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Ascertaining the Extent to which AI is Revolutionizing Architecture: Exploratory Survey

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Abstract
Artificial intelligence (AI) is a computer-based development of science and technology. It has been impacting various facets of life. While extant studies engage with AI in architecture and other fields, including exploring its impact and associated issues, the present study concerns itself with ascertaining the extent to which AI is revolutionizing architecture. Descriptive survey, qualitative method, analytic description, theme-focused and content analyses, and interpretive techniques are employed. The analysis demonstrates that AI is revolutionizing architecture to a large extent amidst the challenges of its adoption. The study concludes that AI plays a crucial role in transforming traditional practices, activities and operations, ushering in a high extent of optimization, efficiency, security resilience, and overall transformation of the field. Organizations and individuals in architecture sector are advised to migrate from the traditional practices and systems to those of AI-driven and smart technologies. Government and Non-Governmental Organizations are charged to support organizations willing to adopt AI but lack finance, resources, and technical capacity.

INTRODUCTION
Artificial intelligence (AI), an initiative of John McCarthy in 1956 (Lukovich, 2023; Chaillou, 2019), has become fruitful and very influential in contemporary times. While John McCarthy initiated the idea of human-based AI in the 1950s, Oliver Selfridge came up with the idea of the non-human based AI in the 1960s, being autonomous

software agents capable of performing tasks undertaken by human beings (Lukovich, 2023; Hoar et al., 2017). This technological breakthrough has been revolutionizing different fields. The field of architecture is not left out. Although there are extant studies (Lukovich, 2023; Pena et al., 2021; Chaillou, 2019; among others) on the impact of AI on architecture, they are not concerned with determining the extent of the impact.

According to Chaillou (2019), AI and other cutting-edge technologies are greatly impacting and proffering solutions to architectural design in four distinctive phases. These are modularity, computational design, parametricism, and artificial intelligence, which are overlapping and interdependent. Besides, there currently exists an insignificant level of integration of AI and other cutting-edge technologies into the field of architecture (Marsh, 2020). This backdrop adversely affects operations and activities in the field. The dire need for change informed this study. In other words, against the foregoing backdrop, the present study seeks to determine the extent to which AI has been revolutionizing architecture.

Purpose, Scope and Stance

The purpose of this study is to ascertain the extent to which AI has been revolutionizing architecture. In ascertaining the extent to which it revolutionizes the field of architecture, the impact of AI on architecture is explored. Thus, determining the extent to which AI has been revolutionizing architecture and exploring its impact on architecture constitute the scope of the study. The paper argues that for more impact of AI on the field of architecture, the integration of AI into this sphere should be examined critically and appreciably through research alongside other means, and stakeholders should make concerted efforts to increase its integration. The efforts include providing resources and manpower for AI integration and usage, and widely creating awareness about the prospects and challenges of AI. The stance of the study revolves around its noted central argument.

Theoretical Grounding

The study is grounded in Venkatesh's et al. (2003) Unified Theory of Acceptance and Use of Technology (UTAUT). The theory explains how technology gets accepted and used in society. UTAUT comprehensively reflects the central ideas of the other major theories of computation, information, technology and communication sciences, and innovation adoption. These are Technology Acceptance Model (TAM), Theory of Reasoned Action (TRA), the Diffusion of Innovations Theory (DOIT), Theory of Planned Behavior (TPB), the combined TAM and TPB (C-TAM-TPB), the Motivational Model (MM), the Social Cognitive Theory (SCT), and the Model of PC Utilization (MPCU). Even from its name, one understands that UTAUT is comprehensive, because of its integration of the different ideas of the eight other theories.

There are four pillars of UTAUT. These are performance expectancy, effort expectancy, social influence, and facilitating conditions (Venkatesh et al., 2003; Lam, 2022). Accordingly, users of technologies, such as AI and smart technologies, expect certain extent of their performance in order to adjudge them as being worthwhile. The performance extent influences or determines the adoption of given technologies. Upon realizing that certain technologies perform well and foster better human performance, individuals get interested in them and make efforts to adopt them. Studies, such as Mersal (2023), Patil et al. (2022), and Darwish (2017), indicate that the integration of technologies into various areas of engineering helps optimize performance and paves way for more groundbreaking results in the field.

