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A Methodology for Embedding Building Information Modelling (BIM) in an Undergraduate Civil Engineering Program

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Abstract: Undergraduate programs face the permanent challenge of constantly transforming to keep an up-to-date curriculum according to globalization and internationalization processes. In the case of civil engineers, professional training should respond to the needs of the Architecture, Engineering, Construction, and Operation (AECO) industry. In this context, Building Information Modelling (BIM) constitutes a process involving shared digital representations of built assets to facilitate design, construction, and operations processes within the industry to form a reliable base for decision-making. The present research develops a methodology and a proposal to embed BIM in an undergraduate civil engineering competency-based curriculum. Mixed method research was applied with a descriptive approach and a concurrent design. The results show that it is possible to implement a curricular design to embed BIM transversally. The study concludes that this design was embraced by the AECO industry, as the number of students, the number of employed graduates, and institutional national and international agreements have positively increased from 2017, at the launch of the program, to 2022.

Keywords: undergraduate curriculum; civil engineering; competency-based curriculum; BIM training; AEC; AECO; BIM; collaborative process; communication

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1. Introduction

Undergraduate programs face the challenge of keeping up with globalization and internationalization processes to stay up-to-date and respond to the demands of international quality standards [1]. In this context, UNESCO [2] has declared that higher education programs need to support their training processes with competency-based curricula, as competencies prepare students to live under variable circumstances while building knowledge and easily adapting to changes in the professional and personal environment [3].

Thus, competency-based curricula should answer society's present-day requirements to provide competent and competitive professionals to each particular field of knowledge while leading it toward progress by proposing potential solutions to the arising challenges. Consequently, competency-based curricula focus on integral performances while developing learning strategies such as self-regulation, autonomy, leadership, teamwork, problem-solving, and critical thinking, among others [4]. Moreover, they enhance lifelong learning (LL), a competency itself, through a dynamic combination of knowledge, skills, attitudes, and values [5].

Therefore, a competency-based curriculum should be constantly revised and updated according to the transformation of each profession. This is what acknowledged accreditation boards worldwide seek to certify [6]. In the case of the Architecture, Engineering, Construction, and Operation (AECO) industry, the Fourth Industrial Revolution or Industry 4.0 [7] has brought some changes to the field, such as introducing new technologies, workflows, and methodologies [8]. Building Information Modelling (BIM) is a process that involves the use of shared digital representations of built assets to facilitate design, construction, and operations processes to form a reliable base for decision-making [9].

BIM relies on tools, technologies, and graphic and non-graphic information for digital representation generation, management, and operation [10]. BIM has been adopted by the AECO industry since mid-2000 as a collaborative process for project management throughout projects' lifecycle to overcome low construction efficiency [11]. In the last 10 years, BIM technologies have continued to develop, organizing the interdependencies between stakeholders in the design, bidding, construction, operation, and maintenance processes. Furthermore, since BIM benefits have come to governments' attention, this methodology has also become necessary in public projects [12].

In this context, the study develops a methodology for embedding BIM in an undergraduate civil engineering program within the framework of a competency-based curriculum. This research implies two (2) main products: the curricular design and its implementation. The implementation was measured and assessed through the number of freshmen, employability rate, and the number of international agreements.

1.1. Competency-Based Curriculum

Competencies are complex, integrated, and dynamic capacities that combine knowledge, skills, attitudes, and values that subjects deploy according to particular contexts [1]. Hence, they imply integral human development and are supported by four (4) attributions: knowing, doing, being, and coexisting [13].

As competencies must be developed and reinforced, they are related to proficiency levels or phases with distinctive characteristics. This ensures gradual and continuous progress within the training processes, as posterior levels of proficiency include the characteristics of the previous ones. According to the socio-formative approach, there are five (5) proficiency levels: pre-formal (P), receptive (R), basic (B), autonomous (A), and strategic (S) [5].

The pre-formal level is associated with a general idea of the competency, while the receptive is associated with a specific idea, operational actions, and partial motivation. The basic level implies simple problem-solving, incorporating technical elements and monitoring processes. The autonomous level involves complex problem-solving, initiative, managing and directing processes, and scientific reasoning. Finally, the strategic level is associated with applying strategies for change based on context, innovation processes, flexibility, and commitment [14].

Competencies are classified into three (3) types: primary, generic, and specific. The first competencies are trained during primary and secondary education; the second ones are transversal to all disciplines in higher education, as they are common to all degree programs and professionals of every knowledge field; and the third ones are proper to particular and specialized environments, answering to the requirements of each profession [1]. Moreover, competencies comprise five (5) different components: capacities, purposes, scopes, requirements, and quality conditions [5], as shown in Table 1.

Table 1. Competencies' components [1].

Component	Explanation	Question
Capacity	Learning products are obtained when competency is achieved	What?
Purpose	Competency intention	Why?
Scope	Context, area, and/or competency level	Where?
Requirements	Knowledge, skills, attitudes, and values needed to achieve the competency	What is needed?
Quality conditions	Situations, procedures, parameters, guidelines, attitudes, and values constitute a quality indicator of achieving a competency	How?

[1] Adapted from [5].

On the other hand, curricula are the concretion of pedagogical theories and training plans to make them effective and ensure learning through teaching. They answer to the culture, time, and particular community within which they are immersed [15]. Curricula are the starting point for the goals to be achieved by the educational process and the steps to achieve them, as well as its main reasons: the practical application of a pedagogical theory in the classroom. Curricula should be aligned with the educational model of each institution [3,16].

It is necessary to analyze the requirements and the situational, professional, and labor problems to determine the relevant curriculum [3,17]. The curricular process within competency-based training implies three (3) different stages: contextualization profile, training plan, and implementation. The first stage, contextualization profile, refers to two (2) activities: the study of the context and the construction of the graduation profile. The second stage, the training plan, is properly curricular design, which encompasses establishing a sequence. Finally, the third stage, implementation, is the study plan's execution with the students [4].

The contextualization 'profile's first stage should consider the local, national and international scenarios. It encompasses an examination of the political, economic, social, labor, professional, and entrepreneurial challenges and requirements. The literature suggests the study of secondary sources and conducting interviews and surveys with the stakeholders, considering employers, researchers, professors, graduates, and entrepreneurs. The construction of the graduation profile includes formulating the competencies to train students, which will orient the curriculum [4]. Generic and specific competencies must be equally considered, as their domains determine the profession's particular contributions to society, and their performance areas describe the scenarios in which the graduates will be developing.

In the second stage, the training plan, the curriculum is developed: the graphical representation of the study plan. It should consider the training areas, the length of the terms or academic periods, and the mandatory and optional subjects with a logical sequence, prerequisites, and credits. More than one subject can contribute to developing and reinforcing the competencies declared in the graduation profile [4].

In the third stage, the implementation, the subjects must be planned, considering the teaching, learning, and assessing methods and the particular educational model of the institution [17]. In addition, the human, technological and infrastructural resources required should also be defined.

1.2. BIM and AECO

Productivity within construction processes has declined over the past years, compared to other engineering fields [18]. Numerous attempts have been made to change this situation, such as the development of collaborative methodologies for project management, like Virtual Design and Construction (VDC), with its elements of Integrated Concurrent Engineering (ICE), Project Production Management (PPM), and BIM. Specifically, BIM supports improving the flow of information, delivering a constructible design, enhancing cost estimation and control, meeting schedule deadlines on time, mitigating conflicts and disputes, increasing productivity, and reducing safety incidents [19,20].

In the past several years, BIM adoption has grown significantly within the AECO industry worldwide [21,22]. From 2011 to 2020, the BIM adoption level significantly changed. According to the NBS [21], while the active use of BIM has increased from 13% to 73% among respondents worldwide, BIM awareness has decreased from 45% to 26% because it has become merely a natural workflow. In 2011, 43% of the respondents were neither aware of nor using BIM; by 2020, this percentage had dropped to 1%. In Latin American countries, BIM adoption has remarkably grown since the end of the last decade, starting with the initiatives from the government of Chile in 2019, with the creation of its public project BIM standard, followed by Argentina, Brazil, Peru, and Colombia [23].

Consequently, the demand for civil engineering professionals with BIM competencies has increased exponentially. This growth of BIM in the AECO industry has motivated its inclusion in education [24]. Moreover, as education is essential to promote productivity in the industry [25,26], universities play an important role in providing BIM-equipped professionals to the industry [27]. However, BIM adoption in education has been solely focused on software operations and skill applications [28,29], even though this change implies not only moving from pedagogical tools in 2D design to 3D visualization [30].

