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Research Article

The "Cognitive" Architectural Design Process and Its Problem with Recent Artificial Intelligence Applications

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Abstract

The connection between cognitive science and the architectural design process reveals significant gaps that limit the full potential of creating effective built environments. A key issue is the insufficient integration of cognitive principles into design workflows. Architects frequently rely on traditional methods and aesthetic considerations without fully understanding how spatial configurations influence human cognition and behavior. While recent AI applications in architecture, such as Computer-Aided Drafting (CAD), Building Information Modeling (BIM), and interactive web and VR presentations, show promising advancements, AI still struggles with complex architectural functions. AI lacks the creativity and imagination inherent in human cognition. It operates based on fixed programming, producing specific outcomes and requiring human oversight to apply insights from one dataset to another. The primary challenge in using AI for architectural design is ensuring minimal design flaws, as replicating human cognitive abilities with AI and various machine learning techniques remains difficult. This research paper aims to explore the relationship between cognitive science, artificial intelligence, and the architectural design process through four main objectives: First, to investigate the integration of AI with current architectural software applications. Second, to examine potential connections between AI and major architectural design trends. Third, to define two frameworks for the Cognitive Architectural Design Process to guide the development of AI systems in architectural design by analyzing key cognitive design theories. Finally, to create a proposed "Architectural Design Process-Cognitive Pilot Map" from an architectural perspective to aid AI programmers in developing architecture design software applications.

Keywords

Architectural Design Software, Architectural Design Process, Cognitive Process, Cognitive Design Skills, AI in Architectural Design, AI and Architectural Software Applications

1. Introduction

1.1. Artificial Intelligence Key Concepts and Terminologies

Artificial intelligence involves designing computer systems to emulate human intelligence. This can be accomplished through various AI methods, including Machine Learning, Expert Systems, Neural Networks, and Reinforcement Learning. AI can also be classified by its degree of autonomy into categories such as Assisted Intelligence, Augmented Intelligence, and Autonomous Intelligence. These AI systems function as agents, employing reasoning and problem-solving techniques like Backward Chaining to exhibit intelligent

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behavior. Consequently, AI serves as a versatile and powerful tool with numerous potential applications. Main artificial intelligence key concepts may be summarized as follows [148, 149].

1.1.1. Agent

In artificial intelligence (AI), an agent is an entity designed to operate autonomously on behalf of a user or another program. Agents perceive their environment, make decisions based on their state and goals, and act to achieve those decisions. They are categorized into:

1) Simple Reflex Agents: React to the current environment state without memory of past events, like a thermostat regulating temperature.
2) Model-Based Reflex Agents: Use an internal model of the environment for more complex decision-making, such as chess-playing programs evaluating moves.
3) Goal-Based Agents: Act based on predefined goals and use search algorithms to determine the sequence of actions, like delivery robots.
4) Utility-Based Agents: Choose actions that offer the highest expected benefit, useful in uncertain conditions, like investment advisors.
5) Learning Agents: Improve performance over time by learning from experiences, as seen in spam filters refining their classifications.

1.1.2. Backward Chaining

Backward Chaining is an AI inference method starting from a goal and working backward to find supporting facts, useful in diagnostic tasks within expert assisting systems.

1) Assisted Intelligence: supports human decision-making by analyzing data and providing insights, while
2) Augmented Intelligence: enhances human cognitive abilities directly.
3) Autonomous Intelligence: involves systems operating independently, such as self-driving cars, raising efficiency and ethical concerns.

1.1.3. Machine Learning

Machine Learning involves training algorithms to improve performance based on data, while Expert Systems replicate human expertise in specific domains.

1.1.4. Neural Networks

Neural Networks, inspired by the human brain, handle complex data patterns

1.1.5. Deep Learning

Deep Learning utilizes multi-layered networks for tasks like image recognition.

Reinforcement Learning enables agents to learn optimal behaviors through interactions and rewards.

1.2. Problem (s)

1.2.1. Relationship Between Cognitive Science and the Architectural Design Process

The integration of cognitive science into architectural design is limited, often leading to environments that fail to fully support human cognition and well-being. Architects generally use traditional methods without considering how spatial configurations affect mental and emotional health. There is also a lack of collaboration between cognitive scientists and architects.

This disconnects results in less effective designs. While AI presents opportunities for design, it struggles to replicate the cognitive aspects of architectural thinking, raising concerns about its ability to produce designs with minimal flaws. Bridging these gaps requires integrating cognitive insights into architecture and improving interdisciplinary collaboration.

1.2.2. (AI) in the Domain of Architectural Software Applications

While in the domain of architectural software applications, some recent AI applications are making impressive strides. AI might excel in automating “Architectural tasks of a routine nature” such as Computer-Aided Drafting (CAD) basic drawing aspects, Building Information Modeling (BIM), interactive architectural presentations on the web, and VR applications in architecture,

However, there are still some complex functions that AI in the field of architecture cannot handle.

1.2.3. General Challenges Facing the Progress of (AI) Technology

Despite rapid advancements, AI faces significant challenges: high development costs, potential job displacement, limited creativity, and the need for extensive research.

Additionally, AI may never fully replicate human capabilities, presenting ongoing hurdles figure 1) in its evolution and application. [128]

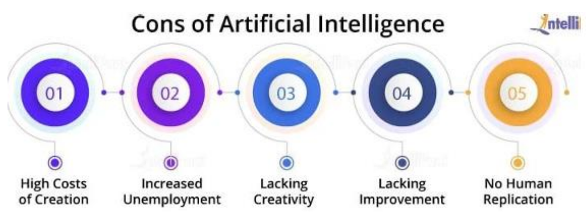

Figure 1. Shows the challenges facing the progress of AI technology [126].

1.3. Research Goal (s)

1.3.1. The First Objective of This Research Is to Explore Recent Integration of AI with

1) Computer Aided Drafting (CAD) Applications

2) Building Information Modeling (BIM) Applications
3) Architectural Rendering Applications
4) Game Engines Applications in Architecture
5) Graphics and Image Manipulation Applications in Architecture
6) VR Applications in Architecture
7) The World Wide Web
8) 3D Printing Technology

1.3.2. The second Objective of This Research Is to Explore Possible Linkage of AI with Major Architectural Design Trends

(1) Traditional Architecture Design
(2) Environmental Architecture Design
(3) Sustainable Architecture Design
(4) Green Architecture Design
(5) Parametric Architecture Design

1.3.3. The Third Objective of This Research is to Define Two Wings for the Cognitive Architectural Design Process

To be used as a general guide for the development of architectural design AI systems, the two wings were defined by the research as:
(1) Cognitive faculties
(2) Cognitive Processing of Information and Accumulated Human Experiences

1.3.4. The fourth Objective of This Research Is to Create the Suggested "Architectural Design Process - Cognitive Pilot Map"

From an Architect Perspective to Assist (AI) Programmers Developing (AI) "Architecture Design" Software Applications

1.4. Research Structure

Overall, information about artificial intelligence is highly diverse, drawing from numerous knowledge areas.

While in the field of architecture, AI's current applications are mostly limited to architectural rendering.

However, developing AI software capable of generating comprehensive designs for complex projects, such as mixed-use developments involving various building types, remains unfeasible.

The diagram below (figure 2) illustrates the structure of the information presented in this manuscript.

