

Adapting engineering education to BIM and industry 4.0: A view from Kolb's experiential theory in the laboratory

*Adaptar la educación en ingeniería al BIM y a la Industria 4.0:
Una visión desde la teoría experiencial de Kolb en el laboratorio*

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ABSTRACT

Currently, the industry is undergoing a transformation toward intelligent manufacturing processes and complete digitization, emerging new information and communication technologies, such as cybersecurity, the internet of things, Big Data, and cloud computing, among others, concepts that are driving forces of the so-called Fourth Industrial Revolution, what is commonly known as Industry 4.0; and due to the implementation of technology in the construction industry, the Building Information Modeling (BIM) methodology arises, proposing new solutions for the work system during the entire building life cycle. An important part of the tasks in preparing for Industry 4.0 and BIM is adjusting engineering education to the requirements of this vision. The objective of this research is to present a proposal for the engineering educator, which consists of how engineering education should be adjusted towards BIM and industry 4.0 from the laboratory, relating Kolb's experiential learning theory, teaching methodologies-learning, and the CDIO (Conceive - Design - Implement - Operate) initiative, resulting in an improvement in the learning environment and in the teaching-learning process that maximizes the competencies of students when learning through their own experience. Finally, this research is the first step towards a more tangible vision of engineering education adapted to BIM and Industry 4.0.

Keywords: BIM, industry 4.0, engineering education, laboratory, teaching-learning, Kolb.

RESUMEN

Actualmente, la industria está experimentando una transformación hacia los procesos de fabricación inteligente y digitalización completa, surgiendo nuevas tecnologías de información y comunicación, tales como ciberseguridad, internet de las cosas, Big Data, computación en la nube, entre otros, conceptos que son impulsores de la llamada Cuarta Revolución Industrial, lo que comúnmente se conoce como Industria 4.0; y debido a la implementación de la tecnología en la industria de la construcción, es que surge la metodología Building Information Modeling (BIM), proponiendo nuevas soluciones para el sistema de trabajo durante todo ciclo de vida de edificación. Una parte importante de las tareas en la preparación para la Industria 4.0 y el BIM es el ajuste de la educación en ingeniería a los requisitos de esta visión. El objetivo de esta investigación es presentar una propuesta para el educador de ingeniería, que consta de cómo se debería ajustar la educación en ingeniería hacia el BIM y la industria 4.0 desde el laboratorio, relacionando la Teoría de aprendizaje experiencial de Kolb, las metodologías de enseñanza-aprendizaje y la iniciativa CDIO (Conceive - Design - Implement - Operate), dando como resultado una mejora en el entorno de aprendizaje y en el proceso de enseñanza-aprendizaje que maximizan las competencias de los alumnos al aprender a través de su propia experiencia. Siendo finalmente esta investigación, un primer paso hacia una visión más tangible de la educación en ingeniería adaptada al BIM y a la Industria 4.0.

Palabras clave: BIM, industry 4.0, engineering education, laboratory, teaching-learning, Kolb.

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INTRODUCTION

Engineering education strongly connects with global economic and social development [1]. This connection is why research has been conducted to align engineering education with the socioeconomic needs of a region, indicating that an engineer requires strong skills in human relations associated with knowledge of contemporary engineering and industrial sciences [2-5]. In addition, the important challenge of engineering education for access to practical experiences in real contexts [6, 7]. In Latin America, higher education pedagogical practices must be transformed to achieve a balance between social skills, knowledge of science, and technical training.

On the one hand the concept of Building Information Modeling (BIM) is defined according to the National Institute of Construction Sciences [8], as the act of creating an electronic model of an installation with the purpose of visualization, energy analysis, conflict analysis, criteria verification key, cost engineering, obtaining products according to the actual execution “as-built,” budget, and others. On the other hand, the BIM concept is defined as the digital representation of an installation’s physical and functional characteristics. Furthermore, it serves as a source of shared knowledge for information about the facility, forming a trusted basis for decision-making throughout its lifecycle from the beginning onward.

In summary, BIM can be identified as a modern construction management process that allows users to create parametric models based on multidimensional objects that are the tool to manage construction projects throughout their life cycle [9-12] and to carry out the process, various computer tools and methods are used. That is why two main groups can be distinguished in BIM projects: tools and methodology [13]. In the group of tools is the different software. Furthermore, the methodology is more complex, since it establishes how the tools interact, how they should be used by users and how users interact with each other.