In reality, BIM implementation implicates the way different parties of the project work in collaboration, from the early stages, to coordinate their inputs and improve the quality of the delivered project while ensuring reliability in its schedule and cost [30]. Therefore, communication and collaboration are key factors in BIM implementation. Unfortunately, to this day, only some approaches in education fully integrate these in BIM training throughout the curriculum while facing this process from an active learning approach [27,31], that is, a learning-centered or constructivist pedagogical model [32,33].

1.3. Goals and Research Question

This study aims to provide a methodology for embedding BIM in an undergraduate civil engineering competency-based curriculum. The methodology was validated through its implementation in an existing civil engineering curriculum. The following research question was formulated: How can BIM be embedded in a competency-based curriculum within an undergraduate civil engineering program? Therefore, the study variables are the competency-based curriculum (dependent) and BIM (independent).

2. Materials and Methods

2.1. Context

The study was conducted with an architecture and engineering faculty from a Peruvian private higher education institution. The proposal implied designing, assessing, and implementing a civil engineering curriculum with BIM embedded based on competencies and the presented methodology.

The following three (3) stages were addressed: literature review, application of interviews, and focus groups. Altogether, these were the inputs to develop a state-of-the-art curriculum. To measure and assess the success of the implementation, indicators such as the number of freshmen, employability rate, and number of international agreements were used.

The present section, Materials and Methods, focuses on the second and third stages, as the first has already been detailed in Section 1.

2.2. Design and Participants

This research adopts a descriptive design approach since the goal is to set and describe a methodology for embedding BIM in an undergraduate civil engineering curriculum. The variables were characterized to determine their components and propose correspondent stages within the methodology. Mixed method research was applied, as the qualitative and quantitative research paradigms were used in different study phases. The design is concurrent since both data types were merged during analysis to gain a richer insight into the study variables.

The study population was composed of two (2) groups: academy and industry referred to as the AECO. In addition, both public and private institutions were considered.

Higher education institutions and organizations from the AECO industry were invited to validate the resultant curriculum, including universities from the USA, Colombia, Chile, and Brazil. They participated through their representatives, which included: students, professors, researchers, technicians, chairs, graduates, and professionals.

2.3. Data Collection and Analysis

Data was collected through three (3) different techniques: documental analysis, face-to-face interviews, and focus groups.

Literature review allowed the identification and analysis of curricular designs worldwide, which could be either embedded or not within BIM. Interviews with external experts in an informal context were also conducted. With this information, the curriculum was developed. Finally, this design went through several institutional academic stages for approval.

For the curriculum proposal validation, interviews were conducted with graduates, chairs, and professionals. Focus groups were developed with professionals from the public and private sectors.

Information coding was used for numerical and categorical data processing. The values and evidence recorded were stored for analysis and assessment. These were the main sources of data to improve and validate the methodology for embedding BIM in an undergraduate civil engineering competency-based curriculum. Therefore, this research paper presents the resultant proposal for the aforementioned curriculum.

3. Results

The principal result of this research is the methodology for embedding BIM in an undergraduate civil engineering competency-based curriculum. The curricular design implies the following components: admission profile; graduation profile including domains, performance areas and competencies; academic areas; study plan; curriculum; teaching, learning, and assessing methods; technology and infrastructure; and 'professors' profile.

3.1. Admission Profile

Proper alignment with the secondary education graduation profile should be considered in an examination of the admission profile. Basic competencies can be expected: communication, knowledge, interaction with the environment, math, citizenship, culture and art, ICT, learning to learn, and autonomy [34].

The suggested admission profile for a civil engineering program with BIM on its curriculum should consider the following skills: effective written and oral communication, ICT knowledge, meta-learning, intermediate English level, and problem resolution. These skills were transformed into competencies considering the five (5) basic components: capacity, purpose, scope, requirements, and quality conditions. Table 2 exemplifies this process, one developed for each proposed skill with meta-learning. Table 3, based on Table 1, addresses the resulting competencies, including those in Table 2.

Table 2. Example of the formulation of competencies. Competency: meta-learning.

Component	Description
Capacity	The student develops autonomy ...
Purpose	... to build knowledge ...
Scope	... in their learning (meta-learning)...
Requirements	... and answering to the simulated challenges of the context ...
Quality conditions	... based on the information provided by others ...

Table 3. Formulated competencies from the admission profile.

Competency Name/Skill	Competency
Communication	The student uses written and oral language to communicate effectively, based on formal language and applying different tools.
Problem resolution	The student critically solves problems to achieve previously established goals based on their experience.
ICT knowledge	The student effectively uses ICT to gather information based on technical knowledge.
English knowledge	The student demonstrates an intermediate written and oral English level to communicate ideas effectively.
Meta-learning	The student develops autonomy in his/her learning (meta-learning) to build knowledge based on the information provided by others and answer to the simulated challenges of the context.

3.2. Graduation Profile

The graduation profile was built upon the domains, performance areas, and competencies. A BIM professional is expected to be able to conceive, design, project, plan, develop, analyze, coordinate, integrate and manage multidisciplinary projects developed in BIM in the field of architecture, engineering, and construction [35]. Furthermore, as public sector clients worldwide have already started to require BIM in their services and supply chains [36], they must be capable of developing in the academy and the private and public sectors.

Furthermore, the graduation profile should consider related specific competencies for a civil engineering program focused on BIM. The suggested related skills are design, coordination, and planning; ICT, BIM, and CDE software; application of concepts for project management; problem resolution; proposal of sustainable and integral solutions. Generic competencies should also be considered. Communication and teamwork are suggested related skills [37].

For the proposed skills, the student outcomes (SO) from the Accreditation Board for Engineering and Technology (ABET) [38] have been taken into consideration. In addition, the final report from Tuning-Alfa Project Latin America [1], which defines the generic and specific competencies for each higher education program, has also been reviewed.

The five (5) proposed skills were also transformed into competencies, as shown in Table 2. Table 4 addresses the resulting BIM-specific competencies.

Table 4. Formulated BIM-specific competencies from the graduation profile.

Competency Name/Skill	Competency
Design, coordination, and planning	The student consistently designs, effectively coordinates, and strategically plans the project and its information to conduct its development based on BIM.
Application of concepts for project management	The student applies the technical, contractual, economic, and financial concepts necessary for project management to contribute to its proper development and reach the client and project's goals.
ICT, BIM, and CDE software management	The student effectively manages ICT, BIM, and CDE to integrate a project's information based on technical knowledge.
Problem resolution	The student assertively solves project problems to ensure compliance with the work plan based on the recollection of the contribution of their peers.
Proposal of sustainable and integral solutions	The student proactively proposes sustainable and integral solutions in architecture, engineering, construction, operation, and maintenance to meet the needs of the present generation without compromising those of the future ones.

3.3. Training Areas and Subjects

Three (3) training areas for a BIM undergraduate curriculum have been identified: BIM Modelling Information, BIM Fundamentals, and Integrated and Collaborative Project Management. These BIM training areas should be correlated with the competencies of the graduation profile.

Regarding BIM Modelling Information, this area is designed to develop skills in the design, construction, operation, and management of BIM models, with graphic and non-graphic information, through the intensive use of ICT for conceiving digital models and generating documentation for a project file. BIM Fundamentals is designed for the teaching-learning of the essential concepts of the BIM methodology as a new construction paradigm. The knowledge includes standards and regulations, interoperability between platforms and models, and articulation between the documentation of a project and the BIM model. It also involves training in collaborative work, which is achieved through a practical workshop. Finally, Integrated and Collaborative Project Management is focused on understanding the design, construction, operation, and maintenance processes, their relationship with the BIM management process, and sustainability over time. Table 5 presents the proposed subjects for each area.

Table 5. BIM training areas and subjects.

