Artificial Intelligence in the Construction Industry: A Competency-Based Examination Through Expert Lens

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Abstract

In recent years, there has been a significant surge in educational institutions' interest in integrating artificial intelligence (AI) as a fundamental resource in the learning process. This trend is not limited to any particular sector but extends to the construction field, an ever-evolving sector where new technologies continually emerge in materials, construction techniques, and contractual relationships. As AI has become an indispensable tool in the construction industry, it is not just a trend but a necessity. It becomes essential for graduates in this discipline to acquire the necessary competencies to effectively address the challenges presented by the current job market. This article, a collaborative effort between academia and industry, explores the competencies and skills essential for students in a construction engineering program at a private university in Chile, particularly in integrating Artificial Intelligence (AI) into the industry. This examination is grounded in the insights and requirements identified by representatives from companies within the construction sector, ensuring that the research is not only academically rigorous but also practically relevant. This research is situated within a qualitative framework and relies on in-depth interviews with industry representatives. For convenience, the sample consists of 14 actively employed professionals in the construction sector who were located through networks of contacts. This study aims to provide a precise understanding of the competencies and skills that underpin the relevance of Artificial Intelligence (AI) in today's job market in the construction industry. With the increasing demand for professionals skilled in areas such as AI-based robotic technology operation, virtual reality, and augmented reality, university programs in construction engineering must adapt to meet the current and future job market demands. The results will not only identify specific AI competencies deemed vital in the construction industry, per the perspectives of the interviewed professionals and experts, but also provide actionable insights into how these skills can be developed and integrated into the industry, enhancing project efficiency and quality. The analysis of semi-structured interviews with industry experts reveals a labor market that highly values critical reflection, ethical principles, interpersonal and management skills, technical mastery in programming, data analysis, mastery of emerging technologies and construction-related software, English, and cybersecurity knowledge. These findings underline the importance of adapting educational programs to prepare future professionals for a labor market where AI is increasingly involved. This article aims to transform how we educate and prepare future professionals to ensure their swift and successful integration into the workforce.

Keywords: *Artificial Intelligence, Construction Engineering, Competencies, Workforce*

Introduction

The construction industry faces a significant change phase in an era marked by unprecedented technological advancements and deep digital transformation. This qualitative study aims to identify the crucial competencies and skills required to understand and apply Artificial Intelligence (AI) in today's evolving labor market. This work delves into how AI revolutionizes construction processes and methods and redefines professional roles within this sector. The primary goal of this article is to provide a detailed and contemporary perspective on the implications and opportunities AI offers to construction industry professionals.

Using a qualitative methodology based on semi-structured interviews with construction sector experts, this study seeks to understand the transformation in this field and define the fundamental skills and competencies for future engineers working in this domain. The interview method will enable us to collect perspectives from distinguished professionals to explore how the increasing relevance of AI is changing the necessary skills in construction engineering. This study highlights the growing demand for AI competencies and its influence on academic preparation, guiding higher education institutions towards training students for a labor market that increasingly values industrialization, robotics, and virtual and augmented reality technologies. The following section provides a literature review showcasing AI's importance in engineering and this sector's required skills and competencies.

AI today

Artificial Intelligence (AI) has made significant advances in recent decades, with experiments and studies outlining its capabilities and limitations. Its paradigms have recently been reassessed, generating innovative applications to solve diverse real-world problems. This progress marks an era of notable change and expansion in the AI field [1-3]. AI has positioned itself as a leader in the current revolution spanning social, educational, economic, health, and technological sectors. In this dynamic context, the accelerated development of AI-based products is propelled by substantial investments from large corporations and governments, with the United States leading support for research and development in this area [4]. AI applications have fundamentally integrated into daily life, manifesting in various forms, from smartphone apps and collaborative robots to the automation of complex processes, advanced security systems, predictive maintenance, and autonomous vehicles [5-8]. However, it is crucial to recognize that the true potential of these innovations to benefit humanity largely depends on creating and maintaining an educational environment that fosters early, ethical, and systematic engagement in this scientific revolution [9]. Therefore, it is essential to equip students and society with the knowledge and skills necessary to participate effectively and responsibly in an AI-driven world [4].

Regarding the contemporary importance of Artificial Intelligence, the Artificial Intelligence Index Report 2023 by Stanford University [10] evidences notable growth in this field. According to this report, from 2010 to 2021, there has been a substantial increase in AI-related publications, growing from 200,000 in 2010 to almost 500,000 in 2012, including articles in academic journals, conference contributions, works in repositories, and patent registrations. This increase reflects growing interest in the area and underscores AI's rapid advancement and expansion in the academic and research realm.

Following this analysis, the educational sector significantly leads in AI-related publications in three main geographical regions: the United States, the European Union - the United Kingdom, and China. This dominance indicates a growing interest and substantial investment in AI research within the educational realm in these areas. Concurrently, it is noted that the industrial sector in the United States shows higher participation in AI publications compared to its counterparts in the European Union - United Kingdom, and China, reflecting differences in focus and intensity of AI research and development among these regions [10].

Currently, Artificial Intelligence (AI) is understood in various ways. The United Nations Educational, Scientific and Cultural Organization [11] defines it as machines capable of mimicking certain functionalities of human intelligence, including aspects such as perception, learning, reasoning, problem-solving, language interaction, and even creative production

[11]. Similarly, Haque and Karandikar [12] describe AI as applications that emulate the structure and functioning of biological neural systems, like the human brain, through Artificial Neural Networks (ANN) in computers. Meanwhile, Castronovo et al. [13] emphasize its application in virtual reality within the context of Architecture, Engineering, and Construction (AEC), improving communication and coordination in these fields.

