined as a framework for the confluence and convergence of technologies such as (i) digital and computational technologies (BIM, video and laser scanning, reality capture, simulation, augmented reality, AI and cloud computing, big data and data analytics, others), (ii) industrial manufacturing (prefabrication, 3D printing and assembly, offsite manufacturing), and (iii) cyber-physical systems (drones, robots, sensors, actuators, others) [24]. This topic includes Construction 4.0, as companies demand this knowledge, thus creating employability. The following technologies are used:

3.1 Building Information Modeling (BIM)

BIM is a methodology that integrates the three-dimensional model of a construction site with geometrical and/or parametrical information [20]. BIM emphasizes collaborative planning and communication, including idea discussion, argumentation, and decision making, among

other factors [25]. It is defined as the shared digital rendering of the physical and functional characteristics of any object [25]. These skills can enhance participants' soft skills and improve their employability.

3.2 Virtual Reality (VR)

Virtual reality (VR) is a visualization technique that can be immersive or non-immersive and has a wide range of applications, including entertainment, marketing, and building construction [26]. The use of VR and digital prototypes (digital mock-ups) for design review is increasingly prevalent during the design and construction phases [26]. Furthermore, an increasing number of commonly used virtual reality software programs are now compatible with BIM technology [20,27].

3.3 Laser Scanning

Laser scanning is a commonly used method to determine the position of an object and measure data that can then be exported as a point cloud [28]. The terrestrial laser scanners allow the measurement of the 3D position of the surface of an object and is a common technology for analyzing 3D information of construction sites [28]. If the laser scanner does not provide enough detail, photogrammetry can be used to complement laser scanning. To obtain orthophotos of surfaces, aerial photogrammetry using unmanned aerial vehicles (drones) is often utilized [29].

The data produced through the use of BIM, virtual reality, and/or photogrammetry can be transformed into a unified format, with numerous technological implementations that streamline this process with every iteration [30].

The research team used this technology in various projects, as documented in our sources [24, 30, 31, 32]. We shared case studies with

students to provide a more comprehensive understanding of how these tools and technologies can be applied. The research utilized laser scanning, point cloud importing, and 3D, 4D, and 5D BIM Modelling technology.

4. METHODOLOGY

Prior to the pandemic, tools and technologies categorized as Construction 4.0 were implemented in civil engineering classes and labs. However, the syllabus required updating for the current health crisis. The employed methodology included: (1) Syllabus Revision; (2) Subject Re-design; (3) Inclusion of employability; (4) Infrastructure analysis; (5) Implementation of laboratories; (6) Subject update; and (7) Assessment of the subject. Figure 1 illustrates the research methodology flowchart.

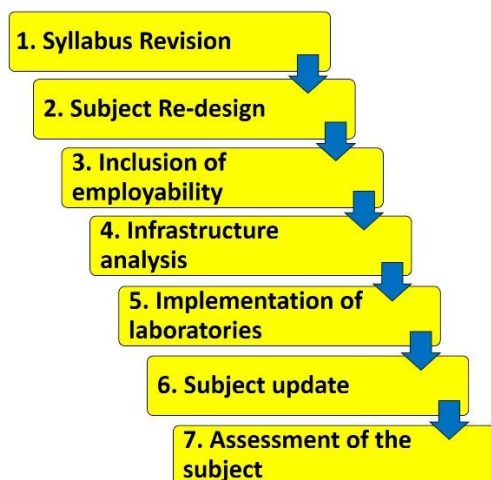


Fig. 1: Research methodology.

5. RESULTS AND DISCUSSION

5.1 Step 1 - Syllabus Revision

The study plans undergo continual review and revision to uphold the goals of the Institutional Strategic Plan 2018-2022 of our university, which aims to implement a competency-based

educational model, enhance academic excellence, and maximize our students' employability. Methodologies that meet these objectives are identified and incorporated. It promoted the adoption of generic competencies, such as self-directed learning, ethics and responsible citizenship, clear communication, logical and mathematical thinking, independent research, collaboration, and participation in projects [33].