Area	Subject
BIM Modelling Information	Architecture, Project File I, Engineering, Project File II, Planning and Schedules, Project File III, Costs and Budgets, Project File IV, Sustainability Management, Project File V
BIM Fundamentals	BIM Basic Concepts, BIM Workshop, Standards, and Regulations, Interoperability I, Interoperability II, Interoperability III
Integrated and Collaborative Project Management	BIM Constructive Processes, Costs Management, BIM Model Integration, Project Management Models, Sustainability Concepts

3.4. Study Plan

The study plan is organized into 5 (five) semesters to gradually train the competencies in accordance with the proficiency levels [14]. Therefore, semester I is associated with a pre-formal level; semester II, with a receptive level; semester III, with a basic level; semester IV, with an autonomous level; and semester V, with a strategic level. Each of the proposed competencies of the graduation profile is developed and reinforced in at least one subject per semester to guarantee this staggering. The proposed sequence also responds to the progression through the BIM maturity levels: BIM 3D, 4D, 5D, and 6D [39].

In fact, over the years, BIM has integrated different dimensions into its methodology. Beginning with the primary spatial dimensions (width, height, and depth) in a 3D BIM model, a fourth dimension was added, incorporating the variable "time", which refers to the planning or scheduling of a project, and is referred to as BIM 4D. Later, a fifth dimension, corresponding to the variable "cost" was added, known as BIM 5D. After that change, a sixth dimension was included, which answers to the variable "sustainability". This corresponds to BIM 6D [40].

Hence, within the study plan, semester I is related to BIM 3D at a basic level, which corresponds to architectural knowledge; semester II, with BIM 3D at an advanced level, corresponds to engineering knowledge. Later, semester III is focused on BIM 4D, planning and schedules; semester IV, on BIM 5D, costs and budgets; and semester V, with BIM 6D, sustainability. This progression may be observed in Figure 1.

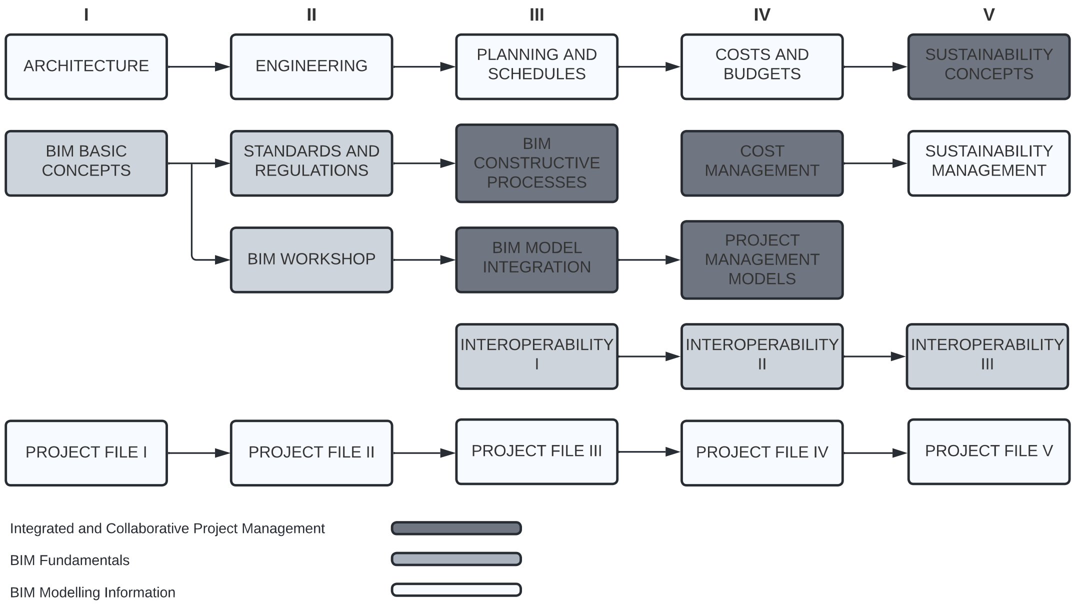

Figure 1. BIM curriculum with subjects and prerequisites.

A five-level sequence is suggested, even though most civil engineering programs in Latin America are developed within ten (10) semesters [1]. The reason is that the proposed methodology focuses on embedding BIM in an existing undergraduate curriculum, not developing a BIM program. Therefore, the proposed sequence is set to merge with another study plan. Therefore, curriculum managers should consider which subjects to include or not, according to the organization of the semesters.

Regarding the number of credits and the condition of the subjects, whether they are compulsory or optional, these questions should be addressed by the country's regulations and institutional policies. Finally, as for the prerequisites for the subjects, Figure 1 shows a suggested route. The subjects have been identified, in greyscale, according to the specific BIM training area to which they belong. For a particular curriculum proposal, these proposed subjects should also be correlated to the competencies of the graduation profile.

3.5. Teaching, Learning, and Assessment Methods

For the teaching and learning processes, active methods are preferred, encouraging the active participation of students towards the construction of their learning [39]. These help to develop and reinforce meta-learning, students' awareness of their strengths and weaknesses through the training process, and lifelong learning [41].

Methods like Project-Based Learning (PrBL) [42], Problem-Based Learning (PBL) [43], Research-Based Learning (RBL) [44], or Team-Based Learning (TBL) [45] are suggested. These enhance a learning-centered or constructivist pedagogical model, in which students have the main role in the training process while professors guide them to achieve shared knowledge construction [33,46]. These methods are also by current project management methodologies since they simulate the need for collaboration in BIM processes and improve educational outcomes [47].

As for the assessment methods, techniques and instruments used to make learning outcomes visible based on the competencies and expected results, they must be properly planned to correspond to a particular intention within the training process. It is recommended to use various techniques and instruments to assess each student properly according to their learning style (active, reflective, theoretical, or pragmatic) [48]. This guarantees the assessment of integral development through the four (4) attributions of competencies [14]. Techniques such as observation, exploration through questions, class exercises, portfolios, tests, written exams, projects, and exhibitions are suggested. In addition, instruments such as checklists, estimation scales, rubrics, and structured evaluation guides are recommended [48].

Specific teaching, learning, and assessment method selection will depend on microplanning [49,50] and the design of the sessions carried out by the professor in the classroom.

3.6. Technology and Infrastructure

The study plan is the starting point for determining the technology and infrastructure needed. Software and hardware are required in laboratories with computers for BIM collaborative sessions. The operating system, processor, available memory, RAM, graphic card, and monitor size and type should be considered.

3.7. 'Professors' Profile

The 'professors' profiles should correspond to the institutional and educational model, the context study, the admission and graduation profiles, the curriculum, the internal regulations, and the academic management policies of each institution. In addition, they should be built according to the generic and specific competencies required for a given profession, as well as the necessary prerequisites, such as studies and working experience [4]. Thus, the specific competencies should be related to each of the subjects of the curriculum.

In this context, the suggested generic competencies are collaborative work, communication, mediation of training, assessment of competencies, and management of resources and ICT. On the other hand, the specific ones are related to using BIM and collaborative platforms and knowledge in project management.

4. Discussion

The discussion addresses the implementation of the proposed methodology for embedding BIM in a particular existing undergraduate civil engineering competency-based curriculum. Therefore, a case study is presented.

4.1. Admission Profile

The admission profile for the civil engineering program is based on the fact that the applicant should have oral and written communication and problem-solving skills. Furthermore, they should be autonomous, with a high capacity for self-learning. In addition, they should have basic ICT knowledge, an intermediate English language level, and math and basic skills in the sciences.

Table 6 shows the formulated competencies for the admission profile, which match Table 3. Additionally, a competency regarding basic math and science knowledge has been added.

Table 6. Formulated competencies for the civil engineering admission profile.

Competency Name/Skill	Competency
Communication	The student uses written and oral language to communicate effectively, based on formal language and applying different tools.
Problem resolution	The student critically solves problems to achieve previously established goals based on their experience.
ICT knowledge	The student effectively uses ICT to gather information based on technical knowledge.
English knowledge	The student demonstrates an intermediate written and oral English level to communicate ideas effectively.
Basic math and science knowledge	The student pertinently applies math and basic sciences knowledge to solve problems based on analytical thinking.
Meta-learning	The student develops autonomy in his/her learning (meta-learning) to build knowledge based on the information provided by others and answer to the simulated challenges of the context.

4.2. Graduation Profile

The graduation profile of Universidad de Lima [51] states as follows:

The civil engineer has a solid background in mathematics and engineering sciences that allows him to respond with solvency and promptness to the challenges posed by the design, construction, supervision, operation, and maintenance of all types of infrastructure.

He has knowledge of philosophy, theories, principles, and technological tools to provide technically solid, creative, and innovative responses, emphasizing safety, quality, economy, and care for the environment within construction project management. Civil engineers have generic verbal and written communication, teamwork, and leadership competencies. In addition, he is aware of the need for continuous learning to quickly integrate and assume the global industry's requirements and modes of action. Finally, the ethical and moral solidity in the exercise of their profession is also characteristic of the civil engineer.

