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ARTIFICIAL INTELLIGENCE 101 FOR ARCHITECTURAL EDUCATION

MİMARLIK EĞİTİMİ İÇİN YAPAY ZEKA 101

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Abstract

This study explores the integration of Artificial Intelligence (AI) in architectural education, reflecting on its transformative impact on design pedagogy. It reviews the evolution of digital technologies within architectural curricula, highlighting key phases from CAD/CAM to computational design thinking and the current era of

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AI. The research investigates how AI is being implemented in architectural schools through both curricular and extracurricular activities, including specialized courses, workshops, and experimental projects. By evaluating the challenges and potentials of current practices, this study offers recommendations for integrating AI into architectural education to foster a more data-driven and innovative learning environment. This analysis aims to prepare future architects to adopt AI tools across all stages of design, from conceptualization to construction, thereby addressing the evolving demands of the profession.

Keywords: Artificial Intelligence, Architecture Education, Machine Learning

Öz

Bu çalışma, yapay zekanın (YZ) mimarlık eğitimine entegrasyonunu araştırarak, tasarım pedagojisindeki dönüştürücü etkisini ele almaktadır. Mimarlık müfredatında dijital teknolojilerin evrimini gözden geçirerek, CAD/CAM'den hesaplamalı tasarım düşüncesine ve günümüzün YZ çağındaki gelişmelere kadar olan ana aşamaları vurgulamaktadır. Araştırma, YZ'nin mimarlık okullarında nasıl uygulandığını hem müfredat içi hem de müfredat dışı faaliyetler aracılığıyla, özel dersler, atölyeler ve deneysel projeler gibi unsurları inceleyerek ortaya koymaktadır. Mevcut uygulamaların zorluklarını ve potansiyellerini değerlendirerek, daha veri odaklı ve yenilikçi bir öğrenme ortamı oluşturmak için YZ'nin mimarlık eğitimine entegrasyonuna yönelik öneriler sunmaktadır. Bu analiz, geleceğin mimarlarının kavramsallaştırmadan inşa sürecine kadar tasarımın her aşamasında, YZ araçlarını benimsemelerini sağlayarak mesleğin gelişen taleplerine yanıt vermeye hazırlamayı amaçlamaktadır.

Anahtar Kelimeler: Yapay Zeka, Mimarlık Eğitimi, Makine Öğrenimi

1. Introduction

Advancements in digital technologies have impacted many fields, including the practice of architecture and, inevitably, architectural education. To gain a deeper understanding of the directions and characteristics of this impact, the literature presents several assumptions and classifications (Bernstein, 2022; Carpo, 2011; Carpo, 2017; Picon, 2010; Schmitt, 1997). While the challenging part of classification is that the thresholds, durations, and changes might overlap or indicate different meanings, they are still helpful. In his 1997 paper, Gerhard Schmitt provides a pioneering classification and evaluates the evolutionary development of designer-computer interaction through three distinct phases: the computer as a tool or instrument, the computer as a medium, and the computer as a partner. Schmitt's distinction remains still valid today (Tong et al., 2023a).

With a retrospective perspective, it can be updated as the CAD/CAM era, where computers served primarily as tools for representation; the era of computational design thinking reflected in design processes; and the current era of artificial intelligence. Alternatively, this tool-medium-partner distinction can be viewed as representation-algorithm-artificial intelligence, or as solid models, computational models, fabrication models, and again, algorithmic models supported by artificial intelligence. Today, the ability to generate, store, and process vast amounts of data is unprecedented. Combined with the growing power of digital tools, this capability plays a crucial role in driving transformation, beyond any specific classifications.

Carpo (2017) identifies two major digital turns: the first in the 1990s and the second in the 2010s. The first digital turn involved the adoption of digital design tools in the design process, focusing on mass customization and the creation of unique, non-standard designs. The second digital turn in the 2010s is characterized by the rise of big data and computational methods, which enable designers to search, analyze, and utilize vast amounts of information. Bernstein (2022) offers a classification of the interaction between architecture and technology into three stages—Computer-Aided Design (CAD), Digital Interstice, and Machine Learning—which aligns with Carpo's theoretical framework. According to Bernstein (2022), the CAD phase covers the representation of architectural information in the digital environment, including computerized drawing, rendering, building information modeling (BIM), and data management. This phase extends traditional drawing techniques to digital orthographic representation and incorporates object-oriented ontology through BIM models. The concept of Digital Interstice, as defined by Bernstein (2022), refers to the coexistence of analog and digital methods. Unlike Carpo's (2017) focus, Bernstein's (2022) classification projects future pivotal points, such as 2030, highlighting a shift towards new ways of thinking and creating, driven by data-driven processes and artificial intelligence.