Figure 2. *Is a diagram illustrating the structure of the information presented in this manuscript.*

1.5. Literature

To grasp the concept of AI technology and its current level of integration with modern digital architectural applications, and for the research to achieve its objectives, it is crucial to provide a panoramic overview of: [1]

1. Artificial intelligence first initiatives
2. Latest trends in artificial intelligence from a general perspective
3. Latest trends in artificial intelligence with architecture design
4. Latest Trends in Artificial Intelligence with Architecture Visualization Applications
5. Latest trends in today's world of architectural computer applications
6. Latest artificial intelligence text applications in the market
7. Latest artificial intelligence image manipulation/editing applications in the market

1.5.1. Artificial Intelligence First Initiatives

The first (AI) initiative evolved as a new academic discipline in 1956. Social media networks like "YouTube", "Facebook", "Amazon", and "Google web search engine", also speech recognition applications like "Cortana", "Siri", and "Alexa" use artificial intelligence. Initially, AI applications

1 Details about all software applications mentioned in this manuscript are found in the supplementary materials document of this research at the following repository: https://drive.google.com/file/d/1i6KNSHRsgy2bgIA041Ll0H9-tSWcyZ8G/view?usp=drive_link. Please note that references of information in the supplementary document are found under the references section of this manuscript

comprised speech voice systems that engaged with humans by conversing in imitation of either female or male voices. [9-17]

1.5.2. Latest Trends in Artificial Intelligence

AI seeks to enable computers to think and learn like humans, evolving beyond pre-programmed routines. It revolutionizes sectors by enhancing functionality and accessibility, with customized chatbots from Google and OpenAI, multimodal models like GPT-4 integrating various media, and generative tools for tasks. AI also accelerates research and faces growing ethical scrutiny. [128-130]

1.5.3. Latest Trends in Artificial Intelligence with Architecture Design

AI is transforming architecture by enhancing efficiency, creativity, and innovation. Key advancements include Generative Design Tools for rapid photorealistic designs, Data-Driven Decision Making for optimizing energy efficiency and costs, VR and AR for immersive visualization, Sustainable Design for greener buildings, and Adaptive Architecture for responsive environments. Collaborative Platforms also improve stakeholder communication. [131-133]

1.5.4. Latest Trends in Artificial Intelligence with Architecture Visualization Applications

Architects can expand the horizons of architectural visualization by engaging in (AI) word prompt testing, digital collage exploration, and even hand-sketch-to-rendering experiments. Top AI architectural rendering applications in the market are: Midjourney, Stable Diffusion, DALL Ɇ, Veras, LookX AI, mnml.ai, and ArkoAI [2] [79]

1.5.5. Latest Trends in Today's World of Architectural Computer Applications

This section introduces a wrap up of the major trends in today's world of architectural computer applications including both the most popular and widely used architecture computer applications, and the evolving Artificial intelligence technologies that are currently available in the market. [3]

Computer Aided Drafting - (CAD)

Computer Aided Design (CAD) primarily assists in engineering drafting, producing 2D and 3D drawings rather than directly supporting design. It integrates traditional tools into a centralized platform, enhancing productivity and accuracy. Often termed Computer Aided Drafting (CADD), CAD applications like AutoCAD, ArchiCAD, and SketchUp improve drafting in various fields. [49-53, 55-56]

Building Information Modeling Technologies - (BIM)

Building Information Modeling (BIM) has become prevalent in architecture, construction, and project management. Originating in the 1970s, early BIM systems included Building Description System (BDS) by Chuck Eastman, RUCAPS, SONATA, REFLEX, and GABLE 4D. These early tools were limited by high costs. Today, major contributions come from companies like Bentley Systems, Graphisoft, and Autodesk. Popular BIM applications now include Graphisoft's ARCHICAD for macOS and Autodesk's Revit for Windows, which are widely used in the industry. [1-8]

Architectural Rendering Applications

Architectural rendering (Arch Viz) involves creating 3D images or animations to showcase architectural designs. These "Computer Generated Renderings" or "Photo Real" renderings are used for presentations. Popular applications include 3DS Max, Blender, VRay, Enscape, and others, with emerging online tools like Coohom also gaining traction. [33, 40-48, 54]

Game Engines in Architecture

A game engine is software designed for creating video games, offering a suite of tools and libraries for development across platforms. Popular engines include Unreal Engine, Unity, and CryEngine. In architecture, Unreal Engine is notably favored by major firms for its advanced visualization capabilities. [57-60]

Graphics and Image Manipulation Applications

Numerous image editing software options are available, including Adobe Photoshop by Adobe Inc. and Corel Painter by Fractal Design Corporation. Free, open-source tools like Krita and GIMP, and paid software such as ArtRage, also exist. Adobe Photoshop is particularly popular in architecture for refining architectural renderings. [61-65]

VR Applications in Architecture

Virtual reality (VR) creates immersive 3D experiences using headsets and pose tracking, applicable in entertainment, education, and business. In architecture, VR lets clients explore and interact with 3D models, offering real-time design adjustments and enhanced client engagement. Popular VR tools include Arki, Enscape, and Unreal Engine, with increasing integration into architectural software. [37-39, 66]

Interactive Architectural Presentation Over the World Wide Web

In simple, an interactive presentation is exactly as it sounds: a presentation that allows multiple audience members to engage with it, utilizing multi-dimensional media. Such presentations typically include web-style features such as navigation, hyperlinks, and hotspots. Numerous architecture software applications offer web-based presentation modules and cloud-based presentation archives. Among the most popular applications are Lumion and Twinmotion, both of which offer online and cloud presentation services. [67]

3D Printing Technology

3D printing, or additive manufacturing, creates three-dimensional objects from CAD or digital models by depositing materials like plastics, liquids, or powders layer by

2 A (table) compiled by the author containing description about each of these applications is found at the supplementary material document

3 There are other numerous software applications that serve the same purpose; however, the literature section introduces the most popular and widely used by major design firms in the architecture, TV, Media, Cinema, and the construction industries.

layer. In architecture, it revolutionizes model-making by rapidly translating CAD drawings into precise physical models.

In construction, robotic arms extrude concrete, and powder binding or additive welding methods are employed to build structures. This technology enhances efficiency and accuracy in both fields, transforming traditional processes and enabling new design possibilities. [68-70]

Latest (AI) Text Applications in the Market

Launched in November 2022 by OpenAI, ChatGPT is a leading AI text application and virtual assistant that allows users to control conversation style and detail.

It sparked a surge in AI interest, becoming the fastest-growing consumer software with over 100 million users by January 2023, elevating OpenAI's valuation to $86 billion.

The emergence of “ChatGPT” spurred the introduction of other competing products such as "Gemini" "Claude" "Llama” and "Grok"

Additionally, Microsoft launched "Copilot" another (AI) text application built on “OpenAI's - GPT-4o” model. [71-76]

Latest (AI) Image Manipulation/Editing Applications in the Market

Since AI's inception in the 1950s, it has been utilized in image editing and creative arts, evolving from early systems like AARON in the 1960s to modern AI-powered tools.

AARON, developed at UC San Diego, used rule-based AI to create simple drawings. In 2020, Adobe Photoshop introduced AI-driven "Neural Filters," showcasing advanced machine learning capabilities.

Contemporary AI image editing enhances functionality by sharpening low-resolution images, identifying image types for edits, extracting subjects, adjusting lighting, refining facial features, and restoring color in old photos.