In this context, and considering the above definitions, this work understands AI as a conjunction of advanced technologies that mimic human cognitive abilities and amplify efficiency and effectiveness in the construction realm. This translates into the ability of machines to process, analyze, and learn from data and experiences, resulting in significant improvements in the planning, design, coordination, and execution of projects in the AEC industry. Here, AI is visualized as a catalyst transforming how construction projects are conceptualized, communicated, and executed, thus redefining innovation and collaboration paradigms in this sector.

The construction sector plays a crucial role in Chile's economy, contributing significantly to the Gross Domestic Product (GDP) with 7% and aggregate investment, with 64% of this [14]. This sector stands out for its economic contribution and high sensitivity to fluctuations and advances in the national economy. Similarly, at the international level, the construction sector is undergoing an accelerated transformation driven by the incorporation of new technologies. This global phenomenon, reflected in the introduction of innovative materials, advanced construction techniques, and changes in contractual relationships, is redefining the construction industry worldwide, marking a turning point in its dynamics and approach [15].

The automation, robotics, and artificial intelligence revolution significantly redefines the Architecture, Engineering, and Construction (AEC) sectors. While there is widespread concern that implementing these technologies could considerably reduce jobs, recent studies assessing the AEC workforce competencies suggest the opposite. These data indicate a growing need to adapt and evolve skill profiles, supporting economic growth and creating new job opportunities without replacing existing positions. ElZomor et al. [5] mention that a clear example of this change is how tasks previously unfeasible due to limitations, complexities, or extended execution times can now be performed more efficiently thanks to automation and robotics.

As previously mentioned, AI has undergone a remarkable transformation, advancing from its original conception as 'intelligent machines' to its integration into the daily life of various economic sectors. A notable example of this integration is the construction industry, where AI has established itself as a key agent of innovation and change [16]. However, proper professional training is indispensable to ensure a successful and ethical adoption of AI in this sector. This education must adapt to the new market demands, focusing on developing relevant skills for future professionals [17].

Incorporating AI in the construction industry has been identified as a significant challenge and a time-consuming process. To effectively address this challenge, education in construction engineering must evolve to meet the changing demands of the labor market. This entails adopting a proactive approach in academic training, which transmits knowledge and prepares future professionals and industry leaders. Such an approach is vital to ensure these professionals' seamless and efficient integration into key roles for the success of construction projects [5].

In line with the above, this study seeks to provide a detailed understanding of the competencies and skills necessary to address AI's growing relevance in the construction industry's current labor market.

The subsequent sections describe the methodology used to achieve the research objective. Then, the main results are presented and discussed in the context of theory and practical application. The study concludes with the limitations and possible directions for future research.

Method

The study was framed within a qualitative approach. The study aims to provide a precise understanding of the competencies and skills that underpin the relevance of Artificial Intelligence (AI) in today's job market in the construction industry. The recruitment process for participants was conducted through a convenience method that involved selecting key experts currently working in the construction industry (who all expressed their informed consent). The reason for this approach was to gain access to a specific profile of participants, namely experts with leadership roles and responsibilities. The recruitment process, therefore, prioritized including professionals with management positions who manage teams and projects. This ensured that participants contributed not only their technical experience but also their perspective on the dynamics of leadership and management in construction. The interviews were semi-structured and conducted both in person and online, according to the needs of the participants. These interviews lasted approximately 25 minutes and were carried out between November and December of 2023.

For interviewees, twelve leading questions were built on key issues for our research aims; they were divided into six sections: Opening, Competencies and Skills, Industry Perspectives and Needs, Further Exploration, Challenges and Opportunities, and Closing questions (appendix). Table 1 presents the profile of the interviewees in our study, summarizing their gender, years of experience, and current roles within the construction industry.

Table 1. Description of the participants.

Identifier	Gender	Years of Experience	Position
P1	Female	19	Technical Office Manager
P2	Male	12	Field Manager
P3	Male	16	Technical Office Manager
P4	Male	11	Project Manager
P5	Male	12	Project Manager
P6	Male	24	Project Manager
P7	Male	16	Construction Manager
P8	Male	6	Field Manager
P9	Male	6	Field Manager
P10	Male	11	Field Manager

P11	Male	23	Project Manager
P12	Female	10	Project Manager
P13	Male	13	Technical Inspection Project Lead
P14	Male	12	Project Manager

In Table 1, participants are described with a unique alphanumeric code ranging from P1 to P14, allowing for individualized analysis and clear referencing of each study participant. Regarding gender, the table shows 14% women (P1 and P12) and twelve men (86%). As for years of experience, these range from 6 to 24 years, with an average of 13.6 years. This diversity in experience provides a rich analysis perspective, including seasoned professionals and those in the earlier stages of their careers. Finally, the current position of each interviewee reveals an interesting mix of roles within the construction sector. The designations of each participant can also be seen in Table 1, ranging from "Technical Office Manager" to "Project Manager," including "Construction Manager" and "Technical Inspection Project Lead." Additionally, one interviewee (P14) representing a structural calculation startup indicates a connection to innovation and entrepreneurship in the sector. These roles demonstrate the functional and hierarchical diversity of the professionals involved in the study, offering a broad range of perspectives on the management, implementation, and evaluation of construction projects.