Today, artificial intelligence (AI) is utilized across a broad spectrum in architectural practice, encompassing conceptual design, analysis, evaluation, construction, and post-occupancy screening. It functions as a decision support system, aids in the automation of design, representation, and evaluation processes, and extends to data-driven design. This transformation in architectural practice significantly impacts architectural education, necessitating a review of the curriculum. This study aims to present how artificial intelligence is addressed within architectural schools through both curricular (separate courses, integration into practical or theoretical classes) and extracurricular (workshops and experimental projects) applications. By evaluating the challenges and potentials of current practices, the study offers recommendations for integrating artificial intelligence into architectural education.

2. Before AI: Earlier Attempts that Integrate Digital Technologies into Architectural Design Education (1990-2010)

In broader terms, the integration of digital technologies into architectural education can be investigated under two axes: (i) CAD (computerization, digitalization, representation) and (ii) computation in design (parametric and algorithmic design, performance-oriented design, simulation, and evaluation). The aforementioned taxonomy can also be redefined as follows with the impact of the advances in AI technologies:

- Computer literacy (Perkovic & Settle, 2009),
- Algorithm literacy (Carpo, 2011),
- Machine learning and big data literacy (Bernstein, 2022).

The term “Virtual Design Studio” was first used by Mitchell and McCullough (1991). By 1993, the internet made it possible to conduct collaborative design experiments between two large groups (Wojtowicz et al., 1993; Tong & Çağdaş, 2005). In the context of remote and internet-based collaborative design practice, numerous applications and experiments have been conducted worldwide. In Türkiye, the first such initiative took place during the spring semester of the 1999-2000 academic year at Istanbul Technical University (ITU), Faculty of Architecture, Department of Architecture. The elective course “Information Technologies in Architecture” included a collaborative Virtual Design Studio project with the Faculty of Architecture at the University of Sydney (Tong & Çağdaş, 2005). Following an undergraduate inter-university remote collaborative design experiment as part of an elective course, ITU introduced a graduate-level elective course titled “Virtual Architectural Design Studio” within the Architectural Computation Master’s Program at the ITU Informatics Institute. During the spring semester of 2001-2002, a virtual studio collaboration was conducted with Uludağ University and in the spring semester of 2006-2007, another was held with Oklahoma University (Tong & Çağdaş, 2005).

Therefore, it can be observed that the experimental studies of remote internet-based collaborative design processes in the 1990s led to the introduction of separate elective courses first at the undergraduate level and then at the graduate level in the 2000s at ITU. Following the pandemic, these remote education studio courses in all architecture schools have become the new normal (Khan & Thilagam, 2022) by the 2020s.

Table 1 presents a general overview of the bachelor’s and master’s level courses offered at ITU. The bachelor course MIM120E-Introduction to Computational Design Tools and Methods in Architecture was introduced in the fall semester of 2017-2018 for the first time. At the master’s level, MBL517E-Digital Fabrication & Prototyping in Architectural Design was first offered in the fall semester of 2016-2017. Additionally, the bachelor course MIM418E/MIM4056E – Design and Fabrication Techniques was introduced in the Faculty of Architecture in the fall semester of 2019-2020. Prior to the establishment of these instructional courses focusing on digital fabrication, relevant skills were introduced through intensive one-week student workshops held between 2007 and 2017. The master’s course MBL549E/MBL559E-Machine Learning in Architecture/Machine Learning in Architectural Design was introduced for the first time in the spring semester of 2019-2020.

Table 1. Reflection of Digital Technologies in Architecture Curricula, Istanbul Technical University Case

Key-concept	Concepts	Course Level and Type	Selected Courses in Istanbul Technical University, Department of Architecture and Architectural Design Computing Graduate Program
Digitalization	Computer-Aided Design, Computer Aided Drawing, Asynchronous Design, Remote Collaboration	Bachelor, Compulsory	BIL101E – Introduction to Computers and Information Systems
		Bachelor, Elective	MIM344E – Information Technologies in Architecture
		MSc, Elective	MBL533 – Computer Aided Architectural Design
		MSc, Elective	MBL538 – Virtual Design Studio
		MSc, Elective	MBL542 – Multimedia in Design
Computation in Design	Design Automation, Algorithmic Thinking	Bachelor, Compulsory	MIM120E – Introduction to Computational Design Tools and Methods in Architecture
		MSc, Compulsory	MBL511 – Knowledge-Based Architectural Design
		MSc, Compulsory	MBL512E – Generative Systems in Architectural Design
		MSc, Compulsory	MBL513E – Digital Architectural Design and Modeling
		MSc, Compulsory	MBL514E – Digital Architectural Design Studio
		MSc, Compulsory	MBL531E – Computer Programming in Architecture
Digital Fabrication	Computer Aided Manufacturing	Bachelor, Elective	MIM418E/MIM4056E – Design and Fabrication Techniques in Architecture
		MSc, Elective	MBL517E – Digital Fabrication & Prototyping in Architectural Design
Data Management	Data Driven Design, Data Refinement	MSc, Elective	MBL515E – Database Design and its Applications in Architecture
		MSc, Elective	MBL549E/MBL559E – Machine Learning in Architecture/Machine Learning in Architectural Design