The implication is that the reliance on human efforts and intelligence alone would not produce such results. Of course, machines are faster in many activities than humans. Thus, when individuals or organizations realize that AI and other smart technologies can perform up to and beyond expectations, they likely become interested in them and adopt them combination with their extant conventional systems and activities. It follows that the performance extent of these cutting-edge technologies drives the adoption of AI and the advocacy for its significant adoption for architectural activities. The essence is to ensure increased or better performance, leading to higher results or productivity in the field of architecture as well as other fields.

Also, individuals consider the efforts expected to be made when adopting a technology, as an innovative system. The expected efforts, when weighed to be higher than the expected results or the erstwhile efforts, individuals get discouraged from adopting certain technologies. When the reverse is the case, there is motivation and appreciable extent of adoption. Next, social factors influence the adoption of technologies, just as they do to non-technological innovations or systems. These include social settings or contexts, social impact of given technologies or innovations, perception, worldviews, attitude, interests, tales, myths and realities about given technologies or innovations, peer influence, and social status, among others.

The study by Hodson et al. (2023) aptly demonstrates the social influence of technologies, as innovative systems in social settings. It describes how social impact addresses salient issues of smart projects, giving priority to human-centered design. It emphasizes the need to deploy more coherent, consistent, and analytical approaches to attain significant changes, and understand social impacts before, during and after smart city projects. In addition, there are conditions that either encourage or discourage the adoption of technologies or other kinds of innovations.

Those that encourage adoption are enablers, while the otherwise ones are detractors. As such, where individuals believe that technologies are needed for optimization, betterment and reformation, organizations are bound to have or strive to acquire such technologies. Where technologies are not believed to have any significant extent of influence, their adoption is seldom considered. Enabling conditions facilitate the adoption of any technologies or innovations. Therefore, given the above exposition, it is quite obvious that UTAUT is apt for this study, as its theoretical framework.

AI Technologies in Architecture

The AI subfields or models having significant presence in the field of architecture include machine learning, deep learning, federated learning, computer vision, robotics, Natural Language Processing (NLP), Internet of Things (IoT), pattern recognition, digital twins and real-time analytics, Building Information Modeling (BIM), and Generative Design (Pasupuleti, 2022; Thuraka, 2022). They have various techniques that function independently and interdependently. When deployed, the techniques impact various areas and activities of architecture. Basically, there are two major approaches to AI. These are:

i. the sub-symbolic systems, which are the selected parameters usually analyzed in a hierarchical way; and
ii. the symbolic systems, which are autonomous processes operating in a non-hierarchical way, whereby the solutions are less expected (Cudzik & Radziszewski, 2018).

There are extant studies that affirm the place of AI in various spheres of life. For example, Mungoli (2023), Pasupuleti (2022), Pasupuleti and Inyang, (2022), Shawana (2022), Thuraka (2022 & 2021), and Ro (2018) unanimously hold that AI technologies can be used for addressing issues in healthcare, education, agriculture, and societal issues. The implication is that AI can also be used to address salient issues in architecture. Similarly, the National Strategy for Artificial Intelligence Bangladesh (2020) indicates that AI has the capacity to carry out tasks undertaken by humans, which involve reasoning, seeing, learning, critical thinking and basic leadership. Although different AI models are applied to architecture, neural networks, swarm intelligence and evolutionary/genetic algorithms are noted to be foremost AI algorithms that are commonly integrated into architectural activities (Lukovich, 2023; del Campo et al., 2020; Chaillou, 2019; Cudzik & Radziszewskí, 2018).

AI techniques are optimizing and revolutionizing bricklaying and painting. Machine learning, deep learning and robotics are very good at predictions and detections. They also optimize and improve decision-making and scheduling at a significant extent. Machine learning techniques include logistic regression, decision tree, random forest, and AdaBoost (Ivanova et al., 2023; Wusu et al., 2022). Deep learning (DL) algorithms are used extensively for architectural design and visualization, including 2D and 3D generative applications (Baduge et al., 2022; del Campo et al., 2020; Mérő, 2019; PWC, 2019).

Pattern recognition involves data and system integration applications. These enhance safety management. When combined with data integration, virtual reality ensures personnel safety, and improves planning, inspection processes, training and AI user education (Lam, 2022). Jaafreh and Jaafreh (2021) argue that their proposed model called “Construction Management Modelling System (CMMS)” can sufficiently address the various challenges to different at construction sites, such as existing and expected obstacles. The CMMS consists of Building Management Systems (BMS), Supervisory Control and Data Acquisition (SCADA), IoT, smart data tags, green building concepts, smart surveillance, self-moving transportation, and mobile technology. The model is AI-based, highlighting the capability of AI solve different problems.