The graduation profile is completed by eight (8) generic and specific competencies, which are presented in Table 7.

4.3. Training Areas and Subjects

The civil engineering program is organized into seven (7) training areas: Engineering Sciences, Construction, Structures, Business Innovation, Project Management, Hydraulics, and Transport and Geotechnics, which develop and reinforce transversally the eight (8) proposed competencies from the graduation profile. Table 8 shows the interrelation between these training areas and their most predominant competencies.

Table 7. Competencies for the civil engineering graduation profile.

Type	Competency Name/Skill	Competency
Generic	Ethics and leadership	The student exercises leadership to guide others upon the changes and challenges of the context, based on ethical commitment and demonstrating honesty, integrity, and responsibility towards society and the environment.
	Teamwork	The student works with teams in multicultural and interdisciplinary environments to achieve common goals based on collaboration and effective oral and written communication.
	Research	The student develops research to build knowledge within the ambit of his profession based on the information available in the environment and answering the challenges of the context.
	Innovation	The student innovates to adapt to the market's requirements within the ambit of his profession, based on its specialization areas and introducing technological changes.
Specific	Design, coordination, and planning	The student creatively, innovatively, efficiently, and effectively creates designs, analyses, plans, builds, operates, and maintains civil engineering projects to fulfill the economic, social, ethical, political, and sustainability needs based on various tools.
	ICT, software, and technologies	The student effectively manages ICT, software, and new technologies to correctly model and interpret a project based on technical knowledge.
	Project management	The student actively assumes manager and technical roles to conduct the development of a project in all its stages based on project management fundamentals.
	Engineering knowledge	The student applies rigorously and integrally math, basic sciences, and engineering knowledge to solve problems within his professional exercise based on his performance.

Table 8. Interrelationship matrix between training areas and competencies from the civil engineering program.

Competency Name/Skill	Area						
	Engineering Sciences	Construction	Structures	Business Innovation	Project Management	Hydraulics	Transport and Geotechnics
Ethics and leadership				X	X		
Teamwork		X		X	X		
Research	X	X	X		X	X	X
Innovation		X		X	X		X
Design, coordination, and planning		X	X			X	X
ICT, software, and technologies	X	X	X		X	X	X
Project management				X	X		
Engineering knowledge		X	X			X	X

Regarding areas related to BIM, Table 9 presents the proposed BIM-related subjects for each of them.

Table 9. BIM-related training areas, subjects, and contents from the civil engineering program.

Area	Subject	Content
Construction	Graphical Engineering	Graphical Engineering is a theoretical-practical subject. Its purpose is to introduce the student to managing and representing geometric and volumetric elements. Its results contribute to developing skills to identify, formulate and solve geometric problems using engineering principles. The following thematic axes are developed: introduction to the graphic environment, geometric constructions, projections, and introduction to the architectural language.
	Building Information Modelling I	Building Information Modelling I is a theoretical-practical subject. Its purpose is to prepare the student for the management of building information. Its results contribute to developing skills to identify, formulate and solve complex problems using engineering principles. The following thematic axes are developed: representation of 3D elements, architectural and structural projects.
	Building Information Modelling II	Building Information Modelling II is a theoretical-practical subject. Its purpose is to prepare the student to manage building information through virtual construction, considering the national standards (RNE). Its results contribute to developing skills to identify, formulate, and solve complex problems using engineering principles. The following thematic axes are developed: structural project of reinforced concrete, structural steel, and structural steel projects.

Table 9. *Cont.*

Area	Subject	Content
	Construction Technology I	Construction Technology I is a theoretical-practical subject. Its purpose is for the student to understand the regulations, processes, and current technologies for building construction using virtual construction software. Its results contribute to developing skills to identify, formulate and solve complex problems using engineering principles. The following thematic axes will be developed: safety in construction works; use of the national building regulations as a control tool; construction processes of buildings; strategies for elaborating metrics; and the understanding, creation, and modeling of construction sequences.
	Construction Technology II	Construction Technology II is a theoretical-practical subject. Its purpose is for the student to understand the construction procedures of infrastructure projects and to recognize and calculate the performance of the machinery used. Its results contribute to developing skills to identify, formulate and solve problems by applying engineering principles. The following thematic axes will be developed: origin and formation of soils; soil as a construction material; control and performance of machinery; construction processes of infrastructure works (roads, bridges, tunnels, dams); and prestressed systems.
	Environmental Engineering	Environmental Engineering is a theoretical-practical subject. Its purpose is to facilitate the knowledge of concepts related to sustainable construction based on the application of sustainable development approaches to construction activities and infrastructure projects in general, in their various stages. Its results contribute to developing ethical and professional responsibility skills in engineering situations and making informed judgments in applying sustainable construction approaches. The following thematic axes are developed: environmental legislation, sustainable development, relative global concepts, global, national, and local environmental problems, sustainable construction, environmental impact studies, evaluation of environmental impact, and environmental management plans.
	Sanitary Engineering	Sanitary Engineering is a theoretical-practical subject. Its purpose is for the student to understand the importance of water for human consumption and its proper use in housing facilities, optimizing the design using virtual construction tools. Its results contribute to developing skills to identify, formulate and solve problems by applying engineering principles. The following thematic axes will be developed: water as the main resource; health services; water supply and drainage systems in buildings; fire protection systems; and sewage collection systems.
	Electro-mechanical Engineering	Electromechanical Engineering is a theoretical-practical subject. Its purpose is to impart design knowledge and basic calculation of electrical and electromechanical installations within a building. Its results contribute to developing skills to apply engineering designs to produce solutions that meet specific needs considering public health, safety, and well-being, as well as global, cultural, social, environmental, and economic factors. The following thematic axes are developed: direct current; alternating current in resistive, inductive, and capacitive circuits; power factor compensation; electrical installations in single-phase circuits, as well as reading plans and their symbols; demand factors and maximum demand; driver selection; and the one-line diagram.
	Sustainable Infrastructure	Sustainable Infrastructures is a theoretical-practical subject. Its purpose is to prepare the student to manage intelligent systems and energy optimization in the different infrastructures aiming at international certifications. Their results contribute to developing skills to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and social contexts. The following thematic axes are developed: sustainable infrastructures, energy management, energy optimization, and self-sustainable structures.
Structures	Reinforced Concrete I	Reinforced Concrete I is a theoretical-practical subject. Its purpose is for the student to analyze and design reinforced concrete elements by applying equilibrium concepts, deformation compatibility, constitutive laws, and the corresponding design standards. Its results contribute to developing skills to apply engineering designs to produce solutions that meet specific needs considering public health, safety, and well-being, as well as global, cultural, social, environmental, and economic factors. The following thematic axes are developed: analysis and design of elements that are part of a building, such as slabs, beams, foundations, and columns.
	Structural Analysis I	Structural Analysis I is a theoretical-practical subject. Its purpose is for the student to understand and apply the main concepts, foundations, and principles of structural analysis in isostatic and hyperstatic systems. Its results contribute to developing skills to identify, formulate and solve complex engineering problems by applying engineering, science, and mathematics principles. The following thematic axes are developed: analysis of geometric stability in reinforcements, energy methods for calculating displacements in isostatic systems, slope-deflection method, force method, moment distribution method, and introduction to the formulation of matrix analysis using the rigidity method.
	Reinforced Concrete II	Reinforced Concrete II is a theoretical-practical subject. Its purpose is for the student to analyze and design foundations, slabs, and seismic-resistant structures. Its results contribute to developing skills to apply engineering designs to produce solutions that meet specific needs considering public health, safety, and well-being, as well as global, cultural, social, environmental, and economic factors. The following thematic axes are developed: use of current standards; design of shallow and deep foundation structures, retaining walls, structural walls, reinforced slabs in two directions; stair design; and seismic resistant structural design and configuration.
	Structural Analysis II	Structural Analysis II is a theoretical-practical subject. Its purpose is for the student to perform modeling and structural analysis based on matrix techniques. Its results contribute to developing skills to identify, formulate and solve complex engineering problems by applying engineering, science, and mathematics principles. The following thematic axes are developed: matrix formulation of reticular elements, framed systems, modeling of shear walls, pseudo-three-dimensional analysis, introduction to finite elements, and introduction to non-linear analysis.
	Earthquake Engineering	Earthquake Engineering is a theoretical-practical subject. Its purpose is to develop the student's ability to seismically analyze and design buildings of various materials, considering current regulations. Its results contribute to developing skills to apply engineering designs to produce solutions that meet specific needs considering public health, safety, and well-being, as well as global, cultural, social, environmental, and economic factors. The following thematic axes are developed: seismology and seismic risk, dynamic analysis of systems with one degree of freedom, seismic response of systems with several degrees of freedom, and seismic-resistant structural criteria.