Another direction is introducing the logic of computational thinking to architecture students through both theoretical and practice-based courses. Luescher and Elwazani (2006) addressed computational thinking in the architecture curriculum by emphasizing the integration of digital technologies and media into architectural education at Bowling Green State University. In their teaching experience, they started with two courses: "mechanical" (focused directly on introducing digital technologies to students) and "architectural" (related to the architectural domain), conducted with an elective course on computer modeling and visualization in architecture (Luescher & Elwazani, 2006). Third – and fourth-year architecture students had access to digital technologies such as laser cutting, prototype modeling, printing, and scanning (Luescher & Elwazani, 2006). All these can be considered an initial experiment in the shift from computer literacy towards algorithmic literacy.

However, printing and scanning remained two-dimensional, unlike the promise of 3D printing in the following decade. Perkovic and Settle (2009) proposed a framework for integrating computational thinking across the curriculum. Within this framework, they identified three key computational thinking skills: computer literacy, computer fluency, and critical thinking and reasoning. The third skill was defined as computational thinking, encapsulated under the novel concept of "computing principles." These computing principles include computation, communication, coordination, recollection, automation, evaluation, and design (Perkovic & Settle, 2009). They suggested and evaluated the structuring of a total of 19 courses to complement each other in teaching these computing principles. Perkovic and Settle (2009) relate computational thinking, as an emerging skill, to Wing's (2006) expression: "Computational thinking is a fundamental skill for everyone, not just for computer scientists. To reading, writing, and arithmetic, we should add computational thinking to every child's analytical ability."

At the graduate level, the Bartlett School of Graduate Studies introduced a one-year master's program in Adaptive Architecture and Computation (AAC at UCL) in 2006, replacing the Virtual Environments program (Schieck, 2008). This program consists of five modules:

1. Introduction to Adaptive Architecture and Computation
2. Digital Space and Society
3. Generative Space, Form, and Behaviour
4. Computing for Emergent Architecture I
5. Computing for Emergent Architecture II (Schieck, 2008).

The AAC at UCL program offered an integrated curriculum that combines theoretical and practical skills and experiences. It is designed at the graduate level and focuses on computational design. This program includes design studio lectures, fieldwork, research-oriented learning, and workshops (Schieck, 2008). On the other hand, Duarte et al. (2012) compared the integration of CAAD into undergraduate architectural education at two schools: Instituto Superior Técnico (IST), Technical University of Lisbon, Portugal, and the University of Campinas (Unicamp), Brazil. At IST, a structured approach was implemented with the following courses included in the curriculum:

- CAD I: Geometric Modeling and Visualization, 1st Semester,
- CAD II: Programming and Digital Fabrication, 2nd Semester,
- CAAD: Computer-Aided Architectural Design Studio, 9th and 10th Semesters.

In contrast, at Unicamp, digital technologies were gradually introduced through elective courses and workshops, focusing on integrating these tools into the existing design studio culture, following a bottom-up strategy. At the undergraduate level, these efforts involved integrating digital technologies into existing curricula (Duarte et al., 2012). At the graduate level, comprehensive programs were developed (Schieck, 2008), apart from the pilot studies for master courses supporting computational design skills (Alaçam et al., 2014; Alaçam & Güzelci, 2017; Bacınoğlu & Alaçam, 2014; Gürer et al., 2012; Güzelci et al., 2021; Varinlioğlu et al., 2016a; Varinlioğlu et al., 2017; Ünlü & Alaçam, 2021). Additionally, both undergraduate and graduate-level student workshops focused on developing algorithmic thinking skills (Alaçam et al., 2018; Duarte et al., 2012; Varinlioğlu et al., 2015; Varinlioğlu et al., 2016b; Varinlioğlu et al., 2017; Wurzer et al., 2011), establishing a significant presence of computational design theory and applications in architectural curricula.

Consequently, efforts to update architectural curricula globally began as experimental studies in the 1980s and evolved into initiatives focused on computer literacy in the early 2000s, eventually progressing to algorithm literacy in the following decade.