Coding, analysis, and ethical considerations

Each session was recorded in audio and video formats, depending on the interview setup. The recordings were subsequently transcribed into MS Word documents. The transcribed responses were organized into MS Excel for content analysis, initially focusing on predefined categories aligning with the research objectives. This analysis involved identifying specific skills and competencies, curriculum suggestions, and expert recommendations for developing these competencies. Additionally, we were attentive to the emergence of new relevant categories during the content analysis. While the study was specifically focused on the objective, the findings provide valuable insights that could be useful for future research.

Informed consent was obtained from all participants before interviews were conducted, and the confidentiality of the gathered information was maintained. Privacy was respected, and the study adhered to an ethical protocol consistent with research standards.

Results

The results below highlight the key competencies and skills identified as essential in Construction Engineering according to interviews conducted with fourteen participants (Table 1). These findings reflect the current market's technical and cognitive demands and the sector's evolving expectations regarding innovation, sustainability, and adaptability. Figure 1 displays the frequencies of competencies identified by interviewees as essential for professionals in the construction industry, particularly in the context of integrating Artificial Intelligence. This visual analysis allows for a quick appreciation of the competencies that construction professionals deem most valuable.

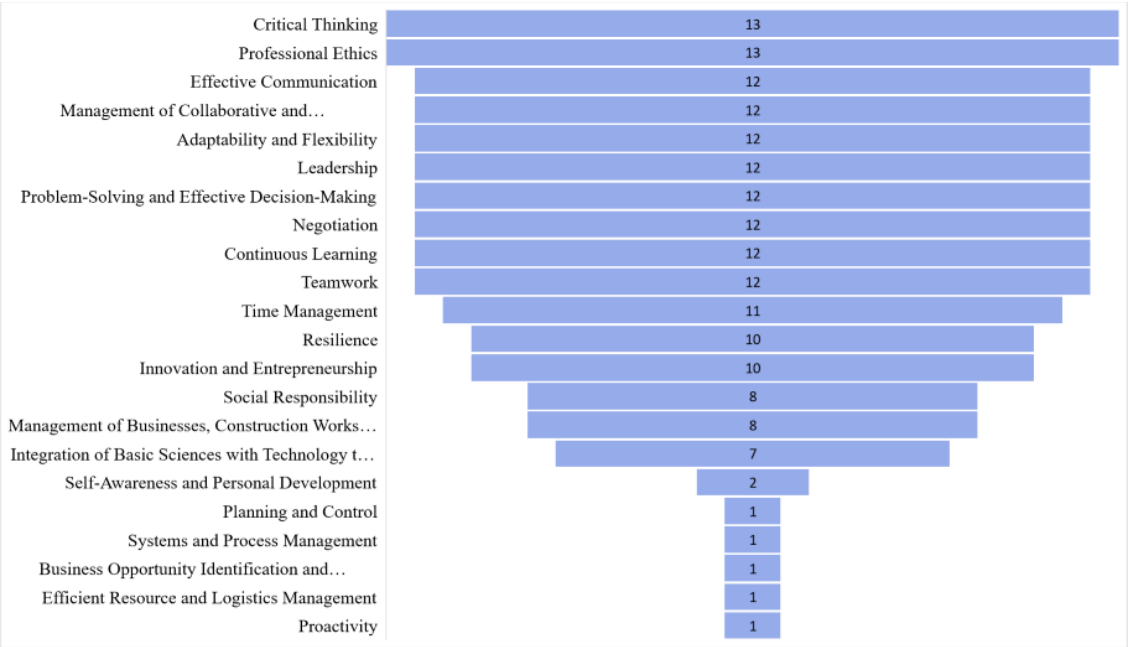

Figure 1. Frequencies of competencies.

As shown in the chart, several competencies emerged from the interviews conducted. This report will focus on analyzing and explaining only the five most mentioned. Although Effective Communication, Management of Collaborative and Multidisciplinary Teams, Adaptability and Flexibility, Leadership, Problem-Solving, Effective Decision-Making, Negotiation, Continuous Learning, and Teamwork have a frequency of 12, we have discriminated according to what the literature indicates as the most relevant since they are vital for professionals who wish to lead and manage teams and projects effectively in the AI era. Below, the most relevant competencies and their meanings are described according to the interview results.

Results about competencies

Critical Thinking: Critical thinking is analyzing situations, arguments, and evidence to form well-reasoned judgments and effective solutions objectively and reflectively. This involves understanding AI applications objectively, questioning outcomes, and evaluating implementation feasibility, as indicated by interviewee P1: *"If we use AI applications like ChatGPT and I just copy and paste information without reflective processing or analyzing the information it provides, we are failing to exercise critical thinking, an essential competency for any professional."*

Moreover, universities must promote this competency, as expressed by interviewee P5: "*Universities should incorporate techniques or strategies into their study programs that enable students to say, you know what? I disagree with the decision or solution provided by artificial intelligence, thus fostering analytical ability."* This underscores the importance of critically analyzing the technology, its integration into existing workflows, and its impact on project quality, costs, and timelines.

Professional Ethics: Ethics is defined as the framework of moral principles and values guiding actions and decisions in a workplace setting. Interviewee P9 highlighted: *"Artificial intelligence is a very valuable technology that will help us in many ways; however, today, it*

is used by many students to do assignments, generating deliverables that they do not review, verify, and claim authorship." This observation underscores the need to focus on ethical and moral aspects, as reaffirmed by interviewee P11: *"The ethical and moral part should be emphasized because AI is a very powerful tool that can also be misused."*
Responsible administration of AI use is essential, safeguarding privacy, security, and fairness. The ethical impact of AI applications, especially regarding sensitive data handling and decision-making automation, must be considered to ensure this technology benefits stakeholders while preserving fundamental human values and rights, avoiding misuse.