Table 9. *Cont.*

Area	Subject	Content
	Prestressed Concrete	Prestressed Concrete is a theoretical-practical subject. Its purpose is for the student to analyze and design prestressed and post-stressed elements. Its results contribute to developing skills to apply engineering designs to produce solutions that meet specific needs considering public health, safety, and well-being, as well as global, cultural, social, environmental, and economic factors. The following thematic axes are developed: advantages and application of prestressed and post-stressed concrete, construction materials and procedures, analysis and design of isostatic and hyperstatic structures, loss of tension, resistance to flexion and shear stress, routing of cables and unbonded cable structures, slabs post-tensioned in two directions, and types of deflections.
	Bridges	Bridges is a theoretical-practical subject. Its purpose is to develop bridge prediction, analysis, and design capabilities. Its results contribute to developing skills to apply engineering designs to produce solutions that meet specific needs considering public health, safety, and well-being, as well as global, cultural, social, environmental, and economic factors. The following thematic axes are developed: basic studies: geological, topographic, hydrological, and others; basic design conditions, loads, and load factors; design of reinforced concrete bridges: slab, deck, and beams; design of composite section bridges, design of support elements and design of gravity and cantilever abutments; design of arch and cable-stayed bridges; prestressed concrete bridges; and construction processes, social and environmental impact.
	Metal and Wooden Structures	Metal and Wood Structures is a theoretical-practical subject. Its purpose is to develop the skills of prediction, analysis, and creativity in designing steel and wooden structures. Its results contribute to developing skills to apply engineering designs to produce solutions that meet specific needs considering public health, safety, and well-being, as well as other factors. The following thematic axes are developed: steel; analysis and design of structural steel elements in tension, compression, and flexo-compression; steel element connections; wood and its structural use; treatment of wood and its properties; and maintenance of wooden and steel structures.
Project Management	Construction Project Management I	Construction Project Management I is a theoretical-practical subject. Its purpose is to introduce the student to the knowledge and development of construction project management skills, using the Lean principles associated with a model integrated with BIM and developing the knowledge areas of scope, schedule, cost, quality, risks, and interest. Its results contribute to developing leadership and work skills in a collaborative environment, establishing goals, planning tasks, and setting objectives. The following thematic axes are developed: introduction to project management; project life cycle; project management processes; initiation, planning, implementation, monitoring, and control; and closure of the integrated model.
	Construction Project Management II	Construction Project Management II is a theoretical-practical subject. Its purpose is to consolidate in the student the knowledge and skills of cost and schedule management, relating them to Lean Construction fundamentals and using computer tools. Its results contribute to developing skills to work effectively in a team whose members provide leadership within a collaborative environment, designing management plans and setting objectives. The following thematic axes are developed: scope of the project, estimation and control of costs, estimation of resources and duration of activities, programming methods, fundamentals of Lean Construction, BIM 4D (schedule), and BIM 5D (costs).
	Operation and Maintenance Project Management	Operation and Maintenance Project Management is a theoretical-practical subject. Its purpose is to facilitate the knowledge of procedures and protocols necessary for the management of operation and maintenance projects, as well as the use of tools for their management and control, to develop skills for decision-making in project management based on indicators reflected in control panels. Its results contribute to developing leadership and work skills in a collaborative environment. The following thematic axes are developed: definition and conception of operation and maintenance projects; scope, risk, time, and cost management; analysis and measurement of productivity; development of control panels; public-private management model; a workshop for analysis and resolution of theoretical and practica cases.
	Lean Philosophy	Lean Philosophy is a theoretical-practical subject. Its purpose is to strengthen the student's knowledge of the Lean philosophy by recognizing their contributions to solving problems. Its results contribute to developing skills to work effectively in a team whose members provide leadership within a collaborative environment, designing management plans and setting objectives. The following thematic axes are developed: philosophy, technology, and culture; Lean theory; product development and design management; Last Planner System; production control systems; value creation; construction losses; Lean Construction approaches; and BIM as a management complement.
	Quality Management	Quality Management is a theoretical-practical subject. Its purpose is that the student understands the main concepts and fundamentals of quality management. Its results contribute to developing leadership and work skills in a collaborative environment, setting goals, planning tasks, and setting objectives. The following thematic axes are developed: history of quality, applied statistics, standards, and management tools.
	Virtual Design and Construction I	Virtual Design and Construction I is a theoretical-practical subject. Its purpose is to initiate the student into the knowledge of the Virtual Design and Construction (VDC) Methodology, which provides a framework for collaboration between Integrated Concurrent Engineering (ICE), Building Information Modeling (BIM), and Project Production Management (PPM), involving organizations, systems, information, and processes. Its results contribute to developing leadership and work skills in a collaborative environment, setting goals, planning tasks, and setting objectives. The following thematic axes are developed: introduction to the VDC Framework, Product-Organization-Process Matrix (POP), metrics, controllable factors, Integrating Project Delivery (IPD), ICE, BIM, and PPM.
	Virtual Design and Construction II	Virtual Design and Construction II is a theoretical-practical subject. Its purpose is to consolidate in the student the knowledge about the implementation of the Virtual Design and Construction (VDC) Methodology, which provides a framework for collaboration between Integrated Concurrent Engineering (ICE), Building Information Modeling (BIM), and Project Production Management (PPM), involving organizations, systems, information, and processes. Its results contribute to developing leadership and work skills in a collaborative environment, setting goals, planning tasks, and setting objectives. The following thematic axes are developed: VDC Framework, Product-Organization- Process Matrix (POP), metrics, controllable factors, Integrating Project Delivery (IPD), ICE, BIM, PPM, Lean and collaborative contracts.