3. AI in Architectural Design Education

Integrating artificial intelligence (AI) and machine learning (ML) into architectural design education is a relatively new topic. However, Van der Vlist et al. (2008) have conducted pioneering studies on this subject at the Eindhoven University of Technology, the Department of Industrial Design. Van der Vlist et al. (2008) utilized a competency-based learning model combined with embodied intelligence to introduce machine learning to design students. Their approach focused on integrating knowledge, skills, and attitudes through hands-on interaction with tangible systems like the Lego Mindstorms NXT. In their teaching experience, they provided a two-week theory-oriented introduction, followed by asking students to explore concepts, develop their own designs, evaluate design alternatives, and demonstrate their work in the third and fourth weeks (Van der Vlist et al., 2008). Proposing a broader framework that encompasses Van der Vlist's educational approach as well, Sanusi and Oyelere (2020) presented a comprehensive review of pedagogical frameworks for introducing machine learning to high school students (K12 level) and non-computer programmers (Figure 1) while highlighting the need for tailored pedagogical strategies. A more detailed comparison, analysis, and evaluation can be found in Sanusi and Oyelere's (2020) paper.

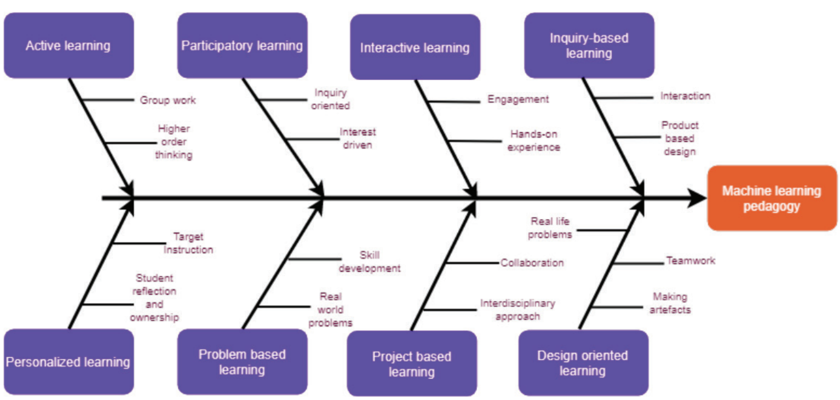

Figure 1. Pedagogical Framework Classification for Introducing Machine Learning
Source: Sanusi, I. T. & Oyelere, S. S., Pedagogies of machine learning in K-12 context. In *2020 IEEE frontiers in education conference (FIE)* (pp. 1-8). IEEE. 2020.

The integration of AI into architectural education has gained significant interest, with various pedagogical approaches and methods being explored to enhance students' understanding and application of AI concepts. One notable approach is problem-based learning, as highlighted in the "Machine Learning Applications in Architecture" course at Middle East Technical University, which emphasizes data literacy, pattern recognition, and intelligent model use through projects that allow students to select topics of interest, such as 3D modeling from 2D drawings or optimizing daylight in architectural designs (Sorguç et al., 2022). Another example is the "Visual Communication I: Visualization and Technical Drawing" course at ITU, which integrates AI-based tools (e.g. Midjourney) to blend traditional hand-drawing techniques with AI-generated imagery, thereby fostering students' creative thinking and digital representation skills (Tong et al., 2023a; Tong et al., 2023b). Additionally, Ceylan (2021) discusses the importance of incorporating AI across various architectural domains, including design, construction, and representation, to prepare students for the evolving demands of the profession. These diverse pedagogical strategies highlight the potential for AI to enrich architectural education by bridging traditional techniques with advanced computational tools, promoting interdisciplinary learning and innovation.

The literature also highlights the transformative potential of AI in architectural education through advanced curriculum adaptations, as discussed by Korra et al. (2022), who explore the incorporation of AI across multiple domains, including Building Information Modeling (BIM), site analysis, and rendering, to foster a more data-driven and technologically competent learning environment. Additionally, Horvath and Pouliou (2024) and Zeytin et al. (2024) propose introducing AI-based methods as core elements in architectural education to enhance students' engagement and learning outcomes. In another study, Başarır (2022) suggests a research-based elective course model that employs AI tools to simulate architectural tasks, encouraging students to define design parameters and use AI to explore various architectural solutions. Collectively, these approaches illustrate a growing recognition of AI's transformative potential in architectural education, from enhancing representational techniques to fostering new forms of creative expression.

Table 2 demonstrates an overview of AI-related courses in Turkish universities with a focus on integrating AI into architecture and design education.