The design, updating, and evaluation of the subject matter through surveys adheres to the following areas: (A) Learning Strategy: Online classes and labs are carefully planned and developed with activities scheduled to each hour. (B) Methodology and Resources: Classes and labs are organized with clarity, prompting students to analyze and contemplate course topics. Content and activities are tied to the student's social or professional environment. Effective digital resources are used throughout the learning process, including platforms, software, ICT, videos, digital applications, and more. Activities that encourage interaction among participants are presented. Learning assessment is related to the subject's objectives, and evaluations are clearly defined. Teacher feedback is an effective tool for learning. Communication and interaction with the teacher are also essential, as the educator should be enthusiastic, attentive, and respectful, fostering student interest in the material. The instructor encourages communication and active involvement during synchronous sessions, both in groups and individually [33].

Additionally, relevant rules and accreditation guidelines were thoroughly examined and incorporated into the development process. Using this information, alternative design concepts and preliminary subject content were created through an iterative approach.

5.2 Step 2 - Subject Re-design

Based on the information obtained in the first step, processes are developed. The university's infrastructure and available technology, the technological capabilities of the student body, and existing logistics are initially assessed to prepare for investment and agreements with providers. In conjunction with this assessment, the initial proposal for modifying the subject is approved.

5.3 Step 3 - Inclusion of employability

The industry and institutions demand specific profiles of graduates who possess requisite competencies, soft skills, and technological expertise that align with changes in the marketplace. Due to the dynamic nature of the professional environment, graduates must be able to adapt to any possible scenario, necessitating flexible content, tools, and technologies throughout their coursework.

5.4 Step 4 - Infrastructure analysis

The findings from prior steps serve as an input. A comprehensive analysis is conducted on both the university's and students' internal and external infrastructure, including hardware, software, and agreements with providers. The logistics management is finalized with the design and proposal of online laboratories.

5.5 Step 5 - Implementation of laboratories

During the subject, students were required to virtually assist to five laboratories. To facilitate this, the institution employed both the Paideia Moodle platform and Zoom. Teachers uploaded all course content and assignment submission folders through Paideia, while Zoom provided links to connect students to computer or mobile sessions. Due to the emergency situation, it was understood by professors and teaching

assistants that some students may not be able to attend classes in real-time.

To ensure all students had access to class materials, bi-weekly 2-hour laboratory sessions were recorded and uploaded for later viewing. Prior to each session, an instructional video was provided to students, detailing the lab and software to be used, and allowing for time to prepare questions related to the task. During the lab, students share their screens to display any software issues they encounter. Subsequently, a summary of the pertinent portions covered in the lab is presented. Additionally, students had access to asynchronous online discussion forums, which have been demonstrated to encourage students to seek assistance with content knowledge beyond the classroom [34].

5.5.1 Laboratory 1: Virtual visit to a construction project using digital twins

Due to the pandemic, on-site visits to construction projects were replaced with online simulations and tours. These virtual visits were created using scanner laser technology, photogrammetry, and BIM, resulting in digital twins that were stored on online platforms. The construction site was toured virtually and interactively by students, and they attained a comprehensive understanding of the organization and construction tasks through the explanations of the project's professionals. Moreover, the participants fashioned the layout plans of the construction site utilizing 3D models. Additionally, students were provided with a link to access the digital twins.

For this laboratory project, the task was to create a report containing essential details of the construction site, such as stakeholders, subcontractors, construction procedures, layout plans, the project's organizational chart,

designated project areas, and heavy equipment used.

5.5.2 Laboratory 2: BIM modeling and quantity surveying

In the lab 2, students were tasked with creating a model of a residential building project using Revit. The blueprints were distributed to the students for this purpose. Their final outputs included a Revit model, a comprehensive material take-off, and lastly, a final report with multiple views of the model. To perform material take-off, students were instructed to export the Revit tables to separate Excel sheets for concrete, reinforcement steel, and formworks.

It should be noted that participants had prior basic knowledge using Revit, as it was taught in a previous subject, so this laboratory enabled their enhanced knowledge with this software.

5.5.3 Laboratory 3: Scheduling and cost analysis using BIM

For this lab session, participants imported the Revit model from lab #2 to Navisworks for the construction process simulation. By doing so, they could track the progress and determine the appropriate construction sequence and Project Schedule. Figure 2 depicts the modeled construction sequence in Navisworks. In addition, they learned how to conduct a Unit Cost Analysis for the primary tasks involved in a construction site.