These advancements reflect AI's role in both artistic creation and practical image enhancement. [4] [77, 78]

2. Materials and Methods

2.1. Analysis of Available Data

AI has made significant strides in various domains, with its application in architecture beginning to reshape the field. While current applications primarily focus on architectural rendering and optimization of specific design aspects, the development of AI tools capable of handling complex architectural projects remains a work in progress. Continued advancements in AI technologies and their integration into architectural workflows hold promise for more comprehensive and innovative design solutions in the future.

AI in Architecture Design

In architecture, AI has begun to make notable impacts, though its applications are still evolving:

1) Architectural Rendering: AI technologies, such as generative design algorithms, assist in creating visual representations of architectural concepts. These tools can rapidly generate multiple design options based on input parameters, enhancing creativity and efficiency in the early stages of design.
2) Design Optimization: AI can optimize building designs by analyzing various factors, including structural integrity, energy efficiency, and material use. For instance, algorithms can simulate different scenarios to determine the most sustainable and cost-effective solutions.
3) Automation of Routine Tasks: AI-driven tools automate routine tasks such as drafting, scheduling, and cost estimation. This automation reduces manual effort and minimizes errors, allowing architects to focus more on creative and strategic aspects of design.
4) Complex Design Challenges: Despite advancements, AI's ability to handle complex architectural projects, such as mixed-use developments involving diverse building types, is still limited. The integration of various design elements and functionalities into a cohesive and innovative design remains a significant challenge. AI systems struggle with the intricacies and contextual nuances required for such comprehensive and multi-functional designs.

Future Prospects

The potential for AI in architecture is vast. Future developments may enable AI systems to generate complete and sophisticated designs by incorporating more advanced algorithms, larger datasets, and better integration of contextual factors. Advances in natural language processing and generative design could further enhance AI's ability to contribute to complex architectural projects.

2.2. Architecture Design Trends

What follows introduces a briefing of the different trends prevailing in the architecture design arena: Traditional or prudent architecture design, Environmental, Sustainable, Green, and Parametric design. The purpose of this section is to explore the intersection of these design trends with artificial intelligence that will be discussed at the latter stages of this paper.

2.2.1. Traditional Architecture Design

While traditional architecture design frequently draws upon vernacular culture, reflecting the traditions of specific times and regions, traditional prudent architecture design embodies the practices of building design from earlier periods. The precise concept of traditional architecture has evolved alongside the development of building styles. [35]

2.2.2. Environmental Architecture Design

Environmental design involves considering the environmental factors surrounding the design of buildings. Its aim is

4A (table) Compiles the leading (AI) tools that enable groundbreaking architectural rendering and visualization capabilities.is found at the supplementary material document to develop spaces that improve the natural, social, cultural, and physical characteristics of specific areas. While traditional prudent design may have inherently considered some environmental factors, the environmental movement, which emerged in the 1940s, has brought this concept to the forefront in a more explicit manner. [34]

2.2.3. Sustainable Architecture Design

Energy consumption, drain of planet earth resources, the "Fossil Oil Crisis" [5], and pollution, (carbon emissions' [6]) have been, and still a major concern of the United Nations since the 1960s of the twentieth century. The oil embargo together with the above concerns led to the emerging of the concept of "Sustainable Development" [7].

Architecture, construction, and buildings have their share in the sustainability plan. "Sustainable Architecture" is usually referring to an architecture design that takes in consideration all possible aspects that ensure minimal negative impact of the building on its natural site, consumption of energy, and treatment of wastewater, and garbage recycling.

2.2.4. Green Architecture Design

The concept of "Green Architecture" emerged from the "Sustainable Development" movement of the 1960s, driven by criticism of urban densities and negative impacts on health and the environment. This movement, encapsulated by the motto "Go Green," sought a return to nature. Earlier, in the 1930s, architect Frank Lloyd Wright had already pioneered working with nature, using natural materials in his designs.

His "Falling Water" house (1930) is a notable early example of green principles in architecture. Green architects focus on minimizing environmental impact, enhancing energy and water efficiency, using eco-friendly materials, and improving indoor air quality to create sustainable buildings. [22, 18-26]

2.2.5. Inter Relationship Between Environmental, Sustainable, and Green Architecture

In certain references, numerous architects mix up the three design paths, occasionally using "Sustainable" architecture interchangeably with both "Green" and "Environmental" architecture.

This confusion arises because all three methodologies center on similar architectural principles, urging architects to create intelligent designs with minimal adverse effects on the environment, ecosystems, and communities. [32]

2.2.6. Parametric Architecture Design

The advancement of digital drawing and modeling during the latter decades of the twentieth century led to the emergence of parametric experimentation.

Since the 1980s, the term "parametric" has been employed to delineate this architectural approach, which involves utilizing parameters within computer models to explore diverse designs.

This architectural style is distinguished by intricate geometric forms like spheres or cubes, which are then arranged based on predetermined parameters. Parametric modeling typically surpasses manual methods in efficiency, saving time and cost.

The hallmark of parametric architecture lies in its generation through computer algorithms or parameters, governing the building's shape. Essentially, parametric architecture employs mathematical algorithms to conceive forms and structures within architectural design. [36]

3. Cognitive Science

3.1. Cognition

The term "Cognition" refers to the mental processes involved in gaining knowledge and understanding that the human brain executes through thought, experience, and sensory perception.

It encompasses various intellectual functions and processes compiled in the following (table 1): [80]

Table 1. *In this table, the author Compiled various cognitive intellectual functions and processes from Ref. [80].*

Perception	Reasoning
Attention	Problem-Solving
Imagination	Decision-Making
Intelligence	Language Comprehension
Memory	Production
Judgment	

3.2. Cognitive Science

Cognitive science is an interdisciplinary field that studies the mind and its processes, including language, perception, memory, attention, reasoning, and emotion. It integrates insights from linguistics, psychology, AI, philosophy, neuroscience, and anthropology to understand cognitive functions through mental representations and computational procedures. [81]

3.3. Cognitive Skills

"Cognitive skills", referred to as cognitive functions, abilities, or capacities, encompass mental abilities distinct from

5 The 1973 oil crisis, led by OPEC, halted oil exports to Western countries supporting Israel, prompting energy diversification efforts.
6 Buildings contribute about 39% of carbon emissions, from sources like boilers, water heaters, and concrete, in addition to transportation.
7 "Sustainable Development" aims to use renewable energy, minimize pollution, enhance agriculture, expand forests, and protect water resources.

motor skills. Examples of cognitive skills include literacy, self-reflection, logical reasoning, abstract thinking, critical thinking, introspection, and mental arithmetic.

These skills differ in processing complexity, ranging from fundamental processes like perception and memory functions to more advanced processes such as decision-making, problem-solving, and “Metacognition” [8]. [82]

3.4. Knowledge Utilization Within the Memory

In cognitive science, the debate is whether knowledge is organized into structured schemas from repetitive experiences or as a network of interconnected nodes.

Schema theory suggests knowledge helps in understanding based on past contexts, while network theories view information as discrete units connected hierarchically, challenging the notion of information loss.

3.5. Major Cognitive Science Theories

The following provides a briefing of key cognitive science theories to determine which might be most effective for architectural design process AI systems

3.5.1. Jean Piaget's “Schema” and “Cognitive Development” Theory

Jean Piaget’s [9] “Schema Theory” in cognitive science explores how the brain organizes knowledge into structured entities called schemas, based on past experiences. His “Cognitive Development Theory” outlines four stages of learning in children: sensorimotor (birth to 2 years), preoperational (2 to 7 years), concrete operational (7 to 11 years), and formal operational (12 years and beyond).