Table 2. Reflection of AI in Architecture Curricula, Case of Turkish Universities

School Name	Course Code – Course Name	Level (Undergraduate / Graduate)	Weekly Hours (Theory+Tutorial+Lab) / ECTS / Semester	Course Type (Compulsory / Elective)	Goals
Istanbul Technical University	Information Technologies in Architecture – MIM4021	Undergraduate	(1+2) / 4 / 5-8th	Elective	The aim is to familiarize students with the use of information technologies for communication and collaboration in architectural design and to experience virtual design studios.
Istanbul Technical University	Artificial Intelligence in Architecture, Planning, and Design – MYZ306E	Undergraduate	(3+0) / 4 / 5th	Elective	The goal is to provide students with a foundational understanding of artificial intelligence and its applications in architecture while encouraging ethical awareness and practical experience.
İzmir University of Economics	Architectural Intelligence: Artificial Intelligence (AI) in Architecture – ARCH362	Undergraduate	(2+2) / 4 / Fall&Spring	Elective	The goal is to equip students with the ability to analyze architectural data using machine learning, apply AI models in their design practice, and preprocess data for machine learning tasks.
Antalya Bilim University	Artificial Intelligence in Architecture – ARC4065	Undergraduate	(3+0) / 3 / Fall	Elective	The objective is to help students understand AI concepts, solve architectural problems using advanced methods, and identify research opportunities in the field of artificial intelligence.
Istanbul Technical University	Machine Learning for Architectural Design – MBL559E	Graduate	3 / 7,5 / Fall&Spring	Elective	The goal is to teach students the fundamentals of machine learning and its application in architectural design, focusing on data analysis, neural networks, and the generation of design projects using machine learning.
Middle East Technical University	Machine Learning Applications in Architecture – BS723	Graduate	(2+2) / 8 / Fall&Spring	Elective	The aim is to provide students with a comprehensive understanding of machine learning and its potential applications in computational design and architecture.

According to Table 2, both undergraduate and graduate courses emphasize building knowledge in artificial intelligence (AI) and/or machine learning (ML), particularly focusing on how these technologies can be applied in architectural design. Students at both levels are expected to develop an understanding of AI's role in architecture. Additionally, data literacy is emphasized, with students learning how to handle, process, and use data effectively in their architectural projects. While undergraduate students are introduced to basic data handling and literacy, graduate students focus on tasks such as model creation and result interpretation, which involves analyzing outcomes from AI models and understanding their implications in the architectural context.

Based on courses offered by universities outside Türkiye, several key findings emerge regarding the integration of AI into architectural education. These studies aim to merge artificial intelligence (AI) with architectural design, focusing on critical engagement with AI technologies and their application in architectural practice. Each course presents a distinct approach to integrating AI into the curriculum.

For example, at Singapore University of Technology & Design (SUTD), the compulsory undergraduate course Artificial & Architectural Intelligences in Design (HTC) – 20.224 encourages students to critically engage with AI paradigms by combining theoretical and practical work, such as essays, presentations, and design mock-ups, to address AI-related societal issues. Another course at SUTD, the elective Creative Machine Learning – 20.318, emphasizes the creative application of machine learning in design, guiding students through prototyping to professional-level design presentations, with a hands-on approach to integrating AI into the design process. Similarly, at the University of Southern California, the undergraduate elective course A.I. in Sustainable Architecture Practice – ARCH-582 focuses on combining AI tools with sustainable architecture. It emphasizes improving building performance and conducting environmental analyses using AI-based solutions, reflecting the growing trend of integrating AI with sustainability principles in architectural education.

Across these courses, students are taught to incorporate AI into their projects, whether through a focus on sustainability or AI-driven design. They explore how AI influences design concepts, decision-making processes, and performance analysis in architectural practice. A notable theme is the practical and creative application of AI, as seen in courses where students engage in hands-on projects like prototyping and scenario-based designs. These tasks challenge students to merge creativity with technical AI knowledge, encouraging them to solve real-world architectural problems using AI and machine learning techniques.

Additionally, strong emphasis is placed on communication and professional presentation skills. Students are required to present their design processes and outcomes effectively, both visually and in writing, to a professional audience. This ensures that they develop not only technical proficiency but also the ability to clearly articulate their AI-driven design solutions. Lastly, collaboration and teamwork are highlighted, particularly in courses where students work together to tackle AI-based design challenges and broader societal issues. This interdisciplinary approach enhances students' problem-solving and teamwork skills, further enriching their architectural education within an AI-driven context.

4. Towards a Pedagogical Framework for Teaching AI to Architects

4.1. Theory-Practice Balance

Undergraduate courses focus on introducing core concepts and practical applications of AI and ML. The emphasis is on familiarizing students with the terminology and tools, and projects are often designed to be more straightforward and instructive, usually completed in teams. These projects help students to apply the concepts they've learned in a manageable way, such as using a decision tree to predict design outcomes based on input data. In contrast, graduate courses involve a more in-depth theoretical understanding of AI and ML, encouraging students to engage in independent research and complex projects. Graduate students are expected to explore data on a deeper level, often creating sophisticated models and conducting comprehensive analyses of how AI can be applied to solve architectural problems. Their projects typically involve greater complexity and demand the production of detailed reports and presentations that communicate their methodologies, processes, and findings clearly. These courses encourage students to investigate advanced AI applications and develop independent research capacities, preparing them for professional or academic pursuits in the field.