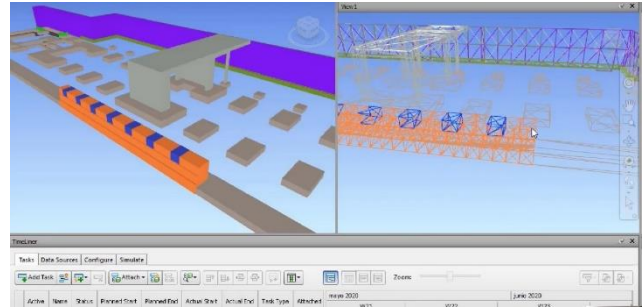


Fig. 2: Screen capture of Virtual Laboratory Session 3: How to Use Navisworks Manage Software to Create 4D Construction Sequences.

5.5.4 Laboratory 4: WBS integration and cost analysis using BIM models in IFC format

During the laboratory session, students were instructed in integrating the work breakdown structure and the unit cost analysis by utilizing the national software Delphin Express. This software facilitates the interaction of BIM models in IFC format, enabling the creation of budgets, unit cost reviews, and direct linking of quantity surveying data from the 3D and 4D models. By the end of the session, students had successfully completed the 5D BIM modeling of the construction site and learned a potent software application.

5.5.5 Laboratory 5: Planning, scheduling, and project budget

For this task, participants were assigned a project involving an underground cistern. They were tasked with creating a quantity survey, unit cost analysis, and budget. Through this exercise, they were able to compare their working method with a traditional tool.

During the planning and implementation of the laboratories, adherence to the 12 guidelines presented in Table 1 was confirmed, as outlined in Table 3.

Table 3: Tips implemented to improve the design and execution of the laboratories

Topic	T01	T02	T03	T04	T05	T06	T07	T08	T09	T10	T11	T1
1 Virtual visit to a construction project using digital twins	X	X	X	X	X	X	X	X	X	X	X	X
2 BIM modelling and quantity surveying	X	X	X	X	X	X	X	X	X	X	X	X
3 Scheduling and cost analysis using BIM	X	X	X	X	X	X	X	X	X	X	X	X
4 WBS integration and cost analysis using BIM models in IFC format	X	X	X	X	X	X	X	X	X	X	X	X
5 Planning, scheduling, and project budget	X	X	X	X	X	X	X	X	X	X	X	X

5.6 Step 6 – Subject update

The validated update was implemented and real-time feedback was received based on available information. During Laboratories 2 and 3, participants learned collaborative modeling and planning of construction sequencing in preparation for specific projects. Conventional formatting was maintained with regular author and institution information and titles were factual and unambiguous. Language was kept clear and objective with value-neutral vocabulary and use of passive tone and impersonal construction. Sentence and paragraph structure was logical with essential information presented clearly and concisely. Color, center, and traveling were spelled with American English conventions. Technical term abbreviations were explained upon first use. The positive feedback from participants and the excellent class average confirmed the efficiency of the teaching methodology. During the most recent lab session, the students compared the methodology learned via BIM tools and technology versus a more traditional one utilizing an excel sheet. The students collectively found the latter to be more challenging in the aspects of automation, collaborative work, integrated project perception, as well as selecting the most suitable construction sequence and identifying constraints. The curriculum should be adaptable for prompt adjustments of tools, technologies, and teaching methods in order to achieve the goal of creating job opportunities.

5.7 Step 7 - Assessment of the subject

During these processes, students' proposals, suggestions, and feedback are taken into account after ensuring their compliance with the institution's accreditation requirements and internationalization standards. Soft skills and technological competencies are evaluated to gauge employability and maintain positive industry and environmental relationships. Furthermore, the development of competencies is guaranteed through thoughtful assessment method design [35]. The effectiveness of this methodology is demonstrated by the high quality of papers and evaluations.

5.7.1. Assessment of the course from the student's perspective

At the end of the semester, for each course taught in the Engineering Department, a survey is applied to students to evaluate 4 categories: A) learning strategy; B) methodology and resources; C) learning assessment; and D) communication and interaction. For each of the categories, the students rate on a scale from 1 to 5 (100%). This value determines the efficiency of the subject in each category and the overall qualification.