Table 9. *Cont.*

Area	Subject	Content
	Strategic Contract Management	Strategic Contract Management is a theoretical-practical subject. Its purpose is to facilitate the knowledge of procedures and protocols necessary for the contractual management of projects and use tools to control them. Its results contribute to developing leadership and work skills in a collaborative environment, setting goals, planning tasks, and setting objectives. The following thematic axes are developed: modality of execution and contracting system; types of tender and stages of the tender process; contract structure; analysis and interpretation of the different types and modalities of contracts; management of contractual risks, changes, and additions, term extensions, disputes and arbitration; the liquidation of work; and preparation of the dossier.
	Occupational Health and Safety Management	Occupational Health and Safety Management is a theoretical subject. Its purpose is to promote a culture of preventing accidents, incidents, and diseases through understanding the main concepts of occupational health and safety management at work in accordance with current legal regulations. Its results contribute to developing skills to communicate effectively with various audiences to mitigate occupational risks. The following thematic axes are developed: fundamentals of occupational health; legal requirements, application, and scope of current laws; occupational health and safety management system; risk factors, rights, and obligations of the parties involved in the civil engineering project; and risk analysis and assessment, occupational health, and safety policies and procedures.
	Disaster Risk Management	Disaster Risk Management is a theoretical-practical subject. Its purpose is to provide the student with the knowledge to prevent and reduce the impact of natural phenomena on an exposed population, their livelihoods, and their heritage. Its results contribute to developing leadership and work skills in a collaborative environment, setting goals, planning tasks, and setting objectives. The following thematic axes are developed: policies, regulations, resilient infrastructures, natural threats, environmental and technological disasters, prevention, contingency, emergency, urgency, and rehabilitation plans.
	Project Risk Management	Project Risk Management is a theoretical-practical subject. Its purpose is to facilitate the development of decision-making skills regarding time and cost objectives, mainly based on managing uncertainties and risk management inherent to any construction project. Its results contribute to developing leadership and work skills in a collaborative environment, setting goals, planning tasks, and setting objectives. The following thematic axes are developed: building and infrastructure projects, financial and economic balance, problems of works, methods for managing uncertainties, risk management processes, qualitative and quantitative risk analysis, synergy, uncertainties and risks, and strengthening of decisions in the management of construction projects.
	Real Estate Management and Development	Real Estate Management and Development is a theoretical-practical subject. Its purpose is to facilitate the knowledge of procedures and protocols necessary for the management and development of real estate projects, as well as the use of analysis and control tools for these. Its results contribute to developing leadership and work skills in a collaborative environment, setting goals, planning tasks, and setting objectives. The following thematic axes are developed: legal framework, legislation, social and environmental responsibility, team management, accounting, finance, planning, budgets, execution, productivity, construction systems, quality, urban management, and marketing.
Hydraulics	Hydraulics	Hydraulics is a theoretical-practical subject. Its purpose is for the student to solve hydraulic problems and achieve its applicability in infrastructure projects. Their results contribute to developing skills to identify, formulate and solve fluid problems by applying engineering, science, and mathematics principles. The following thematic axes are developed: flow and design in open channels, the principle of energy and moment, critical flow, gradually varied flow, rapidly varied flow, design of hydraulic structures, and irrigation and drainage systems.
	Water Supply and Sanitation	Water and Sanitation Management is a theoretical-practical subject. Its purpose is for the student to formulate and execute water supply and sanitation projects and achieve their applicability in infrastructure projects. Its results contribute to developing skills to apply engineering designs to produce solutions that meet specific needs considering public health, safety, and well-being, as well as global, cultural, social, environmental, and economic factors. The following thematic axes are developed: design parameters, supply sources, conduction and distribution lines, design flows, hydromechanical equipment, water system, sewage system, wastewater treatment, and vulnerability analysis.
	Hydrology	Hydrology is a theoretical-practical subject. Its purpose is for the student to determine the design flow from modeling the hydrological cycle and achieve its applicability in infrastructure projects. Its results contribute to developing skills to apply engineering designs to produce solutions that meet specific needs considering public health, safety, and well-being, as well as global, cultural, social, environmental, and economic factors. The following thematic axes are developed: hydrological cycle, hydrographic basin, meteorology, precipitation, statistical models, infiltration, evaporation, evapotranspiration, hydrograph, transit, flow, hydrogeology, stochastic models, and artificial intelligence.
	Hydraulic and Water Resources Engineering	Hydraulic Resources Engineering is a theoretical-practical subject. Its purpose is for the student to formulate and execute hydraulic resource projects based on the law and economics of water and achieve its applicability in infrastructure projects. Its results contribute to developing skills to apply engineering designs to produce solutions that meet specific needs considering public health, safety, and well-being, as well as global, cultural, social, environmental, and economic factors. The following thematic axes are developed: the right to water, the economics of water, planning, formulation, hydraulic systems, costs and budgets, and economic evaluation of hydraulic projects.
Transportation and Geotechnics	Geology	Geology is a theoretical-practical subject. It aims to facilitate the recognition of the global processes of the planet for the adequate understanding of the geological phenomena that occur in it, identifying the role of the Civil Engineer with said processes. Its results contribute to developing skills to identify geological problems and propose general solutions based on the identification, formulation, and resolution of engineering, science, and mathematics problems with the knowledge acquired. The following thematic axes are developed: introduction and fundamental concepts, minerals, rocks, crustal deformation, geological time, geological phenomena, hydrosphere, and geological environments.
	Surveying	Surveying is a theoretical-practical subject. Its purpose is to facilitate the knowledge of reference systems, coordinates and datums, operation and use of distance measurement instruments, angular measurements, and the GPS system. It proposes to carry out the compensation of networks through the observation equations of the geodetic or base magnitudes of the GPS, as well as the representation and the cartographic systems used in Peru, making use of software and digital tools. Their results contribute to developing skills to conduct appropriate experiments, analyze and interpret data, and use engineering judgments to conclude. The following thematic axes are developed: geodesy, geographic information systems, instruments for measuring distances and angles, statistics and theory of dead reckoning, compensation of a network, and cartography.

Table 9. *Cont.*

Area	Subject	Content
	Soil Mechanics I	Soil Mechanics I is a theoretical-practical subject. Its purpose is to provide knowledge about the fundamental properties of soils and their implications in the design and construction of engineering works. Their results contribute to developing skills to conduct appropriate experiments, analyze and interpret data, and use engineering judgments to conclude. The following thematic axes are developed: origin and characteristics of soil deposits; index properties, granulometry and plasticity, classification and identification of soils; hydraulic properties of soils; soil compaction; consolidation and settlement of cohesive soils; and shear resistance of soils. The subject is accompanied by laboratory activities such as standard and special essays.
	Geomatics	Geomatics is a theoretical-practical subject. Its purpose is to provide knowledge about the modalities of georeferenced data acquisition and geographic information systems, cadastral cartography and its updating, unmanned aerial vehicles, and laser scanning using software and digital tools. Its results contribute to developing skills to identify, formulate and solve problems in acquiring georeferenced data and the means used for this purpose, applying engineering, science, and mathematics principles. The following thematic axes are developed: georeferenced data, geographic information systems, cartography, unmanned aerial vehicles, and laser scanning.
	Soil Mechanics II	Soil Mechanics II is a theoretical-practical subject. Its purpose is to provide theoretical and practical knowledge about the behavior of the soil for its application in solving problems related to its interaction with civil engineering works. Its results contribute to developing skills to design environmentally responsible engineering solutions. The following thematic axes are developed: earth pressure and slope stability, sizing of retaining and support walls, superficial and deep foundations, dynamic effects on foundations, and soil improvement.
	Transportation Engineering I	Transportation Engineering I is a theoretical-practical subject. Its purpose is to provide the tools for the design of a highway according to current Peruvian standards. Its results contribute to developing skills to apply engineering designs to produce solutions that meet specific needs considering public health, safety, and well-being, as well as global, cultural, social, environmental, and economic factors. The following thematic axes are developed: description, road classification, vehicle measurement standards, environmental, topographic, geological, hydrological, and hydraulic considerations, earthworks, and geometric layout and design.
	Transportation Engineering II	Transportation Engineering II is a theoretical-practical subject. It aims to develop student investigative capacities for understanding and generating knowledge, applying qualitative and quantitative methods and techniques. Its results contribute to developing skills to apply engineering designs to produce solutions that meet specific needs considering public health, safety, and well-being, as well as global, cultural, social, environmental, and economic factors. The following thematic axes are developed: transportation planning, service levels, signalized and non-signalized intersections, traffic studies, road impact studies, mass transit systems, urban mobility, road safety, and systems of intelligent transport.
	Geotechnics for Transportation Infrastructure	Geotechnics in Transport Infrastructure is a theoretical-practical subject. Its purpose is for students to apply theoretical and practical knowledge of geotechnics in solving problems related to transportation infrastructure. Its results contribute to developing skills to design engineering solutions with an economic, social, and environmental approach. The following thematic axes are developed: evaluation of quarries, characterization of subgrades, embankments, slope stability, retaining walls, and soil stabilization.
	Pavements	Pavements is a theoretical-practical subject. Its purpose is for the student to apply the theoretical and practical knowledge of pavement technology in solving problems related to road infrastructure. Its results contribute to developing skills to design engineering solutions with an economic, social, and environmental approach. The following thematic axes are developed: introduction to pavement engineering, design parameters, structural design of flexible and rigid pavements, and design of asphalt mixes.
	Tunnels	Tunnels is a theoretical-practical subject. Its purpose is for the student to apply geomechanics knowledge in designing and constructing tunnels. Its results contribute to developing skills to design engineering solutions with an economic, social, and environmental approach. The following thematic axes are developed: introduction to tunnel design and construction, geomechanical aspects, design and support methods, construction procedures, instrumentation and control, and urban tunnels.

4.4. Study Plan

The study plan is organized into 10 (ten) semesters, distributed over 5 (five) years of studies. The first year corresponds to introductory subjects, called “the general studies program”, in which civil engineering students share the classroom with future professionals in various fields. From the second to the fifth year, the students are enrolled in subjects specific to their degree.

Generic competencies are trained in the first semester, but specific ones are in the third. Table 10 addresses the interrelationship between the expected proficiency level and subject for every generic competency of the graduation profile, while Table 11 does this with the specific ones. Only the BIM-related subjects which correspond to the Construction, Structures, Project Management, Hydraulics, Transportation and Geotechnics, and Project Management training areas are included.