Today, BIM represents great innovation in the construction industry with the introduction of Information and Communication Technologies (ICT), which is the great revolution in the traditional

construction sector [14-16]. The BIM methodology is spreading worldwide with the promise of much better, more efficient, and higher quality construction projects, with a very positive impact on reducing project life cycle costs.

On the other hand, The Industry 4.0 concept was born under the initiative carried out by academics, industrialists, and the German government to strengthen the competitiveness of the manufacturing sector through the convergence between industrial production and information and communication technologies (ICT) [17-19]. It makes use of technologies such as the Internet of Things (IoT), Cyber-Physical Systems (CPS), industrial automation, connectivity, and continuous information, cybersecurity, intelligent robotics, Product Lifecycle Management (PLM), semantic technologies, industrial Big Data, virtual reality, intelligent manufacturing, among others, to improve the productivity of industrial manufacturing systems [20-22]. In this sense, cyber-connected manufacturing systems improve efficiencies and streamline operations, but they also have the potential to change the way manufacturers and industrial companies operate their businesses. However, for the future scenarios of Industry 4.0, other competencies that allow managers and workers to face the challenges of an increasingly digitized production system must also be addressed [23-26].

Hence, Industry 4.0 has taken on a pioneering role in industrial information technology, which is currently revolutionizing manufacturing engineering. Many industrialized countries have also started adapting their industrial infrastructure to meet the requirements of the Industry 4.0 vision [27], where an important part of the preparation tasks is adapting higher education to the requirements of this vision, particularly engineering education.

Currently, the training of engineering professionals requires competencies for increasingly changing work and social environments, added to the scientific evidence that reveals that knowledge is not static but a dynamic process that constantly evolves [28, 29]. That is why the concern on the part of the universities and their teachers emerges to carry out a permanent search that allows the developing and adapting new teaching-learning methodologies [30-37], which are defined as organized, formalized, and oriented

procedures to obtain a learning objective established, that is, it is the planning of the teaching-learning process for which the teacher adopts techniques and activities that can be used in the classroom, to achieve the proposed goals and make critical and reflective decisions about the expected learning results [38-40]. That is why the need arises for the current engineer to develop skills and competencies in the face of new methodologies, tools, and technologies for the industrial sector.

That said, this research presents a procedure that describes the changes and improvements recommended in the laboratory area. By this, the need arises to create a BIM and Industry 4.0 laboratory for students, highlighting the reflective process of learning towards practice [41, 42], which is derived from the reflection of students on the actions taken in experiences, which leads to the development of skills and competencies that society and industry need [27]. For this second pillar, the experiential learning theory presented by Kolb [43] is used, which considers learning as a process through which knowledge is created through the transformation of experience, significantly improving student learning in The laboratory. Therefore, this work aims to present a generic proposal to adapt engineering education to the requirements of BIM and Industry 4.0, specifying the necessary changes in the laboratory.

THEORETICAL FRAMEWORK

From its inception in the early 19th century until World War II, engineering education in Germany focused heavily on the practice of engineering [44]. The war effort demanded accelerated technology transfer, making great strides. The government began to invest heavily in engineering research and development, and the resulting alliance between government and society emphasized the science of engineering and mathematics over the practice of engineering. The increasing separation between teachers and the curriculum on the needs and expectations of the industry has turned out to be a real threat to competitiveness in the global market [45, 46].

International competition and the development of new technologies have restructured the industry and altered the way engineers practice engineering [44]. With this, new teaching-learning methodologies have emerged, allowing engineering professionals

to train the competencies required by increasingly dynamic work and social environments [47]. In this sense, engineers must complement the technical domain with business and communication skills and understand engineering solutions' ethical and social impact [48, 49]. That is why the need arises for engineering careers to adapt to new tools, methodologies, and technologies to prepare the student from the theoretical to the practical.

In recent years, the construction sector has been experiencing changes in its work system due to the introduction of Information and Communication Technologies (ICTs) and the implementation of the BIM methodology, where technological solutions are proposed for the work system of traditional construction.