Piaget’s theory emphasizes that children actively learn by experimenting, observing, and assimilating information, continuously updating their understanding of the world. This active engagement reflects their role as “miniature scientists” in developing intelligence and knowledge. [83-87]

3.5.2. Lev Vygotsky’s “Zone of Proximal Development” Theory

The “Zone of Proximal Development” (ZPD) constituted a pivotal concept within “Lev Vygotsky’s” [10] framework of learning and development. It delineates the realm wherein a learner operates: the chasm between independent capability and the potential achieved with adult support or through collaboration with peers possessing greater proficiency. [86]

3.5.3. The “ACT” and “SOAR” Theory

In the domain of Human-Computer Interaction (HCI), the most two influential theories are "ACT” [11] and "SOAR" [12], both theories offer insights into how knowledge is stored in memory "ACT" and "SOAR" both address memory through working and long-term types but differ in focus.

"ACT," or ACT-R, is a cognitive architecture theory resembling a programming language, based on psychological research. It provides a framework for tasks like memory retention, language comprehension, and communication, reflecting human cognitive processes.

SOAR is a comprehensive cognitive model integrating abilities like natural language processing, attention, and problem-solving. It simulates virtual humans for face-to-face dialogues and collaboration, exhibiting functionalities such as perception, language comprehension, emotional responses, motor control, and action execution.

Developed at USC's Institute of Creative Technology, it supports virtual environment interactions. [88-90]

3.5.4. Primary Forms of Knowledge Stored in Memory

Typically, there are three primary forms of knowledge stored in memory:

1) Analogical representations resemble picture-like images, Propositional representations consist of abstract, language-like statements with presuppositions, such as "The car is in the garage."
2) Distributed representations, on the other hand, manifest as interconnected networks where knowledge resides within the links between nodes. Analogical and propositional representations are categorized as symbolic representations, whereas distributed representations are viewed as sub-symbolic representations. [88]

3.6. The Cognitive Architecture Design Process

3.6.1. The Architecture Design Process

Architectural design is a complex cognitive task requiring vast, interdisciplinary knowledge. Architects must analyze, integrate, and process diverse information to create functional, aesthetically pleasing buildings. This involves high-level mental processes, transforming concepts into tangible structures while addressing intricate creative challenges.

3.6.2. The Brain – To – Sketch Iterative Design Cycle

The iterative design cycle lacks a universal definition in both academic and practical literature. Academics struggle with replicating findings due to the complex nature of cogni-

8 Metacognition refers to awareness and regulation of one's own thought processes. It involves reflecting on and controlling cognition, or "thinking about thinking." [83]

9 “Jean William Fritz Piaget” (August 9, 1896 – September 16, 1980) was a Swiss psychologist recognized for his contributions to the field of cognitive development.

10 “Lev Vygotsky” is a prominent Russian psychologist, he was renowned for his sociocultural theories, that underscore the pivotal role of social interaction in learning.

11 “ACT” further subdivides long-term memory into declarative and production memory

12 “SOAR” posits a singular long-term production memory—housing both declarative and procedural knowledge.

tive psychology, which affects understanding of iterative processes. In practice, iterations are seen either as a continuous loop of planning, analysis, implementation, and evaluation, or as a simpler process focused on aligning designs with user needs.

Some resources differentiate between iterative and incremental approaches, with the former involving continuous refinement and the latter releasing distinct increments. Issues also arise in translating design ideas to paper, with a noticeable delay affecting the flow of creativity, particularly in CAD applications. [13] (figure 3) [92-96] These frequent interruptions for the flow of design ideas in the brain have a detrimental effect on their design thinking process and sequence, leading to a marked decrease in the overall quality of their final design outputs. [14]

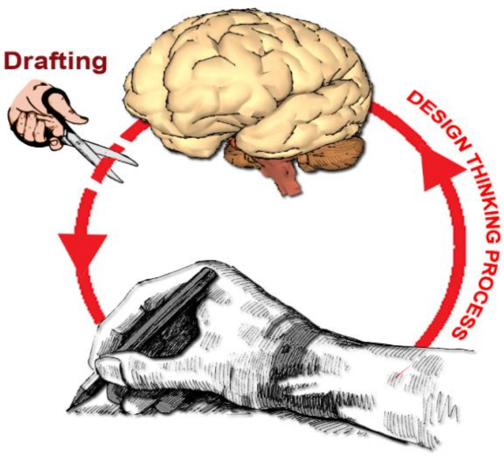

Figure 3. *Is a diagram showing drafting interruptions of "The Brain – To – Sketch Iterative Design Cycle".*

4. Results

4.1. FIRST: AI Integrations

4.1.1. Integrating (AI) with Computer Aided Drafting (CAD) Applications

AI integration in drafting is crucial for automating the creation of engineering drawings. Architecture firms seek solutions to streamline this labor-intensive task. Current AI tools, like Caddie-AI Assistant, (figure 4) use machine learning and computer vision to interpret blueprints, enhancing efficiency and accuracy through pattern recognition and historical data analysis. [100-103]

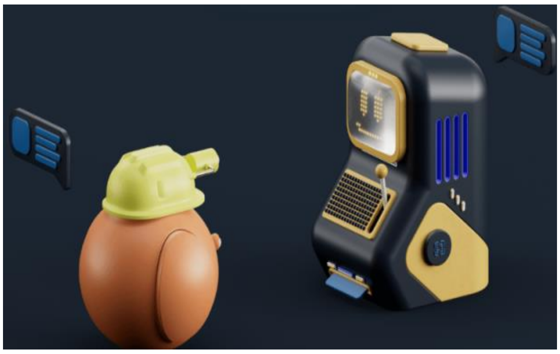

Figure 4*. Is a captured from the Cadie company website representing their AI assistant. [100]*

4.1.2. Integrating (AI) with Building Information Modeling (BIM) Applications

Building Information Modeling (BIM) is limited by outdated technology and rigid requirements. (figure 5) AI integration improves BIM by interpreting relevant engineering data, enhancing design evaluation, and aiding pattern recognition. AI supports tasks like clash detection, energy simulation, and cost estimation. However, high costs and resistance to change pose adoption challenges. [103-105]

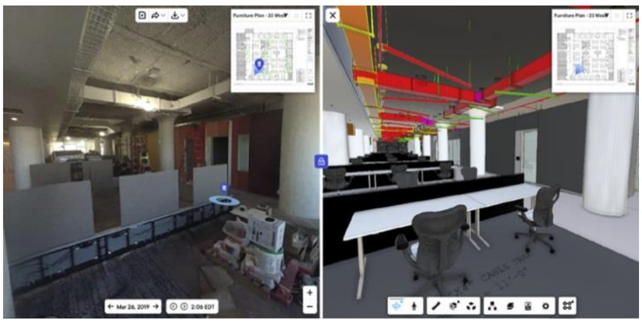

Figure 5. *Image captured with 360 cameras at left and a view of the same scene in a BIM model at right. Image courtesy of Open space and Lee Kennedy Construction.* [15] *[105]*

4.1.3. Integrating (AI) with Architectural Rendering Applications

Artificial Intelligence Rendering (figure 6) uses machine learning to speed up photorealistic image and animation creation. Unlike traditional methods that rely on raw computational power, AI employs neural networks and deep learning to optimize light interactions, reflections, and textures, resulting in faster and more precise visual outcomes. [106]

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13 The diagram is created by the author however some parts of the illustration is obtained from the following resources to minimize the drawing time and effort of the diagram: the Brain 3D model by "Ian Gash" from SketchUp 3Dwarehouse [97] the drawing hand - drawing vector art image by "bioraven" from deposit photos [98], and the hand with scissors vector art image by OpenClipart-Vectors from pixabay [99]

14 The author advises his architecture students to avoid using CAD software like AutoCAD or Revit for initial design concepts. Instead, he recommends finalizing designs on paper before using CAD for precision drafting.