For the undergraduate courses, such as ARC 4065 – Artificial Intelligence in Architecture and ARCH 362 – Architectural Intelligence, there is a notable emphasis on foundational theoretical knowledge and the introduction of AI concepts, tools, and methods, combined with practical applications. These courses typically dedicate a substantial portion of their structure to theoretical lectures, discussions, and conceptual understanding, with practical components like hands-on exercises, assignments, and project work integrated to help students apply their learned knowledge in real-world scenarios. The practical applications are often used as a means to reinforce theoretical understanding and encourage students to develop critical thinking and problem-solving skills in the context of architectural design.

In contrast, the master's level courses, such as MBL 559E – Machine Learning for Architectural Design and MYZ306E – Artificial Intelligence in Architecture, Planning, and Design, demonstrate a more balanced or even practice-oriented approach. These courses tend to focus heavily on applied learning, with a significant amount of time allocated to hands-on projects, coding exercises, data analysis, and AI model development specific to architectural contexts. Theoretical sessions provide the necessary background but are more concise, serving as a foundation for the more intensive exploration of machine learning algorithms, tools like Python, and AI-driven design methodologies. The master's courses are designed to develop specialized competencies and advanced technical skills, preparing students to handle complex architectural challenges through AI and machine learning techniques.

A common theme across many of the courses is the emphasis on project-based learning, especially at the master's level. Courses like MBL 559E – Machine Learning for Architectural Design and MYZ 306E – Artificial Intelligence in Architecture, Planning, and Design heavily integrate project-based learning, where students work on real-world design problems, often utilizing AI tools and algorithms to generate solutions. These courses involve hands-on practice with datasets, either provided by the instructor or collected by students themselves, which promotes active learning and allows for a deeper understanding of machine learning techniques in a practical architectural context.

In contrast, undergraduate courses like ARC 4065 – Artificial Intelligence in Architecture and ARCH 362 – Architectural Intelligence feature a more blended approach, combining theoretical lectures with some project-based elements. These courses typically provide students with structured exercises and classwork that involve using existing datasets, which serves to introduce students to the basics of AI tools and their applications in architecture without the complexities of data collection or preparation. However, there is less emphasis on independent data collection or developing new datasets, reflecting the introductory nature of these courses.

There is a potential gap in the mathematical foundations provided across both undergraduate and master-level courses. While many of the courses touch on specific mathematical concepts such as regression or probability (as seen in MBL 559E – Machine Learning for Architectural Design and MIM 344 – Information Technologies in Architecture), there is no consistent approach across all courses that introduces these foundations as core knowledge. Establishing a more robust mathematical foundation at the undergraduate level could enhance students' understanding of the computational and algorithmic principles underpinning AI and machine learning, making them better prepared for more advanced courses. Similarly, at the graduate level, a reinforced mathematical base could support the in-depth exploration of complex algorithms and data modeling techniques.

The relationship with varying architectural contexts is addressed to different extents across the courses. Undergraduate courses like ARC 4065 and ARCH 362 introduce AI applications in architecture using general contexts, such as bioclimatic design or 3D modeling, providing a broad perspective that caters to foundational learning. Meanwhile, master's courses such as MBL 559E and MYZ 306E focuses on specific contexts, such as urban planning, heritage conservation, or sustainable design, reflecting a more specialized focus. This variation allows for flexibility in application and prepares students for diverse professional paths.

4.2. Instructive/ Integrated/Extracurricular Teaching

The integration of digital technologies into architectural curricula dates back to the 1980s. This integration did not occur simultaneously across architectural schools; it varies from school to school and even from course to course. In the 1990s there was an increase and widespread adoption of experimental integration efforts. These efforts have been manifested as:

- Sub-modules within architectural design studios,
- Separate elective courses,
- Extracurricular student workshops.

Based on the review of the available course catalogs and literature review, AI and machine learning courses in architecture adopt diverse teaching methods, including instructive, integrated, and extracurricular approaches, to align with different educational goals and levels of student expertise. These courses are structured to enhance students' understanding of AI's theoretical and practical applications, contributing to the overall aim of fostering AI literacy and preparing students for evolving roles in architectural practice.

A notable trend is the use of a bottom-up approach in the form of workshops which are elective and increasingly common in architecture schools. These workshops offer targeted, intensive learning experiences that focus on specific AI-related topics, such as data collection methods, coding practices, or the application of particular AI tools. By encouraging students to engage directly with AI technologies in a hands-on, experimental manner, these workshops promote creativity, exploration, and problem-solving skills.