The BIM phenomenon is assuming the revolution in construction work practices, which means both a challenge and an opportunity to achieve the project's objectives [50]. Without forgetting all the advantages that BIM can bring to a project, it is important to point out that there are significant challenges to face in all disciplines found in organizations, that is, the people who make up the construction company and who must prepare to present and adopt the BIM concept [51, 52].

However, despite BIM's great potential to improve collaboration between the parties involved, reducing the time for generating project documentation, among other benefits [52, 53], there are difficulties in successfully implementing BIM. That is why in recent years, there have been numerous studies to analyze the gap between the construction industry and the introduction of Information and Communication Technologies (ICT) since this is a problem that is affecting the performance of the entire process and is trying to diagnose roots of these difficulties [54]. The studies by Mutai [55] associate the success of BIM with the BIM skills and training demonstrated by the project team, whereby the skill set in BIM is determined through collaboration. Azhar [56] indicates that the collaboration generated between different disciplines and users is essential for the success of the BIM implementation. It is then that the need arises to study in more detail the collaborative behavior in implementing BIM.

Recent concepts such as the Internet of Things, Industrial Internet, cloud-based manufacturing, and

smart manufacturing [57] address future-enabled digital production and are generally included in the visionary concept of a Fourth Revolution Industrial or Industry 4.0 [58]. All of these concepts are related to recent technological developments in which the Internet and supporting technologies (e.g., embedded systems) serve as a backbone for integrating agents, materials, products, production lines, and processes of people and machines into and outside the organization's boundaries to form a new type of smart, connected and agile value chain.

The vision of Industry 4.0 will lead to increased technical and organizational complexity of manufacturing processes at the micro and macro level [59], posing substantial challenges, especially to small and medium-sized manufacturing companies [60]. The challenges are not limited to the financial investment required for acquiring new technology but are also related to the availability of qualified personnel at all levels of the organization who can cope with the increasing complexity of future production systems [60].

Luo and Störmer [61] discuss the new qualification requirements in the Industry 4.0 era, such as interdisciplinary thinking, problem-solving, cultural and intercultural competence, and lifelong learning. Furthermore, Coşkun, Y. Kayıkcı, and E. Gençay [27] examine the requirements of the Industry 4.0 era for engineering education from the perspective of the higher education system, highlighting a greater need for flexibility (interdisciplinary collaboration and soft skills), university-industry cooperation, and open learning systems, such as online learning platforms and free access courses at open universities.

Now, the question arises, what competencies should engineering students develop from higher education in the face of this new vision of Industry 4.0?. It is important to highlight that to face this question, future professionals have personal, social, action, and domain competencies for Industry 4.0 [60]:

- On a personal level, Industry 4.0 will lead to greater automation of routine tasks, which implies that workers must face the fact that their current tasks will no longer exist. Such an outlook on the future of one's work requires the ability to observe the bigger picture of society as a whole (the challenges, for example, scarcity

of resources and opportunities, for example, wealth), opportunities for self-development, and commitment to lifelong learning [62].

- Social competence refers to the fact that the individual in an organization requires the ability to communicate, cooperate and establish connections and social structures with other individuals and groups. For this, using new teaching-learning methodologies is essential to develop the student's teamwork capacity [7].
- The capacity of a person related to action refers to the ability to put into action the ideas constructed socially or individually; that is, an individual can integrate concepts into their mental schemes, to transfer the plans to reality successfully, not only at the individual level but also at the organizational level.
- The domain knowledge includes knowing theoretical and software, languages, project management tools, and others that are especially important to a business problem or domain and go beyond the ordinary [60].

On the other hand, digitized production processes, managed intelligently, require professionals who are capable of understanding the basic concepts of network technologies and data processing [63]. Furthermore, statistical methods and data extraction techniques are key skills for future production engineers [64]. Advances in materials technology require skills regarding new production processes [64, 65], for example, 3D printing. Therefore, for engineers, a deep understanding of the interrelationships between electrical, mechanical, and computer components will be a vital skill in developing innovative products and processes and solving quality-related problems [60, 62, 64].