15 OpenSpace's BIM Compare provides an innovative approach to analyzing your job site over time and in relation to your model. This feature enables your teams to quickly identify issues or discrepancies, thereby enhancing transparency, efficiency, and collaboration among stakeholders.

Figure 6. *Is an image generated with "Leonardo AI" software photo credit to Paulo Roberto da Silva. [106].*

4.1.4. Integrating (AI) with Game Engines Applications in Architecture

Game developers increasingly use Artificial Intelligence (AI) to enhance game design and development across various aspects. AI improves photorealistic effects, generates diverse content, and adds intelligence to Non-Playing Characters (NPCs). It creates realistic environments, analyzes player behavior for dynamic gameplay adjustments, and offers personalized experiences through procedural generation of levels and maps.

AI also models player interactions to tailor game mechanics, enhances NPC responsiveness with natural language processing (NLP), and supports adaptive character development. Techniques like generative adversarial networks (GANs) and machine learning foster unique, immersive environments and narratives, reshaping the gaming landscape for richer player experiences. [107]

4.1.5. Integrating (AI) with Graphics and Image Manipulation Applications in Architecture

AI is transforming graphic design by automating content creation and enabling rapid exploration of design options, boosting creativity and efficiency. Generative AI aids in producing icons and textures, and personalizes user experiences, such as product recommendations in e-commerce. However, concerns about creativity, originality, and ethics persist, necessitating a balanced approach. [108]

4.1.6. Integrating (AI) with VR Applications in Architecture

The fusion of AI and VR in architecture is ushering in a "Digital Renaissance." (figure 7) AI streamlines design with predictive algorithms and automation, while VR offers immersive 3D environments for better development and presentations. This partnership enhances creativity and efficiency, providing data-driven insights and innovative design solutions. [109]

Figure 7. *Is an image showing the use of VR glass sets in architecture design and presentation. [109].*

4.1.7. Integrating (AI) with the World Wide Web

Generative AI is enhancing web development by creating local images, addressing issues like broken pages and privacy. Web Diffusion uses AI to simulate web environments and evaluate image quality. Meanwhile, AI in 3D printing is improving automation, reducing errors, and optimizing workflows, though full automation and material expansion are ongoing challenges. [111]

4.1.8. Architecture with ChatGPT

Since its late 2022 launch, OpenAI's ChatGPT has excited architects by transforming design and workflows. It aids in conceptual design, architectural writing, and automating tasks. Future uses may include generating code and CAD models. While boosting productivity, it also underscores the need for architects to maintain unique creativity amidst automation. [122]

4.2. SECOND: Linking AI with Major Architecture Design Trends

This section of the research is introducing concepts of integrating the architecture design trends with artificial intelligence

4.2.1. Linking AI with Traditional Architecture Design

Integrating AI with traditional architecture enhances creativity through innovative design concepts, boosts efficiency by automating tasks, improves accuracy with error detection and compliance, and reduces costs by minimizing waste and labor. It also supports better project management with improved tracking, resource allocation, and client communication. [140]

Examples and Case Studies

The following are examples of buildings designed with the assistance of artificial intelligence, illustrating the diverse applications and benefits of AI in architecture and its significant impact on the future of construction: [140]

1) Shanghai Tower (figure 8) uses AI for optimized energy efficiency, wind resistance, material selection, and construction management, enhancing stability and comfort.

Figure 8. *Image of the Shanghai skyline in sunset featuring the Shanghai Tower Image by Gensler [140].*

2) Skanska's Project HALO uses AI-powered robots for precise construction tasks, boosting efficiency, safety, and reducing costs and errors.
3) XtreeE's AI-designed 3D-printed house in France combines aesthetic innovation with structural integrity, optimizing material use and sustainability.
4) The Edge in Amsterdam (figure 9) uses AI for energy optimization, climate control, and space management, enhancing comfort and sustainability.

Figure 9. *Image Exterior shot of The Edge building in Amsterdam Image by edge.tech [140]*

4.2.2. Linking AI with Environmental Architecture Design

AI enhances environmental outcomes by optimizing building design, urban planning, and resource efficiency, supporting SDGs like climate action and ecosystem health.

It models climate impacts, aids in low-carbon energy, and detects spills. However, its high energy use and risk of resource over-exploitation require careful implementation to balance benefits and drawbacks. [141]

4.2.3. Linking AI with Sustainable Architecture Design

AI and generative design are transforming sustainable architecture by optimizing building efficiency, natural light, and material use while reducing waste and energy dependence. This approach minimizes carbon footprints but raises ethical concerns like AI bias and job impacts. Responsible implementation is key to balancing benefits with maintaining human creativity in architecture. [142]

4.2.4. Linking AI with Green Architecture Design

The U.S. Green Building Council's [16] LEED rating system [17] evaluates buildings based on quantitative criteria, translating properties into statistical values for database storage. Green building aims at resource-efficient, environmentally responsible structures.

AI integration in green buildings enhances sustainability by addressing issues like thermal loss and improving assessment accuracy. Recent advancements include drones with AI for measuring thermal resistance and capturing environmental data, optimizing evaluation processes and supporting greener building development. [29-31, 143-144]

4.2.5. Linking AI with Parametric Architecture Design

AI-driven parametric design automates repetitive architectural tasks, boosting productivity, reducing costs, and ensuring accuracy with codes and standards. It accelerates prototype development and supports complex designs through algorithms, fostering innovative and efficient structures.

However, ethical concerns like data privacy and bias must be managed through collaboration among architects, data scientists, and engineers. [145]

4.3. THIRD: Defining the Two Wings of the Cognitive Architectural Design Process

4.3.1. Recent (AI) Architectural Design Models

AI in architectural design includes low-autonomy models and advanced systems like swarm intelligence and neural networks. Subsymbolic systems are hierarchical and require detailed parameter analysis, while Symbolic Systems offer greater autonomy with varied outcomes.

Evolutionary Algorithms, including Genetic Algorithms, optimize multi-criteria design. Swarm Intelligence enhances generative design with emergent behaviors. Future AI-driven

16 The "U.S. Green Building Council - (USGBC)" is a non-profit organization founded by three members from the "American Institute of Architects – (AIA)" together with representatives from over 60 architectural design firms in 1993.

17 The overall (LEED) evaluation system rates the building through four major levels: Platinum, Gold, Silver, and Basic Certifications

design assistants may improve by learning from human preferences, refining and understanding design processes more effectively. [113]

4.3.2. Selecting a Suitable Cognitive Design Theory for Integration of AI with the Design Process

Jean Piaget's "Schema theory" influences cognitive science by explaining how the brain organizes knowledge into structured schemas, which is useful for integrating AI into architectural design. Unlike Lev Vygotsky's "Zone of Proximal Development" or theories like "ACT" and "SOAR," Piaget's model offers a clear, structured framework for mapping knowledge.