There are gaps within Tables 10 and 11 regarding the five (5) proficiency levels because these levels are addressed within the subjects that are not detailed in the mentioned tables. Furthermore, even though Table 8 states which competencies are developed and reinforced within the training areas, only some subjects within that particular training area focus on developing and reinforcing all of the mentioned competencies. The entire civil engineering curriculum, with all the subjects, their condition, number of credits, and prerequisites, is shown in Figure 2. BIM-related subjects, mandatory and elective, have been pointed out in grey.

Table 10. Interrelationship matrix with proficiency levels between subjects and generic competencies from the civil engineering program [2].

Semester	Subject	Generic Competency			
		Ethics and Leadership	Teamwork	Research	Innovation
III	Graphical Engineering		P	P	
	Geology		P	P	
IV	Building Information Modelling I		R	R	
	Surveying			R	P
V	Building Information Modelling II		R	B	P
	Environmental Engineering		R	B	P
	Construction Technology I		R	B	P
	Soil Mechanics I			B	P
	Geomatics			B	P
VI	Construction Technology II		B	B	R
	Sanitary Engineering		B	B	R
	Construction Project Management I	B	B	B	R
	Soil Mechanics II			B	R
VII	Construction Project Management II		B	A	B
	Electromechanical Engineering		B	A	B
	Transportation Engineering I			A	B
VIII	Operation and Maintenance Project Management	A	A	A	A
	Lean Philosophy		A	A	
	Virtual Design and Construction I	A	A	A	A
	Quality Management	A	A	A	A
	Transportation Engineering II			A	A
	Geotechnics for Transportation Infrastructure			A	A
	Hydraulics			A	
	Water Supply and Sanitation			A	
	Reinforced Concrete I			A	
	Structural Analysis I			A	
IX	Virtual Design and Construction II	A	A	S	S
	Strategic Contract Management	A	A	S	
	Occupational Health and Safety Management	A	A	S	
	Pavements			S	S
	Hydrology			S	
	Reinforced Concrete II			S	
	Structural Analysis II			S	
	Earthquake Engineering		A	S	
	Prestressed Concrete			S	
X	Sustainable Infrastructure			S	S
	Disaster Risk Management	S	S	S	
	Project Risk Management	S	S	S	
	Real Estate Management and Development	S		S	
	Tunnels			S	S
	Hydraulic and Water Resources Engineering			S	S
	Bridges			S	S
	Metal and Wooden Structures			S	S

[2] Note: P = Pre-formal, R = Receptive, B = Basic, A = Autonomous, S = Strategic.

Table 11. Interrelationship matrix with proficiency levels between subjects and specific competencies from the civil engineering program [3].

Semester	Subject	Specific Competency			
		Design, Coordination, and Planning	ICT, Software, and Technology	Project Management	Engineering Knowledge
III	Graphical Engineering	P	P		
	Geology		P		P
IV	Building Information Modelling I	P	R		P
	Surveying	P	R		P
V	Building Information Modelling II	R	R		R
	Environmental Engineering	R			R
	Construction Technology I	R	R		R
	Soil Mechanics I	R	R		R
	Geomatics	R	R		R
VI	Construction Technology II	B	B		B
	Sanitary Engineering	B	B		B
	Construction Project Management I		B	P	
	Soil Mechanics II	B	B		B
VII	Construction Project Management II		B	R	
	Electromechanical Engineering	A	B		B
	Transportation Engineering I	A	B		B
VIII	Operation and Maintenance Project Management		A	B	
	Lean Philosophy		A	B	
	Virtual Design and Construction I	A	A	B	
	Quality Management		A	B	
	Transportation Engineering II	A	A		A
	Geotechnics for Transportation Infrastructure	A	A		A
	Hydraulics	A	A		A
	Water Supply and Sanitation	A	A		A
	Reinforced Concrete I	A	A		A
	Structural Analysis I	A	A		A
IX	Virtual Design and Construction II	S	S	A	
	Strategic Contract Management			A	
	Occupational Health and Safety Management			A	
	Pavements	S	S		S
	Hydrology	S	S		S
	Reinforced Concrete II	S	S		S
	Structural Analysis II	S	S		S
	Earthquake Engineering	S	S		S
	Prestressed Concrete	S	S		S
X	Sustainable Infrastructure	S			S
	Disaster Risk Management		S	S	S
	Project Risk Management		S	S	S
	Real Estate Management and Development			S	
	Tunnels	S	S		S
	Hydraulic and Water Resources Engineering	S	S		S
	Bridges	S	S		S
	Metal and Wooden Structures	S	S		S

[3] Note: P = Pre-formal, R = Receptive, B = Basic, A = Autonomous, S = Strategic.

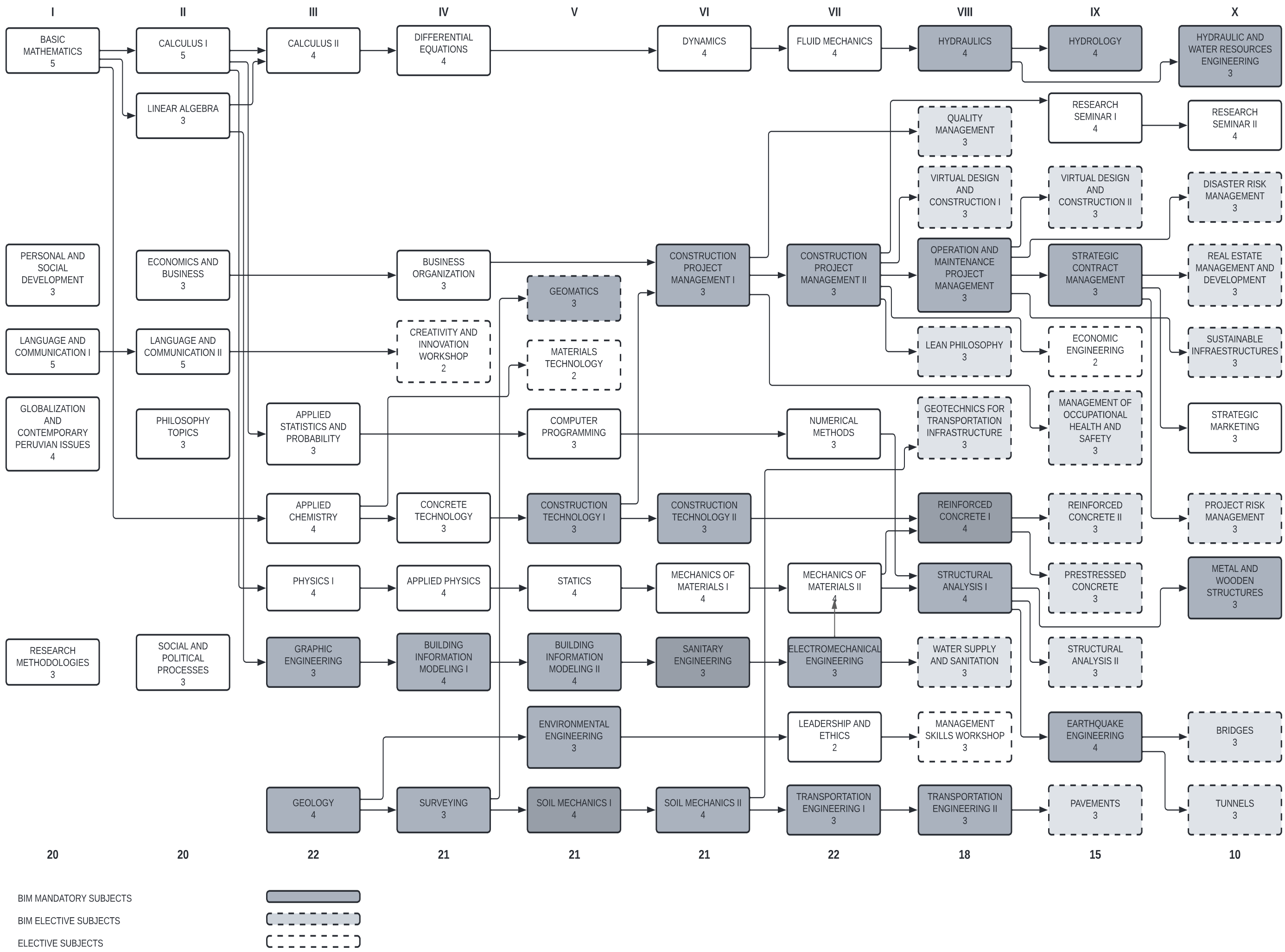

Figure 2. Civil engineering curriculum with subjects and prerequisites. Adapted from Universidad de Lima [51].