On the one hand, adapting education to the vision of BIM and Industry 4.0 has been a new challenge for the laboratory in recent years. Decentralized virtual laboratories have emerged in real-time. Buhler, Kuchlin, Grubler, and Nusser. [66] developed a virtual automation laboratory for engineering students, creating an integrated learning environment for computer science and automation engineering students, where they could access and control various devices over the Internet. On the other hand, Zarte and Pechmann [67] present a concept to teach the vision of Industry 4.0 to students from fields other than computer science (such as mechanical or

industrial engineering) using a simulation game, creating a method to modify the conventional simulation games to teach key aspects of Industry 4.0 to students. Taking this perspective, they derive requirements for future engineering education, for example, collaboration and problem-solving in virtual environments and teams of human robots [48, 68].

In addition to other important results, they show why intercultural social skills will gain importance [69]. Furthermore, Faller [70] addresses the problems faced by SMEs (Small and Medium Enterprises) that adopt technologies related to Industry 4.0 due to a lack of skills and proposes a laboratory concept for universities of applied sciences to educate on the necessary and highly qualified human resources for local SMEs. Anjarichert, Gross, Schuster, and Jeschke [71] propose virtual learning environments immersed in the manner of Industry 4.0, which allows international teams to collaborate remotely, allowing immersion in virtual worlds based on natural user interfaces. Several works discuss and show how new concepts, tools, and competencies can be integrated into engineering education using these laboratories or learning factories [30, 33, 60, 72].

Therefore, several investigations examine ways to transform education from theory to practice. By changing how we teach engineering, we consider new teaching-learning methodologies, Information and Communication Technologies (ICT), and new learning environments, thus increasingly moving the student to engineering practice.

CDIO: A New Vision for Engineering Education

After the 20th century, engineering education evolved into the teaching of engineering sciences [44, 69]. As a result, the industry in recent years has found that graduates, while technically capable, lack many skills required in real-world engineering situations [45, 46]. That is why institutions such as emerged in the late 90s, an initiative called CDIO, which was originally conceived by the Massachusetts Institute of Technology (MIT) [73, 74], and which corresponds to an educational framework that provides students with the engineering foundations established in the context of "Conceive - Design - Implement - Operate" real-world systems and products [73, 75]. Today, MIT and other leading American, European, Canadian, British, African, Asian, and New Zealand institutions have strengthened this collaborative CDIO

initiative to develop and implement this educational framework around the world, both for curriculum planning for results-based evaluation [76, 77].

The general objective of the Syllabus CDIO is to formally summarize a set of knowledge, skills, and attitudes that students, industry, and academia desire for a future generation of engineers [78-80].

As mentioned earlier, the results that students are expected to know and implement when they graduate and the Syllabus Levels (SL) are shown below in Table 1.

Regulatory frameworks like CDIO can be used to define expected outcomes regarding personal, interpersonal, and systems-building skills learning objectives necessary for modern engineering practice. Thus, CDIO can be the foundation for a rigorous assessment process based on learning outcomes.

Adapt the laboratory to Industry 4.0: Implementing Kolb's experiential learning theory to the laboratory

What is the most appropriate procedure to include practical laboratory experiences under this vision?

Table 1. Syllabus levels according to CDIO.

SL1	Disciplinary knowledge and reasoning. Knowledge of underlying mathematics and science. Fundamental knowledge of engineering. Fundamental knowledge, methods and tools of advanced engineering.
SL2	Personal and professional skills and attributes. Analytical reasoning and problem solving. Experimentation, research and discovery of knowledge. Systemic thinking. Attitudes, thinking and learning. Ethics, fairness and other responsibilities.
SL3	Interpersonal skills. Teamwork and communications. Communications in foreign languages.
SL4	Conceive, design, implement and operate systems in the business, social and environmental context. External, social and environmental context; and business and business context. Conceiving, engineering and managing systems; designing, implementing and operating.

Source: Adapted from [75, 77].

According to Kolb [43], learning is the process by which knowledge is created through the transformation of experience. Creating a learning and practice environment that maximizes students' abilities to learn through their own experience. What is the most appropriate procedure to include practical laboratory experiences under this vision? According to Kolb [43], learning is the process by which knowledge is created through experience transformation-creating a learning and practice environment that maximizes students' learning abilities through their own experience. Learning comes from three main sources: learning from content, learning from experience, and learning from feedback [43, 81].