4.3.3. The Proposed (AI) Mapping Guide

The proposed (AI) mapping guide consists of two "Cognitive Architecture Design Process" wings summarized in the following (table 2):

1) First Wing: Cognitive faculties (figure 9)
2) Second Wing: Cognitive processing of information and accumulated human experiences (figure 16)

Table 2. Summarizes the two wings of the "Cognitive Architecture design process".

THE TWO WINGS OF THE "COGNITIVE ARCHITECTURE DESIGN PROCESS"			
FIRST WING		**SECOND WING**	
Cognitive Faculties		**Cognitive Processing of Information and Accumulated Human Experiences**	
1	Perception	1	Data Mining
2	Attention	2	Probabilities
3	Imagination	3	Iteration
4	Intelligence	4	Alternatives
5	Memory		
6	Judgment		
7	Reasoning		
8	Problem-Solving		
9	Decision-Making		
10	Language Comprehension		
11	Production		

4.3.4. First Wing: Cognitive Faculties

The following are 11 key elements of "Cognitive Faculties" which are: Perception, Attention, Imagination, Intelligence, Memory, Judgment, Reasoning, Problem-Solving, Decision-Making, Language Comprehension, and Production (figure 10)

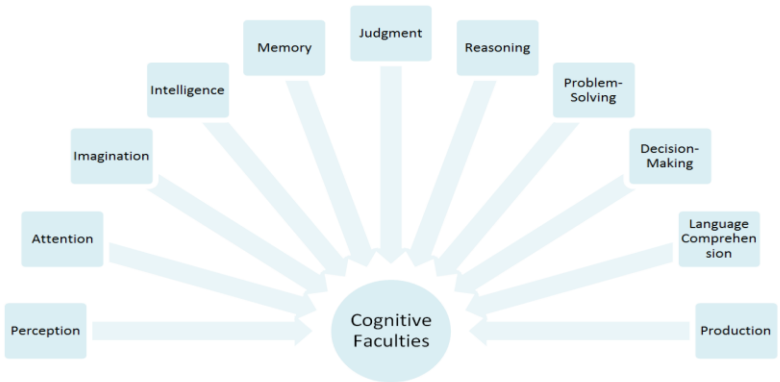

Figure 10. Is a diagram showing the 11 elements of "Cognitive faculties".

Perception

Perception combines sensory input and prior knowledge to shape how spaces are experienced, influencing architectural design. Understanding perception helps architects enhance user experience by considering physiological and psychological effects. AI simulates human perception using techniques like Convolutional Neural Networks (CNNs) and depth sensing to analyze and interpret visual data. [116-118]

Attention

Attention Insight uses deep learning to predict where users focus on content by analyzing a large dataset of images. It provides accurate visual attention forecasts (90-94%) and generates heatmaps, helping identify design issues without new participant data. The platform's insights aid in optimizing user experience. [119-120]

Imagination

AI lacks true creativity, functioning within its programming to generate outcomes based on human input. In architectural design, generative AI can produce impressive images from quotes but often exhibits flaws in 3D renderings.

This highlights AI's limitations in fully capturing the nuances and practicality of human-designed sketches. [121-122]

While the resulting image appears visually appealing, the AI struggled to accurately interpret certain 3D elements of the sketch. Instead, it rendered a large wall obstructing the space beneath the right side of the train tracks, whereas the original sketch shows no such wall below the main concrete beam supporting the railway. (figure 11)

This is in addition to incorrect interpretation of the building facades on the right side of the flying bridge tunnel.

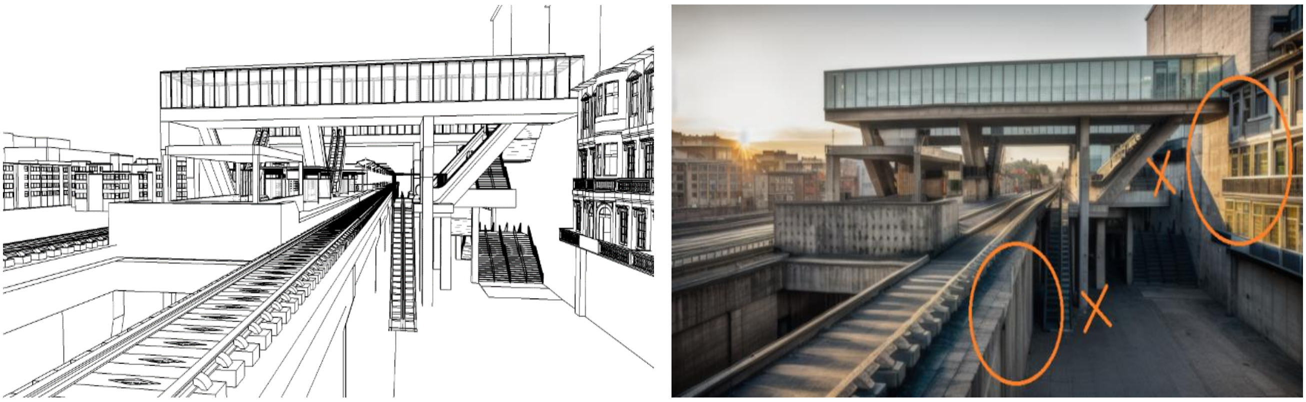

Figure 11. *Showing a 3D rendering generated by an online architecture AI application based on a sketch of a train station created by the author of this paper. While the resulting image appears visually appealing, the AI struggled to accurately interpret certain 3D elements of the sketch up is the 3Dimensional sketch, below is the generated AI rendering.*

Intelligence

Human intelligence involves abstract thinking, reasoning, and problem-solving, assessed by IQ tests in visual-spatial, verbal, and numerical skills. (figure 12)

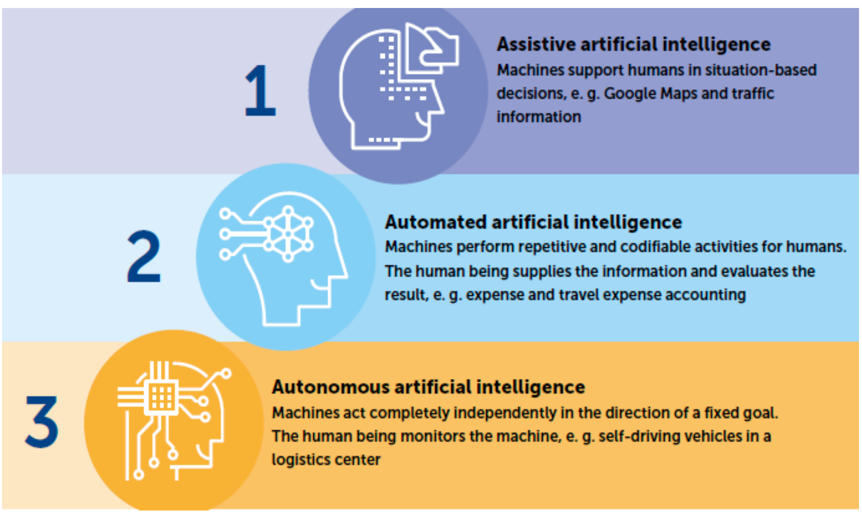

Figure 12. *Shows AI three main categories. [124].*

Theories vary from hierarchical models to interrelated abilities. AI systems, including assistive, automated, and autonomous types, mimic these cognitive functions by learning from data, assessing conditions, and making decisions. [123, 124]

Memory

Einstein's belief in the primacy of imagination over knowledge highlights creativity's role in AI design. (figure 13) AI systems use memory functions—like encoding and retrieval—to learn and evolve, mimicking human cognition through memory networks.