Effective Communication: This competency involves transmitting and receiving information accurately and timely. In the context of AI in the construction industry, effective communication is crucial for facilitating collaboration among various stakeholders, such as engineers, architects, workers, and stakeholders. As highlighted by interviewee P3: *"There's an interesting challenge in how to ask and interact with AI to generate the expected results, I believe that's key,"* including providing instructions, questions, or requests to an AI model to meet user requirements.

Likewise, as mentioned by interviewee P11: *"Construction professionals must have competencies such as effective communication because ultimately we are going to receive a lot of data and answers from AI, and we have to communicate them to project members."* This involves explaining AI technical concepts, presenting data, analyzing results accessibly, clearly, and concisely, and ensuring all project stakeholders understand AI-based decision-making. Effective communication is also crucial for training and adopting new AI technologies in construction, ensuring teams are well-informed and prepared to use these tools efficiently.

Management of Collaborative and Multidisciplinary Teams: This competency focuses on leading and coordinating teams composed of individuals from various disciplines, promoting collaboration and synergy to achieve shared goals in construction projects. In the context of integrating AI in construction, this competency is essential, as indicated by interviewee P9: *"Interdisciplinary collaboration is closely related to artificial intelligence since it helps us detect interferences and ensures the various specialties of each project are effectively coordinated,"* as projects often require collaboration of AI experts, construction engineers, calculators, architects, operators, and professionals from various specialties. Additionally, interviewee P10 emphasizes: *"Interdisciplinarity is fundamental, especially in the construction area, as artificial intelligence is gradually taking care of optimizing processes and efficiently integrating the different disciplines of the projects."*
Managing multidisciplinary teams effectively involves harmonizing different perspectives and working methods to achieve common objectives. This includes setting clear goals, fostering open communication, resolving conflicts, and ensuring all team members understand and are aligned with the project's goals.

Adaptability and Flexibility: The ability to adjust and effectively respond to changes and challenges in a dynamic environment. Adaptability and flexibility are crucial in integrating AI into the construction industry due to the constantly evolving nature of technology and construction project requirements. This includes the ability to adapt to new tools and working methods driven by AI, such as real-time data analysis or automated resource management, as stated by interviewee P3: *"Look, I like to think of the following idea, just as at some point we had to adapt to the use of the computer, which was a nice and entertaining adaptation; now*

professionals must adapt to artificial intelligence knowing that this evolution will significantly enhance our capabilities."

It also involves the flexibility to modify project work programs in response to insights provided by AI solutions and the ability to work effectively with interdisciplinary teams and emerging technologies. A clear example would be a construction team's ability to quickly adapt their construction strategies based on predictive analyses provided by AI algorithms, ensuring operational efficiency and proactive risk management, as mentioned by interviewee P12: *"One of the key challenges is for professionals and their environment to start understanding how to manage devices and applications that integrate AI and not see it as something that will go against our work but as a valuable support tool. Adapting to changes and having the ability to learn new things is fundamental for any professional."*

Results about skills

Below are the skills interviewees consider essential for professionals in the Construction Engineering field in the era of AI integration. Figure 2 displays the skills ranked according to the frequency with which they were identified in the content analysis of the interviews.

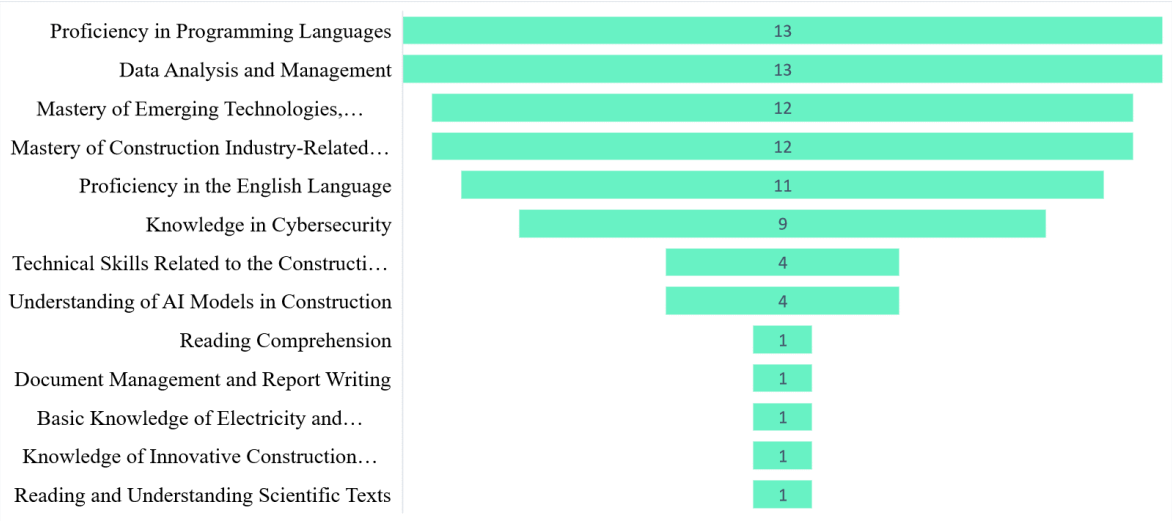

Figure 2. Frequencies of skills.

In this case, the first six most frequently mentioned skills are described according to Figure 2.