- Learning from the content: discovering new ideas, principles, and concepts.
- Learn from experience: an opportunity to apply content in a real environment or that simulates reality.
- Learn from feedback: the results of the actions taken and the relationship between the actions in the experiment and performance.

In the literature, different learning theories are listed [82], in which they are most commonly used for engineering education [83-85], such as Kolb's Experiential Learning Theory [43], Felder and Silverman's Model of Learning Theory [86], the VARK Learning Theory Model [87], and the cognitive theory of multimedia learning [88]. These methods could be used better to understand Information and Communication Technologies (ICT). The experiential learning method creates an environment that requires the participant to engage in some personally meaningful activity [27], allowing the student to apply prior knowledge while developing a commitment to practice [89], Kolb's experiential learning cycle is perhaps the most influential and cited academic model of experiential learning theory [90]. A circular model of the four-stage experiential learning cycle developed by Kolb [43] is used to generate changes in behavior, attitudes, and knowledge.. This model is selected as the most appropriate learning theory to fit engineering education in the vision of Industry 4.0 [27]. Kolb's Experiential Learning Theory, shown in Figure 1, provides a framework for designing active, collaborative, and interactive learning experiences that support this transformative process and emphasizes sensory and emotional engagement in the learning activity.

Learning becomes effective when a student progresses through this four-stage cycle: (1) having a substantial experience followed by (2) observing and reflecting on that experience that leads to (3) the formation of abstract concepts (analysis) and conclusions, which are then used (4) to test hypotheses in future situations, resulting in new experiences. These four stages allow students to thoroughly investigate a topic through different activities and allow for different learning styles to be accommodated [83]. According to Kolb [43], the knowledge outcomes acquired through the interaction between theory, experience, and learning can begin in any of the four stages. Therefore, learning styles are the product of the following variables: feeling, watching, thinking, and doing. Each stage can be assigned to these variables [83].

Therefore, according to Kolb [43], learning is effective when the student "feels," based on the interaction with the object of study; when he "watches," which includes a reflection process; when she "thinks," which implies a process of abstract conceptualization, in which the student creates a model of the lived experience; and when it "does," it involves an active experimentation stage, in which it replicates the model to another experiment [91].

Developing a laboratory that brings the student closer to reality, as required by BIM and Industry 4.0, within the framework of engineering education, according to Coşkun, Kayıkcı, and Gençay [27], is done through the implementation of Kolb's Experiential Learning Theory, where engineering students are divided into groups. The steps are listed below:

- Concrete experience: which means direct practical experience when carrying out a new task; that is, it corresponds to a set of step-by-step instructions that demonstrate a new concept. Therefore, students follow step-by-step instructions to learn and gain a broad understanding of Industry 4.0 and its applications.
- Reflective observation: includes activities such as discussions and reflective questions requiring students to reflect on their practical experiences (practical exercises), which allow them to work in Industry 4.0 compliant environments. For example, after completing the concrete experience to analyze the components of a car assembly line, the students are then asked to discuss how, why and what kind of robotics they have to put on the

Source: Adapted from [27], [43], [83].

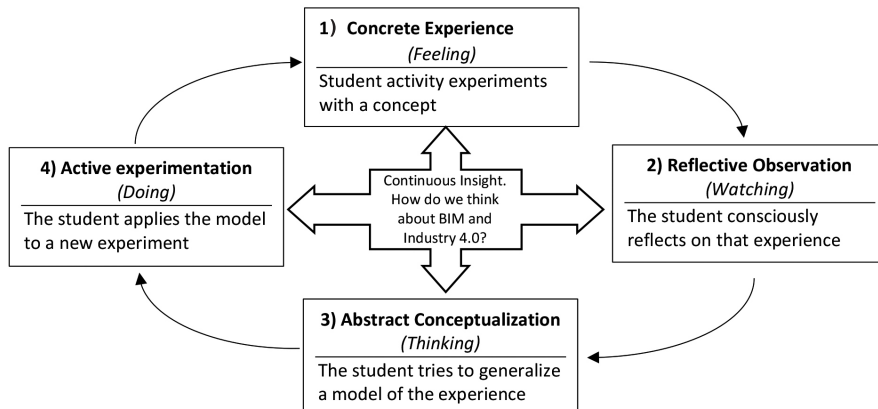


Figure 1. Kolb's learning styles model and experiential learning theory.

assembly line. Reflective observation activities should encourage interaction between students to achieve a higher level of reflection.