While enhancing AI sophistication, these systems must address data security concerns, especially in large language models. [125]

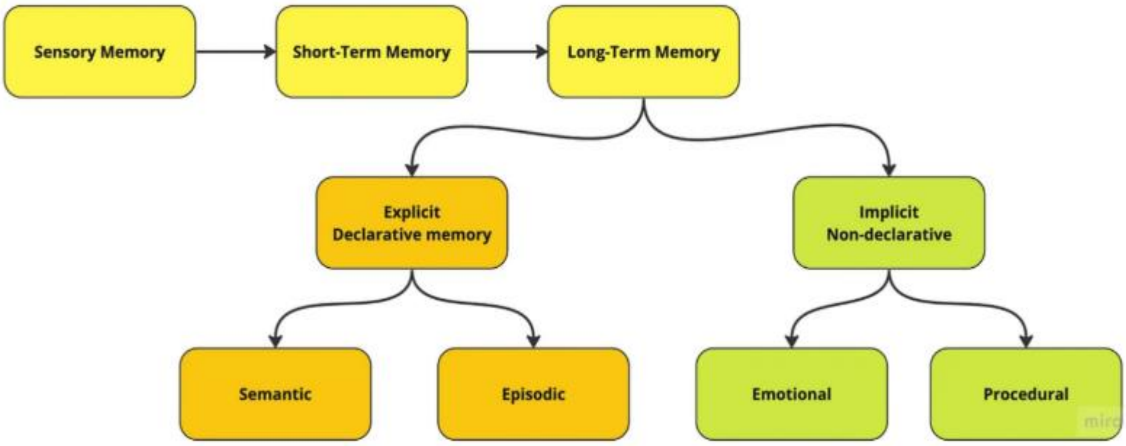

Figure 13. *Shows various memory types. [125].*

Judgment

AI excels at predicting outcomes and automating tasks but lacks creativity, ethical reasoning, and emotional intelligence. Human judgment is crucial to address these limitations, enhance accuracy, and make strategic decisions. Combining AI with human expertise ensures better outcomes by managing biases and ethical concerns. [126]

Reasoning

AI is transforming business by automating tasks such as email drafting and data analysis, allowing humans to focus on strategic planning. (figure 14) Advanced AI systems, including reasoning engines and Large Language Models (LLMs), use methods like Chain-of-Thought and Reasoning and Acting. Salesforce's Einstein Copilot illustrates AI's efficiency-enhancing potential. [127]

Figure 14. *Shows Salesforce's Einstein Copilot. [127].*

Problem-Solving

A "problem-solving agent" in AI addresses complex tasks through perception (data gathering), a knowledge base, reasoning, and planning. It also includes actuation for interaction, feedback for adaptation, and learning for improvement. These agents, used in game-playing, robotics, and decision-making, vary in complexity based on their applications. [135]

Decision-Making

Companies are adopting a data-driven approach, using connected device data for decision-making. While human analysis with tools like spreadsheets has limits due to cognitive biases, AI can process large data volumes, uncover patterns, and reduce biases. (figure 15) Combining AI's efficiency with human judgment is key for better, adaptive decision-making. [136]

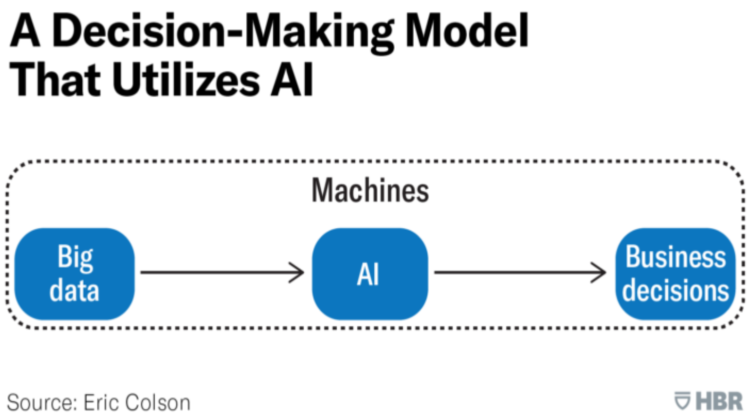

Figure 15. *Is a diagram showing a Decision-making model that utilizes AI. [137].*

Language Comprehension

Proficiency in multiple languages is vital in a connected world, and AI is revolutionizing language learning. Traditional methods often fall short, but AI tools like NLP and machine learning personalize lessons, offer real-time feedback, and provide 24/7 access through chatbots and virtual tutors. Future VR and AR advancements promise immersive experiences, though concerns about over-reliance, privacy, and bias remain. [137]

Production

A production system (figure 16) in AI automates tasks using rule-based frameworks with conditions (LHS) and actions (RHS). It includes a global database, production rules, and a control system for rule management. While simple and modular, it suffers from opacity, inefficiency, and lack of learning. Systems can be monotonic or non-monotonic, using inference rules for automation. [139]

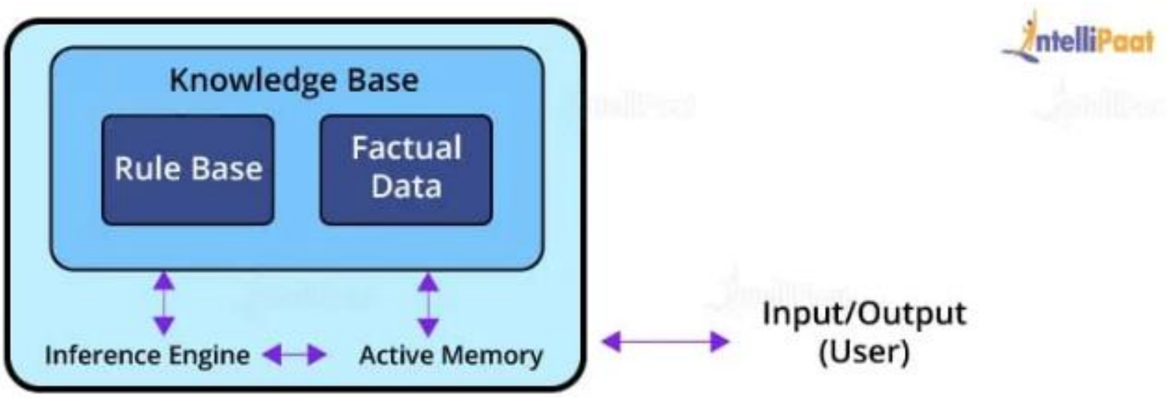

Figure 16. *Is a diagram showing the fundamental structure of an AI production agent. [139].*

4.3.5. Second Wing: Cognitive Processing of Information and Accumulated Human Experiences

The research defined four key elements influencing the Cognitive Processing of Information and Accumulated Human Experiences which are: Data Mining, Probabilities, Iteration, and Alternatives (figure 17)