Among the aspects evaluated in the survey were the following:

A) Learning Strategy:

- The teacher creates online classes and exercises, and allocates coursework.
- The teacher distributes coursework in a manner that evenly distributes study hours.

B) Methodology and resources:

- The teacher clearly explains the development of activities and tasks, including the activity object, work dynamic, expected products, and other relevant details.

- The teacher delivers the course material with clarity and thoroughness.
- The teacher employs inquiries, clarifications, instances, imagery, related links, and additional materials to facilitate comprehension of the analyzed sections.
- The teacher contextualizes the course material and activities within social or professional settings.
- The resources used throughout the course, including readings, cases, videos, forums, presentations, and digital applications, among others, have proven to be effective in facilitating my learning process.

C) Learning assessment:

- The evaluations are aligned with the course objectives.
- The feedback presented by the teacher provides valuable insights for my learning.
- Evaluations, assignments and course activities are clear.

D) Communication and interaction:

- The teacher's enthusiasm fosters my interest in learning.
- The teacher encourages dialogue and active participation in synchronous meetings (Zoom, Meet, etc.).
- The teacher shows a positive attitude towards receiving queries and feedback.

The survey yielded a sustained effectiveness rate of 96% over the course of four semesters, surpassing all categories of other engineering department subjects. The methodology proved to be highly efficient. Tables 4, 5, 6 and 7 display the average scores gleaned from the end-of-semester survey for the course in 2020-2, 2021-1, 2021-2 and 2022-1. During the semesters, students expressed that the tools and

technology available in classes and laboratories were highly beneficial.

Table 4: End of semester 2020-2 survey results

Survey Category	Core components of Education 4.0	Average efficiency of subjects of the Engineering Department (%)	Subject efficiency (%)
A. Learning strategy	C01 Competencies	87.0	100.0
B. Methodology and resources	C02 Learning Methods, C04 Infrastructure	84.6	94.8
C. Learning assessment	C01 Competencies	84.4	93.8
D. Communication and interaction	C03 Information and Communication Technologies	88.0	98.2
GENERAL QUALIFICATION		85.8	96.4

Table 5: End of semester 2021-1 survey results

Survey Category	Core components of Education 4.0	Average efficiency of subjects of the Engineering Department (%)	Subject efficiency (%)
A. Learning strategy	C01 Competencies	89.2	98.5
B. Methodology and resources	C02 Learning Methods, C04 Infrastructure	87.2	96.1
C. Learning assessment	C01 Competencies	86.2	97.1
D. Communication and interaction	C03 Information and Communication Technologies	90.0	96.3
GENERAL QUALIFICATION		85.0	96.1

Table 6: End of semester 2021-2 survey results

Survey Category	Core components of Education 4.0	Average efficiency of subjects of the Engineering Department (%)	Subject efficiency (%)
A. Learning strategy	C01 Competencies	89.8	96.8
B. Methodology and resources	C02 Learning Methods, C04 Infrastructure	87.8	94.5
C. Learning assessment	C01 Competencies	87.6	95.9
D. Communication and interaction	C03 Information and Communication Technologies	90.0	95.6
GENERAL QUALIFICATION		85.8	94.4

Table 7: End of semester 2022-1 survey results

Survey Category	Core components of Education 4.0	Average efficiency of subjects of the Engineering Department (%)	Subject efficiency (%)
A. Learning strategy	C01 Competencies	89.4	98.5
B. Methodology and resources	C02 Learning Methods, C04 Infrastructure	87.4	96.1
C. Learning assessment	C01 Competencies	86.6	97.1
D. Communication and interaction	C03 Information and Communication Technologies	90.4	96.3
GENERAL QUALIFICATION		85.4	96.1

5.7.2. Assessment of the course from the perspective of an international jury of experts in teaching innovation

The pedagogical methodology implemented in this subject was one of the winners of the Award for Innovation and Best Practices in Teaching 2022 organized by the Pontificia Universidad Católica del Perú, where an international jury of experts in teaching innovation evaluated 71 teaching experiences of which 25 were the winners [36]. Among other aspects, the jury highlighted that:

- The innovative idea is related to the development area of generic competencies and the sub-area of collaborative skills development.