- Abstract conceptualization: students are expected to create a theoretical model and generalize what was done. This stage may be difficult to achieve in short hands-on activities. Class discussions can help connect the learning experience with the general theory. At this stage, the teacher's intervention is important. For example, students can be asked to create a digitization scenario by applying robotic technologies based on the steps they take. In this part, brainstorming applications such as mind mapping software are also used.
- Active experimentation: Students are ready to plan and try another concrete experience at this stage. At this time, they can perform this task without detailed instructions. They can combine some related topics from the first experience so that later topics build on the previous ones.

Botelho [92] proposes a rethinking of the computational simulation used in higher education in Engineering based on Kolb's Experiential Learning Theory and Belhot's Learning Cycle. The pedagogical approach they present can act as a reference point for discussions in the area of Engineering Education, considering the use of Kolb's theory as a model for the development of the teaching-learning process and computer simulations as a didactic tool.

Currently, universities worldwide are advancing towards Industry 4.0 in laboratories; for example, the Universidad del Bío-Bío in Chile has an industrial

robotic arm intended to develop prototypes of construction elements through 3D printing (three dimensions) for companies. Being an initiative under the auspices of the Interdisciplinary Center for Productivity and Sustainable Construction of Chile (CIPYCS) allows the development of new components and construction systems in less time, reducing environmental impact, reducing workplace accidents, and increasing efficiency and versatility [93]. Therefore, this robot is intended to support the research and technological development of the building, both in the academic field and at the service of the industry, thus moving towards Industry 4.0. Also, the same University created a laboratory, which works through the use of Discrete Event Simulation and BIM, under an environment of extreme collaboration, a system developed by NASA that was adapted to be used in this laboratory and that seeks to shorten construction times.

Likewise, this is the case of Turkish German University in Germany, where they have a Lego-Lab Laboratory [27], where students work on Industrial Lego Designs using Lego Mindstorms (Lego Educational Robots), in which they understand the application of the Industry 4.0 concept simulating entire production lines. Lego Mindstorms systems provide programmable brick computers, modular motors and sensors, and a variety of Lego Technic elements, which can be used to simulate entire production lines. Sensors such as touch, light, distance, sound, servo-motor/rotation sensors, and programmable brick computers provide the components necessary for developing intelligent

manufacturing models and concepts that are fundamental to the vision of Industry 4.0. In addition, they established a 3D printing lab in the visual production lab, creating realistic digital design factory models, and feedback is used to remedy design flaws.

Another example is the Vienna University of Technology in Austria, which decided to build the first Industry 4.0 Pilot Factory in Austria [60]. The objective of this Pilot Factory is to have a “Smart Production,” where technology solution providers, Information Technology contractors, and software designers develop new concepts, models, technologies and systems in cooperation with scientific partners, validating the results together with the technology applied to the manufacturing companies, in the experimental area of the pilot factory. Furthermore, it provides access to new technologies, and ICTs for companies, especially SMEs, which do not have their research infrastructure.

Therefore, developments in laboratory technology, such as 3D printing, could transform from rapid prototyping to rapid manufacturing and, ultimately, mass customization. As a result, the synergistic efforts of students and researchers would significantly contribute to the adaptation of engineering education to BIM and Industry 4.0 since an outstanding education in engineering must contain a combination of scientific investigation and industrial application.

METHODOLOGY

The following is a proposal for a generic framework for engineering education, consisting of two main pillars: the curriculum and the laboratory. These pillars are interrelated and even dependent on each other. In addition, they are integrated by concepts of the BIM methodology; and by technologies and methods of Industry 4.0 that are carried out in conjunction with scientific research, ideas, and developed prototypes (see Figure 2).

Source: Adapted from [27, 33].