In addition to workshops, AI courses are categorized into elective and mandatory formats, each serving different educational purposes. Elective courses provide flexibility and choice, allowing students to explore AI and machine learning topics aligned with their interests and career aspirations. Courses like MIM 344 – Information Technologies in Architecture are typical examples, where students can choose to gain deeper insights into specific areas of AI applications, such as digital fabrication or computational design. These elective offerings highlight the importance of personalized learning pathways in contemporary architectural education.

On the other hand, mandatory courses ensure a foundational understanding of AI concepts across all students, making AI literacy a core component of the architecture curriculum. These compulsory courses, often positioned early in the academic journey, introduce essential AI competencies, such as algorithmic thinking, basic programming, and data analysis. This approach reflects the growing recognition of AI as an indispensable skill set for future architects, ensuring that every graduate possesses at least a baseline proficiency in these critical areas.

A significant emphasis is also placed on the integration of AI and machine learning into studio practice, a hallmark of architectural education. Many courses, particularly at the graduate level or in the later years of undergraduate programs, are designed to incorporate AI tools and methods directly into design studios, where students work on collaborative projects that simulate real-world scenarios. For example, the MBL 559E – Machine Learning for Architectural Design course, typically offered in the fourth year or at the master's level, uses studio environments to explore how AI can enhance design processes, optimize environmental performance, or address complex spatial challenges. This integration fosters a dynamic and interactive learning experience, bridging theory and practice.

Moreover, the courses often follow a holistic curriculum structure, where different modules are designed to complement each other and build progressively on students' knowledge and skills. For example, foundational courses on AI basics, typically positioned in the first or second year, are followed by advanced courses in the third or fourth year that focus on specific applications, such as urban planning, heritage conservation, or generative design. This structured approach ensures a comprehensive understanding of AI, from foundational knowledge to specialized applications, creating a coherent educational pathway that supports the students' growth as future professionals.

Most AI and ML courses in architecture are offered during specific semesters, typically reflecting their role within the overall curriculum. For the academic years reviewed, such as ARC 4065 – Artificial Intelligence in Architecture, offered in the fourth year during the fall semester, providing a capstone experience that builds on earlier foundational courses. Similarly, introductory courses like ARCH 362 – Architectural Intelligence, positioned in the second or third year, often in the fall semester, to introduce key AI concepts early in the academic journey. More advanced courses, such as MBL 559E – Machine Learning for Architectural Design, offered in the fourth year or at the master's level during the spring semester, build on prior knowledge and encourage students to apply AI tools in complex, real-world contexts. This pattern suggests a general strategy where foundational courses in the first and second years lay the groundwork for more advanced, specialized studies in the third and fourth years, promoting a coherent progression from basic understanding to applied expertise in AI and ML in architecture.

4.3. Constantly Changing Nature

In the ever-evolving landscape of technology, the rapid pace of innovation continuously offers new tools and techniques, which are quickly replaced by the next advancements. This dynamic environment presents a unique challenge for educators designing courses to introduce AI to architecture students. The difficulty lies in specifying particular tools or programming languages in course syllabi, as they may become obsolete in the near future. To address this challenge, educators must focus on fundamental concepts and frameworks that change more slowly over time. A strategic approach involves structuring the course around four key modules that provide a resilient foundation for learning AI in architecture: Theory, Problem Framing, Automation, and Symbiotic Communication.

a- Theory Module: The theoretical component should be positioned as the core of the course, providing students with a deep understanding of the principles underpinning AI and machine learning. Rather than focusing on specific tools or software, this module would cover fundamental topics such as algorithmic thinking, data literacy, and the ethical implications of AI in architecture. By grounding students in these core concepts, the course ensures that they acquire knowledge that remains relevant despite the rapid turnover of specific technologies. This module would also introduce foundational mathematical and computational theories that support AI, offering a strong base for further exploration into more advanced applications and methods.

b- Problem Framing: This module encourages students to develop critical thinking skills by learning how to frame problems effectively, whether context-dependent or not. Here, students would explore various approaches to defining architectural challenges, understanding the context in which AI can be applied, and identifying the limitations and opportunities presented by different problem scenarios. By emphasizing the importance of context, this module prepares students to adapt their understanding to different architectural environments and project types, enabling them to select or develop appropriate AI tools and methods. The focus on problem framing ensures that students learn to approach AI not merely as a set of tools but as a way of thinking about design and analysis in a broader, more flexible context.