Mastery of programming languages: This skill focuses on understanding and effectively using specific programming languages, such as Python, Java, or C++, among others, to develop and implement Artificial Intelligence solutions in the construction sector. This proficiency is key for designing, customizing, and maintaining software and algorithms that address unique construction challenges, such as automated project management, risk analysis, or simulations. Interviewee P4 emphasizes, *"It's important that students acquire programming skills during their professional training. I believe deepening mastery of programming languages greatly contributes to professionals offering efficient solutions in their field we are currently training and even requiring people with programming skills in the company."*

Mastery of programming languages enables professionals to develop tailored AI systems, like predictive models for inventory management, programs for resource allocation optimization,

or tools for advanced construction data analysis. It also allows the creation of customized user interfaces for data visualization and interaction with AI systems. Furthermore, deep programming knowledge is essential for integrating AI solutions with other digital systems used in construction, such as Computer-Aided Design (CAD) software or Geographic Information Systems (GIS). Interviewee P14 highlights, *"Programming skills are essential nowadays, I'd say in most careers."*

Data analysis and management: This skill involves the ability to collect, process, analyze, and effectively use data, especially in construction projects where AI plays a crucial role. Interviewee P4 notes, *"Given that construction deals with a large amount of information, much of which is unstructured or not standardized, this would complicate the implementation of AI-based applications or tools. Therefore, it's important to know how to analyze and manage data to train AI models."* In this context, data analysis and management focus on transforming large volumes of information, such as sensor data, construction progress records, measurements, and coordinates, into actionable insights to improve decision-making and operational efficiency of projects.

The ability to analyze and manage data in construction with AI includes using data analysis tools and techniques, such as data mining, natural language processing, and machine learning, to identify patterns, predict trends, and optimize processes. For example, historical construction data can be analyzed to predict project delays or sensor data can be used to monitor a building's structural behavior in real-time, ensuring its quality, integrity, and safety.

Similarly, interviewee P5 mentions, *"Another key skill is understanding databases and statistics because artificial intelligence works on databases and generates a response based on that, generating statistics, and one can ask it to deliver certain percentages, weightings, and ultimately one can make decisions,"* this is essential to ensure decisions are reliable and meet regulatory and privacy standards. Professionals with this skill can drive significant improvements in the planning, execution, and maintenance of construction projects, leveraging the potential of AI to turn data into competitive and operational advantages.

Mastery of emerging technologies, applications, and tools related to AI: This skill refers to the ability to understand, manage, and effectively apply the latest technologies, applications, and AI tools specific to the construction industry. It includes a deep knowledge of AI systems, such as machine learning, robotics, and virtual and augmented reality, and how these can be applied to enhance construction processes, from design to execution and maintenance, as exemplified by interviewee P5: *"Structural designs are based on architecture and what is being proposed is to go directly from architecture to an artificial intelligence that generates an automatic predesign of most of the main structural elements."*

Professionals with this skill are at the forefront of using advanced data analysis software and Building Information Modeling (BIM) systems, among others. For instance, interviewee P14 mentions, *"xxxx is a start-up that developed a device placed on the crane tower capable of using machine learning vision tools to track progress on site, specifically for concrete elements."* This demonstrates how AI tools can optimize construction site logistics, resource management, tracking, and quality control.

Mastery of this technology enables the implementation of innovative solutions that improve efficiency, safety, and sustainability in construction projects, as highlighted by interviewee P4: *"A clear example of technological advancement in the construction industry is the use of*

drones for various activities, such as inspections in confined or unsafe areas. Now, instead of exposing people to potential risks, drones equipped with laser scanners are used to perform a detailed survey of the area based on point clouds; this method significantly improves the safety and efficiency of the process. In the field of robotics, innovations such as explorer robots stand out, for example, Spot from Boston Dynamics." This integration places companies at the technological forefront, which is crucial for competitiveness and innovation in the current market.

Mastery of construction industry-related software: This skill focuses on efficiently using various construction industry-specific software programs. It includes tools like Building Information Modeling (BIM) systems for detailed design and project management, project management software for planning, tracking, and controlling construction, and structural analysis programs to assess the feasibility and safety of designs, as mentioned by interviewee P13: *"I have witnessed the remarkable influence and valuable support of various software, especially those associated with BIM methodology and others that, when integrated with AI, can yield many benefits including those from Autodesk, SAP2000, and ETABS."*

Moreover, as highlighted by interviewee P2: *"In today's construction landscape, mastery of specialized software has become a critical factor for project success. Tools like Building Information Modeling (BIM), project management software, and data analysis platforms are redefining how we approach everything from design to project execution."* Therefore, mastering this software is essential for improving accuracy, efficiency, and quality in all aspects of construction, from conceptualization to project delivery. For example, AutoCAD, Revit, where Autodesk already incorporates AI technology into its products, Microsoft Project, SAP2000, or ETABS are mentioned.

Mastery of the English language: This skill refers to the ability to understand, speak, read, and write in English effectively, which is fundamental in the globalized construction industry, especially in projects that integrate AI technologies. English is often the language used in technical documentation, software, and international communications, so its mastery allows professionals to access a wide range of resources, collaborate efficiently on international projects, and stay up-to-date with the latest trends and advancements, as indicated by interviewee P5: *"Studying English is key nowadays, as we are in a globalized world and it will allow us to carry out projects in almost any country."* Similarly, P8 mentions, *"Mastery of English is fundamental in AI integration, as it facilitates access to the latest research, technologies, and international collaborations related to this topic."*

Knowledge in Cybersecurity: This skill involves understanding and applying digital security practices to protect data and infrastructures related to AI in the construction industry. Given the increasing reliance on digital and AI systems, such as BIM and process automation, cybersecurity knowledge is essential to prevent cyberattacks, loss, or manipulation of critical data. This includes implementing security protocols, managing protection software, and staying informed about the latest threats, as highlighted by P5: *"AI works with a lot of data, which can be very sensitive; hence companies won't want to give their data to just any company to propose a solution, then that's a big challenge I think the artificial intelligence industry has to take charge of and somehow guarantee the security that your data will be used safely and not leak or be misused."*

Interviewee P8 mentions a concrete example: *"In the mining sector, a company has created a chatbot based on ChatGPT, but with its database. This allows for analysis and queries of*

specific company data without compromising the confidentiality of the information," demonstrating how AI solutions can be designed to maintain data integrity and confidentiality.