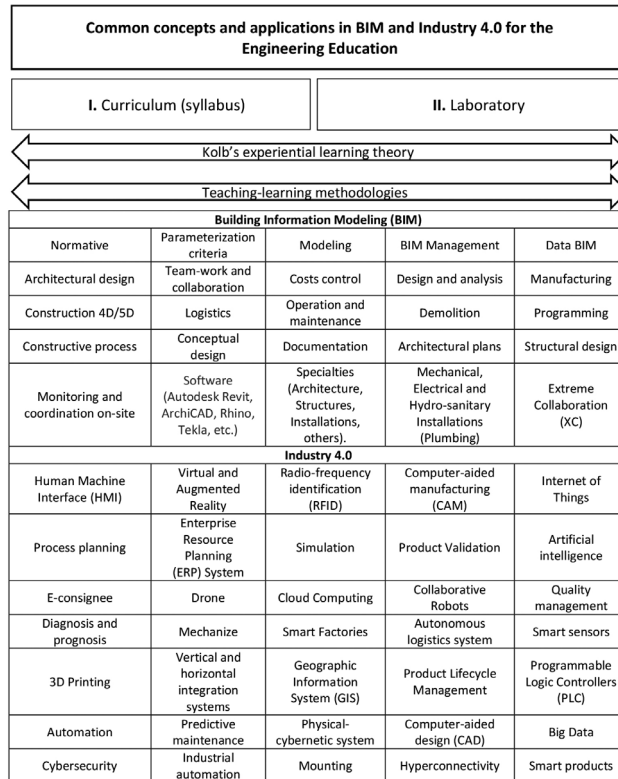


Figure 2. Generic Framework for Engineering Education: Concepts of BIM and Industry 4.0.

INTEGRATION OF TEACHING-LEARNING METHODOLOGIES

The idea is to identify the progression of teaching-learning methodologies used, provide engineering teachers with a guide to determine which methodology to apply, and take students from theory to practice. Based on the above, Table 2 presents the progression of identified teaching-learning methodologies that would allow obtaining personal and professional competencies and attributes of engineering students, which may be related to one or more stages of Kolb's experiential learning and the identified learning outcomes. In addition, it shows which stage of Kolb's experiential learning the Syllabus Levels (SL) established by CDIO predominates.

RECOMMENDATIONS

Curricula for programming courses should be adjusted in such a way as to introduce not only low-level programming languages but also new programming languages that are more common in the artificial intelligence and information science communities, such as Python (programming language). In the next term, the programming skills of engineering students must be improved in object-oriented programming in a common course for all engineering disciplines [94].

Besides, some technologies such as intelligent systems, hardware systems (industrial applications), and cybersecurity, should be implemented or integrated into engineering courses due to of the

Table 2. Progression of teaching-learning methodologies.

Kolb's experiential learning theory	Progression of Identified Methodologies	Identified Learning Outcomes	Syllabus Levels (SL) according to CDIO
Concrete Experience (Feeling)	• Exhibition class. • Tutorships. • Conceptual map. • Diagram V. • Briefcase. • Seminar.	• Knowledge of new technologies in Industry 4.0 and BIM. • Understand the impact of engineering solutions in a global, economic, and environmental setting, in a social context. • Knowledge of the use of modern tools, necessary for the practice of Industry 4.0 and BIM	SL1: Disciplinary knowledge and reasoning.
Reflective Observation (Watching)	• Workshop. • Brainstorming. • Debate. • Round tables. • Virtual forum.	• Reflective capacity of the manufacturing process and its components. • Ability to identify, formulate and solve problems in Industry 4.0 applying BIM. • Ability to communicate effectively. • Conceive systems and processes for Industry 4.0 and BIM.	SL3: Interpersonal skills.
Abstract Conceptualization (Thinking)	• Problem Based Learning (PBL). • Case study. • Simulation. • Collaborative learning.	• Design and conduct experiments, as well as analyze and interpret data. • Design a system, component, or process to meet the desired needs within realistic constraints. • Design systems and processes for Industry 4.0 and BIM. • Analytical reasoning and problem-solving.	SL2: Personal and professional skills and attributes.
Active experimentation (Doing)	• Apply what you have learned to the BIM and Industry 4.0 Laboratory.	• Ability to apply knowledge of mathematics, science and engineering to Industry 4.0. • Ability to integrate multidisciplinary teams. • Long-term learning. • Implement, operate systems and processes for Industry 4.0 and BIM. • Practical knowledge of Industry 4.0 and BIM. • Replicate the model with other experiments.	SL4: Conceive, design, implement and operate systems in the business, social and environmental context.