c- Automation: The third module addresses the processes that can be automated using AI tools and techniques. Instead of teaching specific software or programming languages, this module would provide a comprehensive understanding of the types of tasks in architectural practice that can benefit from automation. Students would learn about data-driven design, generative design methods, optimization techniques, and how AI can automate repetitive or data-intensive tasks, such as site analysis, energy modeling, and parametric design. The aim is to help students identify where AI can add value by increasing efficiency, accuracy, and innovation in architectural workflows, regardless of the specific tools available.

d- Symbiotic Communication: The final module focuses on developing a symbiotic relationship between AI tools and human creativity. This involves fostering a dialectic dialogue or multi-adaptive communication between architects and AI systems, where both continuously learn and adapt from each other. This module would explore the co-evolution of human and machine intelligence, emphasizing the importance of a collaborative approach to design. Students would be encouraged to think about AI not as a replacement for human creativity but as a complementary partner that enhances their ability to innovate and solve complex problems. This module would also address the ethical considerations of using AI, promoting a critical understanding of the implications of automation and machine learning in the context of architectural practice.

5. Conclusion and Discussion

The proposed framework for integrating AI into architectural education represents a strategic response to the rapidly changing technological landscape that is reshaping the field of architecture. This manuscript outlines a flexible and adaptive course structure, recognizing both the potential and challenges that AI brings to architectural practice. By focusing on core principles and providing a balanced approach between theory, application, and ethical considerations, the framework aims to equip architecture students with the necessary skills to navigate a future where AI plays a central role.

A key strength of the proposed framework lies in its emphasis on foundational knowledge that is less prone to obsolescence. By centering the curriculum around core theoretical concepts—such as algorithmic thinking, data literacy, and ethical considerations—the framework ensures that students acquire a deep understanding of AI's underlying principles. This focus on the fundamentals provides a robust foundation that enables students to adapt to new tools and technologies as they emerge, fostering a mindset of continuous learning and flexibility.

Moreover, the framework effectively incorporates a problem-solving orientation by emphasizing both context-specific and context-independent approaches. This dual focus allows students to engage with AI tools in a variety of scenarios, from highly defined design challenges to more open-ended, exploratory projects. By training students to frame problems and identify opportunities for AI applications, the framework enhances their ability to apply AI creatively and critically, regardless of the specific technological tools at hand.

The integration of automation and symbiotic communication as core modules further strengthens the framework by addressing both the practical and collaborative dimensions of AI in architecture. The automation module provides students with insights into the types of tasks that can be streamlined or enhanced through AI, promoting efficiency and innovation in architectural workflows. At the same time, the emphasis on symbiotic communication fosters a nuanced understanding of how AI can complement human creativity, encouraging a collaborative and ethical approach to design.

However, the success of this framework will depend on its adaptability to the continually evolving technological environment. To remain relevant, the course materials such as assignments, project briefs, and presentation contents must be regularly updated to reflect the latest advancements in AI tools and techniques, while retaining its focus on fundamental principles. Additionally, the framework should allow for flexibility in teaching methods and course content, enabling educators to respond dynamically to new developments in the field.

For undergraduate programs, it is recommended to introduce foundational AI concepts early in the curriculum through compulsory courses that cover basic AI principles, machine learning, and data-driven design strategies. This should be complemented by elective courses that focus on specific AI applications, such as generative design, parametric modeling, and Building Information Modeling (BIM). Practical, project-based learning modules, workshops, and collaborative studio projects should be integrated to provide hands-on experience, fostering creative thinking and encouraging experimentation with AI tools. Moreover, a foundational introduction to the core mathematics would provide deeper insights and support students' relational thinking skills. This would be helpful for students to become active learners instead of merely remaining tool users.

At the master's level, AI courses should cover deeper advanced topics, including algorithm development, deep learning, and the use of AI in sustainable design practices. Graduate courses should focus on interdisciplinary applications, combining architecture with computer science, engineering, and data science. Specialized modules could explore the use of AI for complex problem-solving, predictive modeling, and real-time performance analysis. Thesis projects and research-based electives should encourage students to engage with AI at a strategic level, developing innovative solutions to contemporary design challenges.

To successfully implement AI in architectural education, institutions must also address several challenges, such as ensuring equitable access to AI resources, providing adequate training for educators, and embedding ethical considerations throughout the curriculum. Furthermore, adopting a flexible, modular approach to AI education that allows students to build competencies progressively will enable a more personalized learning experience, catering to diverse interests and career paths.

In conclusion, AI integration in architectural education offers significant potential to reshape how architecture is taught and practiced. By thoughtfully incorporating AI at both undergraduate and graduate levels, educational institutions can empower future architects to innovate, adapt, and excel in a data-driven world, ultimately contributing to more sustainable, efficient, and creative architectural solutions. As technology continues to advance, it is crucial to maintain an ongoing dialogue between academia, industry, and practice to keep educational practices aligned with the profession's evolving needs and opportunities.

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