4.5. Teaching, Learning, and Assessment Methods

In line with the learning-centered or constructivist pedagogical model, active methods are preferred for the sessions. The assessment methods respond to it.

ICT, software, CDE, and technologies, such as virtual reality or drones, stand out. Students are exposed to various of these early in the program. Methods like PrBL, PBL, and TBL are used within the classroom. Micro-planning is developed within one-hour coordination sessions between all the professors of each subject, which take place weekly. Additionally, RBL is used throughout the entire curriculum according to the Gradual Implementation Research Competencies (GIRC) Program [5].

4.6. Technology and Infrastructure

The civil engineering program has a specialized laboratory where students can study and research the following areas: BIM, photogrammetry, virtual and augmented reality, virtual design and construction, and artificial intelligence applied to civil construction. The laboratory is fully equipped with high-performance computers and cutting-edge technology. Additionally, the laboratory was designed to promote integrated and collaborative work between students and professors, creating a friendly non-formal learning environment that encourages creativity and innovation, as seen in Figure 3.

Figure 3. Laboratory of *Simulación de Proyectos*.

4.7. 'Professors' Profile

The 'professors' profiles were defined according to the generic and specific competencies to develop and reinforce each subject. In addition, the suggested generic teaching competencies (collaborative work, communication, mediation of training, assessment of competencies, and management of resources and ICT) were also considered.

5. Conclusions

As a result of the civil engineering program, with BIM embedded transversally throughout the curriculum, it can be observed that the number of students had grown from 139 (in 2017, when the program was launched) to 1041 (in 2022). This represents a stable increase for six consecutive years, as shown in Figure 4.

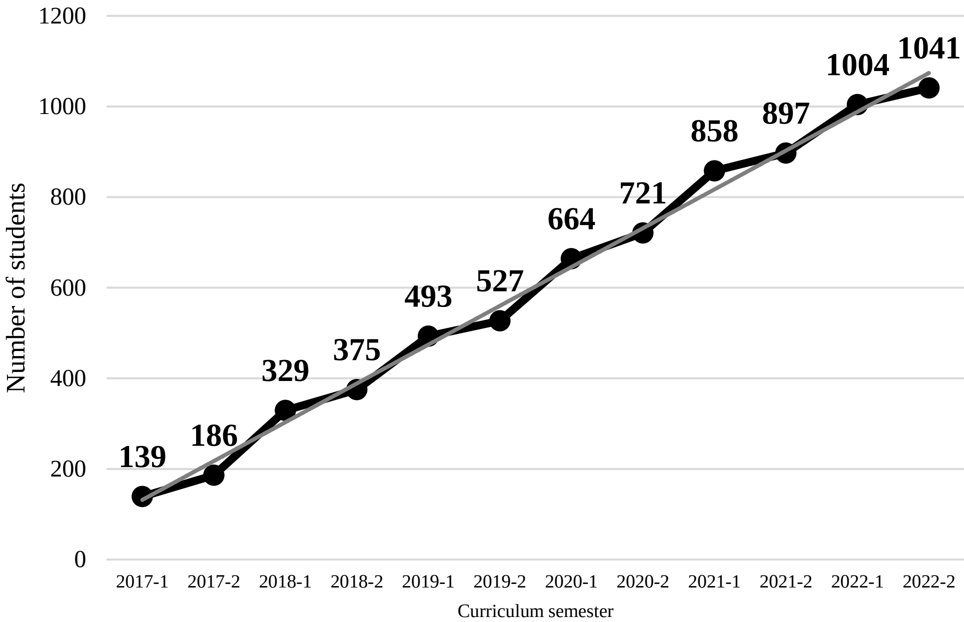

Figure 4. The number of students per semester within the civil engineering program.

Furthermore, from the first group of graduated students (33 bachelor's degrees), who finished their studies in December 2021 and graduated in July 2022, 90.91% (30 bachelor's degrees) are currently employed within the first year of finishing their studies. Likewise, the second group of students finished their studies in July 2022 but still await degree conferral, from which 65.38% (17 students) are employed, as shown in Figure 5. These students anticipate bachelor's degrees by December 2022, when they finally graduate.

The employment rates reveal a positive reception and recognition within the group of stakeholders, as the employers are transnational, international, and well-recognized national companies of the AECO industry who consider BIM-trained B.S. graduates among their recruitment options. Additionally, some of the most common positions occupied by the graduates are BIM Modeler, Assistant, Supervisor, or Coordinator, which also reveals the industry's need for this professional.

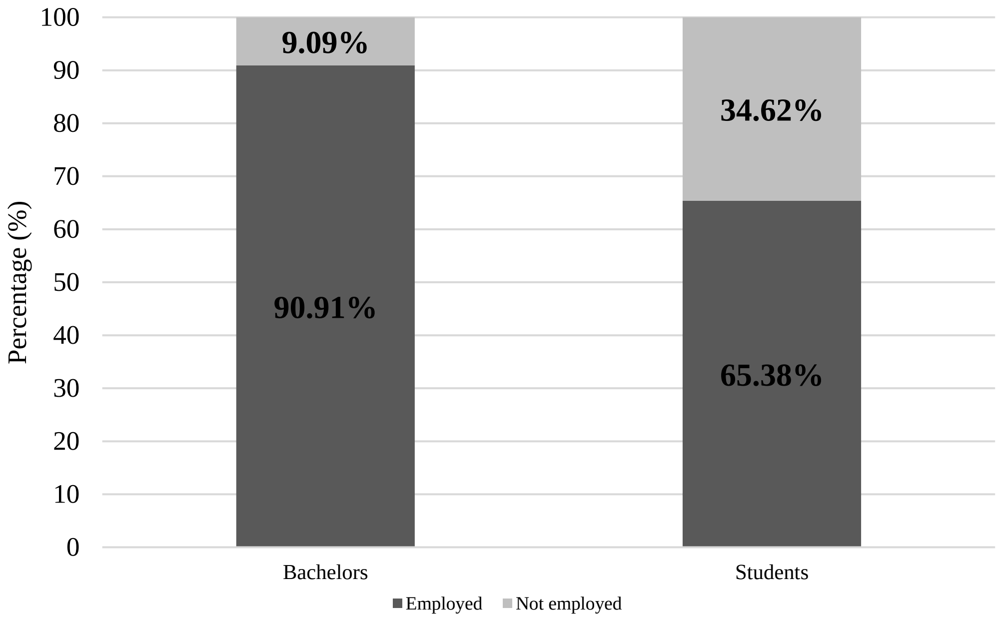

Figure 5. Percentage of employed B.S. graduates (December 2021) and students (July 2022) from the civil engineering program.

The interest in research and innovation has increased similarly as the civil engineering program has progressed. The program has established academic alliances with major national and international organizations, such as the Stanford Center for Professional Development, the Global Resilience Institute, the *Instituto Nacional de Defensa Civil* of the Peruvian Ministry of Defense, and the *Instituto Nacional de Calidad* of the Peruvian Ministry of Production, among others. These positive results validate the curriculum proposal since they show its visibility in the AECO industry.

However, the above was only possible with the appropriate dissemination activities to show the potentialities and differentials of the implemented curricular design with BIM embedded transversally. Workshops, presentations, conferences, and proper marketing have been a key support to this task. Since its launch in 2017, the civil engineering program has been attractive to the AECO industry due to its innovative BIM approach, which is well connected with VDC [52].

The literature review and experienced industry managers elaborated the curriculum's design, with stakeholders invited to validate it. Furthermore, the presented curriculum design has been permanently improved according to the changing needs of the AECO industry. Therefore, future works may apply the methodology for embedding BIM in other AECO programs, such as architecture and industrial engineering.

Furthermore, this paper focuses on macro-planning, and further research may include micro-planning, reporting specific ambits within the training areas and particular subjects. Embedding BIM within the Construction training area and its corresponding subjects, as addressed in Table 9, including the mechanisms designed, implemented, and assessed to develop and consolidate BIM-related competencies in undergraduate students, is a matter for further research, including students' perception of the development and reinforcement of BIM-related competencies.

Finally, considering that BIM supports generating graphic and non-graphic information within the context of a project, the presented curricular approach should be complemented with proper training in process and organization management. The presented civil engineering program attains this training by incorporating VDC in the curricular design, which will be addressed in a future paper.

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