- The results reflect interesting contributions for the students.
- The clarity and effort to align the curriculum was highlighted.
- The process is described step by step and as a result of this documentation it is possible to understand the sustainable and transferable nature of this innovation.
- The proposal evidences that it comes from a reflective process on the part of the teachers to incorporate technology in the subject. The stages described in the results are evidence of this reflection.

5.8 Final discussion

The validated update was implemented and real-time feedback was received based on available information.

Comparative of Academic Approaches

This study demonstrates the feasibility and value of incorporating virtual construction tours as an alternative to physical site visits in light of the COVID-19 crisis and related restrictions. Many universities offering similar courses have been forced to replace on-site visits with qualified online practices presented through spreadsheets or scanned documents.

Regarding the proposal to organically integrate BIM into the civil engineering degree curriculum and this specific course. BIM was introduced in every laboratory session and included in student homework assignments. In contrast, conventional academic practices do not provide BIM training or require homework related to its use. Instead, BIM is only presented as an elective course and not as a tool to be applied in all career courses.

Software and Hardware

The lab sessions used construction digital twins on the Matterport platform. This platform provided students with easy access to virtual

tours, but coordinating with the construction teams to survey the site with the Matterport Pro2 scanner presented a significant challenge. On the other hand, in terms of the software used by the students for BIM modeling, the university provides each student with an educational license from Autodesk that allows them to use Autodesk Revit and Navisworks Manage on their computers to complete homework assignments. Table 8 illustrates the software and hardware tools utilized.

Table 8: Software and hardware tools used

Tools and Technologies	Software and Hardware
Building Information Modeling (BIM)	Autodesk Revit, Autodesk Navisworks
Virtual Reality	Samsung Gear VR
Laser Scanning	Matterport Pro 2
Point Cloud importing	Matterport platform, Autodesk Recap

Industry input

Regarding the Architecture Engineering and Construction national industry, according to Murguía et al. there is a high need to incorporate professionals with BIM skills in the private and public sector. BIM implementation in projects increased from 25% in 2017 to 39% in 2020, so nowadays this percentage should be at 50%. Additionally, the mandatory BIM policy conducted by the Peruvian public sector since 2019 [37] should also be considered. The proposal should be regarded positively by companies as it focuses on the sector's needs.

Relevance of Study

This paper presents a successful case study of using new tools to enhance the teaching and learning experience in both virtual and face-to-face classrooms. BIM tools are introduced organically within the deliverables of a basic construction management course, and virtual site tours are made feasible when in-person tours are not possible.

The limitations of the work. Possible future work

The primary limitation of this study is that it describes the strategies used to innovate

teaching and learning during the COVID-19 pandemic emergency lockdown, but it could be adapted to similar circumstances or to fully virtual courses. Following the end of the crisis, modifications were made, such as reintroducing physical visits to construction sites, but the implementation of BIM deliverables remains.

A potential subject for future research is:

- It is recommended that there should be a discussion with students about their perceptions of the virtual tour lab site through the use of larger focus groups.
- Additionally, a study should be conducted to evaluate the value of this proposal for the employability of civil engineering graduates from the university in the AEC industry.

6. CONCLUSIONS

The students have successfully learned Construction 4.0 technological transformations, which were implemented in the laboratories. These highly valued technologies can now be applied to work in various fields including industry, research, teaching, and learning.

The survey results indicate that the Construction 4.0 concept was achievable and various current and emerging technologies were implemented. Additionally, the survey revealed that online infrastructure proved to be an ideal solution for pandemic-related needs and challenges. Innovative pedagogical procedures and flexible best practices were employed, resulting in significant benefits.

Based on an evaluation of teaching innovation by an international expert jury, the proposed methodology and resulting outcomes were notable for their clarity, alignment with the curriculum, reflective approach to technology integration, sustainability, transferability, among other factors. The expert jury concluded that it could be replicated cost-effectively and adapted to suit the needs of other institutions.

The use of Building Information Modeling (BIM), Virtual Reality and Lean Construction in this course provided students with a broader understanding of construction processes and building construction. Despite being hindered by the inability to visit physical construction sites, students successfully navigated BIM to create a comprehensive digital twin, including 3D, 4D, and 5D models from initial blueprints. The methodology is designed to allow for adaptation during the health emergency and post-pandemic phases by proposing a balanced utilization of online platforms, software and hardware for conducting online classes, laboratory experiments and/or construction site visits.

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