identification of technologies and the association of this to a subject program by the expert. For example, cybersecurity is necessary for analysis, confidentiality and commercial value, oriented to the protection of wireless communications and the security of systems in the cloud. Also, integrate courses into curricula such as machine learning, artificial intelligence, data analysis methods, security systems and protocols, network security, privacy, data security and security management, embedded systems, industrial automation technology, robotics industrial and real-time systems [27]. As the BIM methodology and Industry 4.0 systems grow, more autonomous and intelligent manufacturing environments will be seen. Engineering students must be proficient in artificial intelligence and machine learning to design and implement such methods.

On the other hand, it is necessary to incorporate the emergence of new engineering services and the use of technology as an essential tool for the teaching-learning process so that graduate engineers understand what they have been taught and can contribute to developing engineering products and implementing them. That is, to develop solutions focused on the practice of engineering as one of the guiding principles promoted by CDIO.

It is important to emphasize that it is not appropriate to classify teaching methodologies in only one of the phases of experiential learning [43] since this could represent a conceptual error. Each methodology can comprise the four phases proposed by Kolb. As shown in Table 2, the same occurs regarding the results identified for each stage.

Conversely, it is recommended that an engineering project should be for all engineering students, in general, to allow students from different engineering disciplines to define and work on the same project. The Engineering Project course should require the collaboration of teachers from different engineering programs so that students can create project teams that contain students from different disciplines. In this way, it is possible to carry out much more realistic and interesting projects. In addition, a better teamwork organization would be enabled since the project would be carried out with students from different disciplines.

That said, the engineering teacher must understand what the industry and the international market demand

of the future engineer, from the language used to how the teacher transmits knowledge, motivating the student and making learning happen effectively.

CONCLUSIONS

In this qualitative research, a generic framework for BIM and Industry 4.0 education was proposed, which consists of implementing components to the curriculum and the laboratory to adjust engineering education to the BIM and Industry 4.0 vision, addressing how it should be considered a laboratory-adapted to the requirements of these visions, using Kolb's Experiential Learning Theory, being of great importance to adjust engineering education to the vision of Industry 4.0, also using teaching-learning methodologies, to improve the concrete experience (feeling), reflective observation (watching), abstract conceptualization (thinking), and active experimentation (doing), and thus prepare the student from the theoretical to the practical, developing both interpersonal and professional skills.

Learning factories are a promising approach to skills development. Linking learning strategies and the latest trends in manufacturing enables training, research, and education in different areas of engineering. Therefore, students must gain practical experience in industrial applications before graduation to understand and follow the problems and challenges in implementing Industry 4.0 applications while still studying.

This research methodology can be used with various global technological trends such as sustainability, Big Data & Data Science, innovation, technology-based entrepreneurship, and others since they use proven models worldwide, regardless of the educational model or the focus of competencies that use the institution. Therefore, the main contribution of this research is to address the issue of new models, tools, and experiences necessary to "modernize" and improve the curricula of engineering undergraduate programs.

The design is a novel contribution to relating industry 4.0 to engineering education, presenting a procedural proposal for the teacher that describes the improvements in the areas of curriculum development and the laboratory, using Kolb's experiential learning theory and methodologies of

teaching-learning. Allowing, in addition, a learning environment in the classroom and practices that maximize the students' skills when learning through their own experience and previous knowledge. With this, it is possible to align the practical laboratory experiences with the expected learning results and justify the incorporation of equipment, training of civil servants and teachers, and investment in a University Campus.

The competencies and skills demanded in the 21st century is essential for future professionals, such as critical thinking, solving real problems, creativity, collaboration and communication skills, metacognitive abilities, the ability to convert difficulties into opportunities, and others. For this reason, students in a future production scenario must develop specific skills to face the new challenges related to technological and computer developments and business models. Therefore, there is a general need to rethink competencies in light of new technological developments that significantly impact how future production systems are designed. This theoretical approach to aligning engineering education with the vision of BIM and Industry 4.0 is intended to be the first step towards a more tangible vision of moving students from theory to engineering practice.

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