Results on recommendations for adjusting the curriculum

Table 2 displays the frequencies of the recommendations made by the interviewed construction experts.

Table 2. Emerged recommendations from experts and frequencies.

Recommendations for adjusting the curriculum	Frequency
Cross-disciplinary incorporation of AI into the curriculum	14
Encouragement of soft skills development	14
Establishment and strengthening of ties between academia, the industrial sector, and technology companies	13
Training in AI ethics and legislation	13
Emphasis on teaching programming languages	13
Integration of data management and analysis	13
Continuous adaptability of the curriculum to technological changes and market needs	12
Promotion of innovation and creativity	12
International perspective in curriculum design	4

The recommendations from experts in the field underscore the need for a holistic educational approach encompassing generic competencies, advanced technical skills, and interpersonal and adaptive abilities. These recommendations are presented below, according to what the interviewees mentioned.

1. Cross-disciplinary integration of AI in the curriculum. Implies integrating artificial intelligence not as an isolated module but as an interconnected element across all learning areas in the Construction Engineering program. *It is important to integrate artificial intelligence transversally into the curriculum of the Construction Engineering career, ensuring that students master both the theoretical foundations and their practical applications in the industry (P1).* For this, the following is suggested:
    - Introductory courses with AI fundamentals: Introduce basic AI concepts in introductory courses to familiarize students with this technology's terms, applications, and potential.
    - Specific AI modules in technical subjects: Include AI modules in subjects such as design, structural calculation, and hydraulics, among others, where AI can have direct applications, such as design optimization, construction monitoring and control, and risk analysis.

- AI case studies in construction projects: Analyze cases where AI has been successfully used in the construction sector, integrating them into various subjects to show its real and practical impact.
- Development of integrated projects: Propose integrative projects where students must apply AI to solve complex problems, thus fostering a holistic understanding of its use in construction.
- Simulations with AI tools and applications: Use specialized software and applications to simulate construction situations that require AI, allowing students to experiment with these tools in a controlled environment.
- Integration of industry-related AI standards: Align the curriculum with professional standards that include AI competencies, ensuring students acquire the necessary skills for future entry into the workforce.

2. Promoting the development of soft skills: It is imperative to foster the development of soft skills, among which critical thinking stands out, to complement the technical training of students. These skills, including effective communication, teamwork, leadership, conflict resolution, etc., are essential for success in an industry that requires intensive and efficient collaboration. Integrating critical thinking into the curriculum promotes a deeper understanding and reflective evaluation of problems and solutions in construction. For this, courses should be designed to teach technical fundamentals and challenge students to analyze, question, and assess different approaches and solutions through case studies, debates, and collaborative projects. *The emphasis on soft skills, such as effective communication and teamwork, is crucial even in a technologically advanced environment (P4).*

3. Establish and strengthen links between academia, the industrial sector, and technology companies: To prepare Construction Engineering students for current challenges, the academic program must establish and maintain strong links with the industrial sector and technology companies. This tripartite approach ensures a theoretically solid education and is deeply rooted in current practice and technological innovation. *It is recommended to strengthen partnerships between universities, construction companies, and technology firms to keep students up-to-date and prepared for the labor market demands (P10).* Therefore, the following is recommended:
   - Partnerships with the industry: Establish collaborations with construction companies and organizations to enable students to gain real-world experience and understand the current needs and challenges of the industry. These partnerships can include internships, capstone projects, mentorships, and forums and panels with sector leaders.
   - Joint initiatives with technology companies: Coordinate alliances with technology companies, especially those specializing in AI, where students can access the latest generation of tools and software, experiencing professionals at the forefront of technological development. Collaboration could include educational licenses for construction software, training workshops, and innovation challenges.
   - Applied research: Encourage joint research projects between academia and industry to solve practical problems and develop new AI applications in construction. This enhances the quality of education and contributes to the advancement of the construction industry.
   - Events and networking: Organize regular events such as job fairs, talks, and webinars with industry and technology professionals to strengthen students' networks and knowledge of current trends.

- Centers of excellence: Establish centers or labs of excellence within the university with the support of industrial and technological partners, where practical applications of AI in construction can be explored and demonstrated.