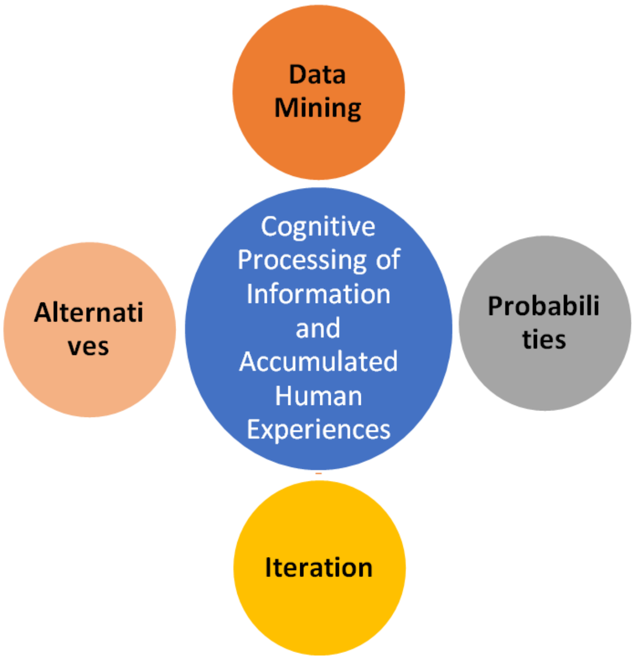

Figure 17. *Is a diagram showing the four key elements influencing the Cognitive Processing of Information and Accumulated Human Experiences.*

Data Mining

An architect's design quality improves with experience, reflecting their evolving expertise. For an AI system to generate high-quality architectural designs with minimal flaws, it must access a vast "Big Data" repository of architectural practices, like the extensive knowledge gained through years of professional practice. [18]

Probabilities

Probabilistic modeling combines AI with probability theory to guide learning from experience-based data. It provides a framework for handling uncertainty in models and predictions, crucial for scientific data analysis, machine learning, robotics, cognitive science, and AI, making it a key approach in designing adaptive, intelligent systems. [134]

Iteration

Machine learning development benefits from an iterative approach: start with a basic prototype, gather feedback, and refine progressively. This method helps when multiple options exist, and the best choice isn't clear. Using tools like MLOps for rapid experimentation accelerates development. Iteration applies to data labeling, model training, and deployment for ongoing improvement. [146]

Alternatives

AI boosts material selection and optimization in architecture by assessing performance, sustainability, and cost. It analyzes material properties and environmental impacts to aid decision-making.

AI also streamlines workflows, enhances productivity, and fosters creativity by generating diverse design alternatives based on data, design goals, and user preferences, expanding creative possibilities. [147]

4.4. FOURTH: Creating the Suggested "Architectural Design Process - Cognitive Pilot Map" From an Architect Perspective to Assist (AI) Programmers Developing (AI) "Architecture

The following (figure 18) illustrates the proposed "Architectural Design Process - Cognitive Pilot Map"

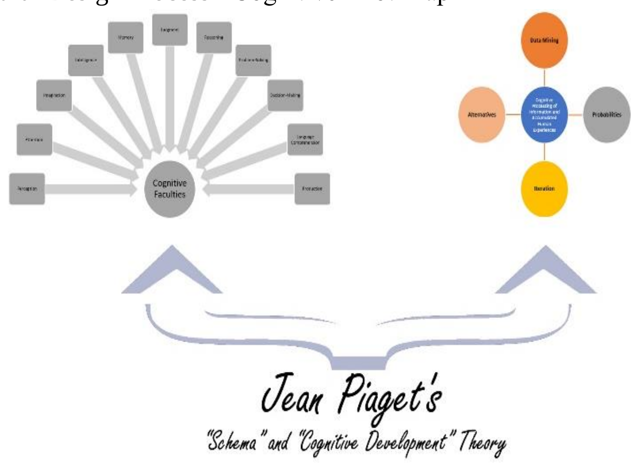

Figure 18. *The proposed "Architectural Design Process - Cognitive Pilot Map"*

5. Conclusion

5.1. AI Integration with Engineering

Artificial Intelligence (AI) is transforming numerous industries, and engineering is no exception. The integration of AI into engineering drawings is revolutionizing design, prototyping, and analysis processes.

5.2. Role of AI

AI's role extends beyond simply replacing traditional

18 In 1880, the U.S. Census Bureau faced data processing challenges until Herman Hollerith invented the Hollerith Tabulating Machine, reducing processing time from ten years to three months. Innovations continued with Fritz Pfleumer's magnetic tape in 1927 and the Colossus machine during WWII, which scanned messages rapidly. These developments contributed to the NSA's formation in 1952 and the evolution of big data, which now refers to complex data sets analysed using advanced methods. [114]

drawing methods; it enhances engineers' capabilities by automating mundane tasks, increasing precision, and fostering innovation. [138]

5.3. AI Revolution

AI revolutionizes engineering by converting visual elements into actionable data, automating repetitive tasks, and enhancing design with predictive analysis and simulation. It improves accuracy by detecting errors and integrating multi-disciplinary drawings.

5.4. AI Implementation

AI implementation involves data collection, model development, and CAD integration, promising efficiency and innovation while addressing challenges in interpretation and context.

6. Discussion

Ethical Considerations

The use of artificial intelligence (AI) raises several ethical concerns that must be addressed to ensure responsible deployment and to safeguard human rights and societal values. Key ethical aspects include:

1) Privacy: AI systems often rely on vast amounts of personal data, raising concerns about data privacy and security. There is a risk that sensitive information could be misused or inadequately protected, leading to breaches of privacy.
2) Bias and Fairness: AI algorithms can inadvertently perpetuate or amplify biases present in training data, resulting in unfair treatment or discrimination against certain groups. Ensuring fairness and mitigating biases is crucial to prevent AI from reinforcing existing inequalities.
3) Transparency and Accountability: AI systems, especially those using complex algorithms like deep learning, can be opaque in their decision-making processes. It is essential to ensure transparency in how decisions are made and establish accountability for outcomes to build trust and facilitate ethical oversight.
4) Autonomy and Control: The growing capabilities of AI systems, particularly in areas like autonomous vehicles and military applications, raise questions about human control and decision-making. Ensuring that humans retain ultimate control and that AI systems act in ways aligned with human values is a critical ethical concern.
5) Job Displacement: AI and automation have the potential to displace jobs and alter employment landscapes. Addressing the socioeconomic impact on workers and ensuring equitable transitions and retraining opportunities is an important ethical consideration.
6) Security and Safety: AI systems can be vulnerable to hacking and misuse. Ensuring the security of AI systems and preventing malicious use, such as in cyberattacks or surveillance, is essential for maintaining safety and security.
7) Moral and Legal Responsibility: As AI systems become more autonomous, determining who is morally and legally responsible for their actions becomes complex. Clear guidelines and frameworks are needed to address accountability for decisions made by AI.

Overall, addressing these ethical aspects involves balancing technological advancements with considerations of human rights, fairness, and societal impact.

Ongoing dialogue, regulation, and ethical frameworks are necessary to navigate the challenges posed by AI and to ensure that its benefits are realized in a responsible and equitable manner.

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Yasser Osman El Gammal is the sole author. The author read and approved the final manuscript.

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Data Availability Statement

There is no data set associated with this paper.

Conflicts of Interest

The authors declare no conflicts of interests.

Appendix

Supplementary document uploaded in the following repository:
https://drive.google.com/file/d/1i6KNSHRsgy2bgIA041Ll0H9-tSWcyZ8G/view?usp=sharing

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Biography

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Research Field

Yasser Osman El Gammal: Architectural design, Interior design, Architectural education, Virtual reality, New theories in architecture, Professional best practices, Interdisciplinary research in sustainable and green architecture and their intersection with other disciplines