4. Training in AI ethics and legislation: Students should be educated about the legal challenges presented by this emerging technology. This aspect of the curriculum should address ethical issues such as data privacy, algorithmic bias, responsibility in automated decision-making, and the social impact of automation and AI in the construction industry. Education in AI ethics should go beyond theoretical concepts, involving students in discussions, case analyses, and simulations that confront them with real situations where they must weigh the ethical implications of their technical decisions. Additionally, it's important to offer a clear understanding of current and emerging legislation related to AI, including data privacy regulations, drone usage, robotics in construction, and safety standards, to ensure students are informed about the legal frameworks that regulate the application of these technologies. This includes integrating ethics modules into technical courses and collaborating with AI law and ethics experts to offer an interdisciplinary perspective. Encouraging a critical and reflective approach to how technology affects society and the environment and how engineers' decisions can have long-term repercussions is vital. Training in these aspects enriches students' technical capability. It prepares them to be responsible and conscious leaders in the future of construction engineering, a field increasingly influenced by artificial intelligence and automation. *Educating on AI use's ethical and legal aspects is important to prevent misuse and overreliance on automated responses without critical analysis (P8).*

5. Emphasize programming language instruction: As mentioned in skills, including programming in the Construction Engineering program is essential to align education with current technological trends, especially using Artificial Intelligence (AI). Basic courses should establish a solid understanding of key languages like Python, Java, etc., applying this knowledge through projects that simulate real construction scenarios. This practical approach allows students to see the direct relevance of programming in resource optimization, process simulation, and customization of construction software. *Students must acquire programming knowledge, as artificial intelligence operates based on algorithms. Understanding these algorithms and how they function is key (P12).*

6. Integrate data management and analysis: Students should acquire skills to collect, process, and analyze data to inform and optimize decision-making in construction projects. This is crucial for navigating the growing sea of data generated by modern technologies, including AI. Teaching data management would cover data capture and storage, cleaning, and analysis preparation. Meanwhile, data analysis would involve training students in statistical methods, data mining, and visualization and using analytical tools to interpret trends, predict outcomes, and extract valuable insights. *Students should be prepared for data management and statistical analysis, as these are key skills in interpreting information processed by AI (P5).*

7. Continuous curriculum adaptation to technological changes and market needs: It is crucial to continuously adapt to technological advancements and market demands. This involves establishing mechanisms for periodic curriculum review, where feedback from industry experts and technological allies is used to adjust and update content and teaching methods. Such a process ensures that educational programs keep pace with

technological innovations and reflect the most current practical and theoretical skills required in the construction industry. *It is recommended to constantly update the curricular grids to reflect technological advances and respond to the changing needs of the industry (P7).*

8. Encouraging innovation and creativity: Innovation and creativity in the Construction Engineering program are fundamental to preparing students to face the unique challenges of a constantly evolving sector. To achieve this, the curriculum should include activities and teaching approaches that inspire students to think beyond traditional solutions and encourage exploration and experimentation. This can be through design and construction projects inviting students to apply theoretical knowledge in practical scenarios, challenging them to innovate in sustainability and energy efficiency, and integrating emerging technologies like AI. Additionally, courses should encourage students to question conventional methods and seek new ways to solve complex problems. On the other hand, incorporating workshops, hackathons, and design competitions where students can collaborate in multidisciplinary teams is an excellent way to stimulate creativity. These activities should be complemented by talks and seminars led by innovators and industry leaders who can share their experiences and insights on the latest trends and technologies in construction. *It is crucial to encourage innovation and creativity to stimulate students to think innovatively and creatively in applying AI solutions in construction (P14)*.

9. International perspective in curriculum development: This implies integrating best practices, standards, and technologies used in the global construction industry into the curriculum. This approach ensures that students are up-to-date with global trends and technological advancements and prepared to work internationally. To achieve this, it's crucial to incorporate comparative studies of how artificial intelligence and other advanced technologies are applied in construction in different countries. Additionally, establishing academic exchanges and collaborations with foreign universities and entities would allow students and teachers to gain a broader and more diverse view of construction engineering. *It is important to observe international trends in AI and construction processes to adopt the best practices and technologies globally (P3).*

Discussion

An in-depth analysis of semi-structured interviews with construction industry experts identified current trends and labor market needs in an ever-evolving technological landscape. Figure 1 indicates that "Critical Thinking" and "Professional Ethics" are essential competencies, underscoring the importance of objective judgment and a solid foundation in moral principles when utilizing advanced technologies like AI. These results highlight a trend toward valuing reflection, objective judgment, and a strong moral foundation in using complex technologies.

In the current era of technological advances and global transformations, the training of professionals becomes essential to address emerging challenges. In this context, the Tuning Latin America Project [18] has played an important role in defining the core competencies that professionals from various disciplines should cultivate. This article outlines the essential competencies for professionals in the construction industry in the context of AI integration, which have already been described. To better understand these competencies, they have been classified according to the framework proposed by the Tuning Latin America Project [18].

Table 3 shows the relationship between the competencies identified in this study and the project categories of the Tuning Project.

Table 3. Competencies identified in this study and the project categories of the Tuning Project [18].

Competence	Associated Competence from the Tuning Project	Type of Competence	Type of Generic Competence
Critical Thinking	Critical and self-critical abilities	Generic	Systemic
Professional Ethics	Ethical commitment	Generic	Systemic
Effective Communication	Oral and written communication abilities	Generic	Instrumental
Management of collaborative and multidisciplinary teams	Interact with multidisciplinary groups and provide comprehensive civil engineering solutions	Specific	N/A
Adaptability and Flexibility	Ability to act in new situations	Generic	Systemic

The categorization of competencies according to the Tuning Latin America Project provides an organizational structure for our analysis. It highlights the relevance of these competencies in the context of education and professional training in the region. This Project, focusing on harmonizing curricula and promoting key competencies, establishes a solid framework for assessing professionals' readiness across various fields. The ability to critically evaluate AI solutions becomes an indispensable skill to ensure responsible and effective applications in construction, as mentioned by Hernandez-de-Menendez et al. [19].

Competencies such as "Effective Communication," "Management of Collaborative and Multidisciplinary Teams," and "Adaptability and Flexibility" emphasize the importance of interpersonal and management skills in coordinating complex projects and adapting to the rapid technological transformations experienced in construction.

Regarding skills, Figure 2 underscores the importance of "Mastery of Programming Languages" and "Data Analysis and Management." These findings highlight a trend toward valuing programming language mastery and handling large volumes of information, which is essential for designing and applying AI solutions in construction. Boltsi et al. [20] mention that when students learn about computational thinking along with science, technology, engineering, and mathematics (STEM areas), they can use and better understand computing techniques in areas they may already know or find easier to understand. This is important because it allows them to see how different areas of knowledge connect and complement each other. For example, they can use programming to solve a math problem or deeply understand scientific concepts. This learning method helps them improve their computing skills and teaches them how different subjects unite to solve real problems. It is very valuable in today's world, where combining knowledge from different areas is fundamental to innovating and creating new solutions.

On the other hand, "Mastery of Emerging Technologies, Applications, and Tools Related to AI" and "Mastery of Construction-Related Software" were highlighted by interviewees, showing the need for an updated education that includes the latest tools and applications

related to AI. In this context, Obi et al. [21], researchers from the United Kingdom, emphasize the relevance of learning Building Information Modeling (BIM) systems for Construction students, suggesting that such tools should be incorporated through collaborative activities based on analyzing projects grounded in real problems. Other authors [22, 23] also discuss the relevance of these tools in preparing future construction professionals. Furthermore, "Mastery of the English Language" and "Knowledge in Cybersecurity" were highlighted with high frequencies, reflecting the globalization of the construction sector and the growing importance of information security.

The study's findings have direct implications for the education and training of future professionals in Construction Engineering. Including a curriculum that emphasizes competencies and skills, from programming to data management, and integrates ethical and communication considerations is imperative to prepare future professionals for a labor market increasingly integrating AI. It is recommended that the Construction Engineering program comprehensively incorporate AI elements, from introductory courses to integrative projects and case studies reflecting real AI applications in construction. Moreover, collaboration with the industry and technology companies should be intensified to provide students with a realistic and practical view of AI implementation.

Continuous adaptation of the curriculum to technological advances and market demands is essential. International standards and best practices should be considered to ensure students are prepared to operate globally. Innovation and creativity, along with the development of soft skills, complete the profile of the modern construction professional.

Conclusion

This study aims to explore and understand the competencies and skills professionals require in the context of AI integration in the construction industry. To achieve this goal, we selected industry experts through convenience sampling and conducted semi-structured interviews. These interviews were adapted to the participant's needs and conducted in person and remotely, allowing us to gather valuable insights into current labor market trends in this sector.

We identified 22 competencies and 13 essential skills for professionals in Construction in the context of Artificial Intelligence integration. The analysis of semi-structured interviews with industry experts reveals a labor market that highly values critical reflection, ethical principles, interpersonal and management skills, technical mastery in programming, data analysis, mastery of emerging technologies and construction-related software, English, and cybersecurity knowledge. These findings underline the importance of adapting educational programs to prepare future professionals for a labor market where AI is increasingly involved.

Integrating AI in construction is not just an emerging technological trend but a fundamental transformation in the industry. The competencies and skills identified in this study reflect the need for comprehensive preparation from technical aspects such as programming and data management to soft skills like effective communication, team management, and adaptability. Education in construction engineering must evolve to incorporate these essential elements, ensuring that future professionals can technically lead and manage projects and adapt to a constantly changing environment.

Limitations

This work was based on a qualitative method involving interviews. It is important to note that although the convenience sampling method provided accessibility to a group of experts, this approach might lack the necessary diversity for the sample to be considered representative of the global construction industry.

Future work

As previously mentioned, this paper reports part of the results obtained from the interviews, aiming to produce a more comprehensive report incorporating emerging findings. Furthermore, future research could explore the effectiveness of current educational programs in incorporating the competencies and skills identified in this study. It would be valuable to investigate the direct impact of these skills on productivity and innovation in real construction projects. Comparative international studies could also provide a broader perspective on how different countries and cultures address AI integration in construction. Finally, investigating the perception and receptiveness of current construction engineering students towards these proposed curricular changes would be interesting.

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Appendix 1. Leading interview questions.

Type of Qs	Questions
Opening	Question 1: In your experience, how has the construction industry evolved with the integration of Artificial Intelligence, and what are the main challenges it currently faces? Question 2: Can you provide specific examples of how Artificial Intelligence has benefited or transformed construction projects?
Competencies and Skills	Question 3: Considering advancements in AI, what technical skills and competencies do you believe are essential for construction engineering students today? Question 4: How should construction engineering programs adapt to better prepare students for using AI technologies in the future?
Industry Perspectives and Needs	Question 5: From the perspective of professionals and companies in the sector, what is the current demand for knowledge and skills related to AI in the construction industry? Question 6: How do professionals in your field perceive the relevance of AI in their daily work and the efficiency and quality of projects?
Further Exploration	Question 7: What role does interdisciplinary collaboration play in integrating AI into construction, and how can students prepare for this? Question 8: How do you see the future of Artificial Intelligence in the construction industry over the next five to ten years?
Challenges and Opportunities	Question 9: What are construction professionals' biggest obstacles when integrating AI into their projects? Question 10: What unexplored opportunities do you see for applying AI in construction?
Closing	Question 11: Based on your experience, what recommendations would you make to foster the development of AI-related competencies in future construction engineers? Question 12: Could you list the key skills and competencies you consider indispensable for a newly graduated construction engineer in the current technological landscape?