Extent of Revolutionizing Architecture

Although the extent to which AI is revolutionizing architecture cannot be easily determined, this study considers the extent on the basis of the impactful role AI plays in the field of architecture and how its integration has been transforming the field. AI gets the field of architecture automated, transformed, innovated, optimized and rebranded in various ways. Onsite and offsite constructions, designs, planning, and scheduling have changed with the application of AI and smart technologies. For example, Grasshopper, ANSYS CFX, and CityEngine are examples of AI-based innovations in urban planning and architectural designs (D’Apuzzo et al., 2022). With these in place, AI is undoubtedly revolutionizing architecture at a large extent.

The application of AI techniques in architecture also revolutionizes professionalism, experiences and opportunities (Lukovich, 2023; Marsh, 2020; Cudzik & Radziszewskí, 2018; Taleb & Musleh, 2014; Schneider, Koltsova & Schmittt, 2011). More so, tasks, projects, designs and other architectural activities are well planned, managed, streamlined, optimized, controlled, monitored and transformed by applying different techniques of the AI subfields. Efficiency and quality are two major results of their application in the field of architecture. Furthermore, interactions among workers, machines and objects are monitored by smart wearable, such as helmets and vets (Schwab, 2016). AI help provides valuable insights for maintenance and safety. It does these through sensors, drones, and other technologies. These are also ways through which AI has been revolutionizing architecture in various regards.

More so, construction documents and communications are automated by Natural Language Processing (NLP) algorithms. The automation helps to reduce the time spent on administrative tasks. Thus, projects are done expediently. Project managers use several AI techniques to plan, design and manage buildings and infrastructure more effectively. Site surveys and the collection of data to generate 3D models of buildings are done better these days using Aerial drones, which AI techniques. Also, K-means Clustering and Mean shift are AI technologies that optimize, analyze and manage data on construction sites. While the former helps foster effective management and optimization of construction processes and materials, the latter optimizes and analyzes construction site data to a large extent (Xu et al., 2021).

Faster R-CNN, Canny Edge Detector, and Mask R-CNN are computer vision algorithm applications. They are used for: identifying and tracking construction progress and elements; identifying defects and other construction elements; and segmentation of images that help identify specific objects in construction images (Alsakka et al., 2023). Apart from the aforementioned ways through which AI revolutionize architecture, the integration of AI and other smart technologies into architecture allows for the realization of the goals of environmental sustainability. This assertion is given credence by studies such as those contained in the table below.

Table 1: Impact of Technologies on Green Building

Studies	Findings
Rane et al. (2023) **Badawy et al. (2021)**	The use of technologies fosters compliance with principles of green building in Palestine as well as beyond. This innovative approach revolutionizes new and existing buildings, saves energy, reduces waste, and improves environmental quality in general.
Sadowski (2021)	The implementation of green building policies, such as the New European Bauhaus principles, allows for the attainment of sustainable architecture education. Architects are guided by new design indicators that focus energy, environment, indoor climate, and society. These indicators reflect the objectives of the European Green Deal. The indicators enable architects to uphold renewable energy use and biodiversity protection, thereby contributing enormously to circular economy.
Liu et al. (2022)	The application of deep learning techniques to building design and planning optimizes the design of green buildings in smart cities, traffic flow, and other architectural activities. It also reduces energy consumption, and enhancing the efficiency of green buildings.

	Also, deep learning proffers a high level of prediction, with which accuracy is attained much more than what that offered by traditional methods.
Aliero et al. (2022)	Smart energy products, networked sensors, and data analytics software play crucial role in monitoring environmental data and the energy consumption habits of occupants. Smart technologies enhance the control of engineering and building activities, thereby modernizing them variously.
Darwish (2020) **Ismail and Afifi (2019)** **Abbasi and Hasan (2017)**	The application of smart and green technologies to building and construction presents prospects and challenges to the attainment of sustainable smart cities. Strategic integration of architecture intelligence systems can help address the challenges, allowing for advancement in achieving the goals of environmental sustainability.
Mersal (2023) **Wu and Maalek (2023)** **Megahed and Hassan (2022)**	The integration of digital technologies, such as building information modeling (BIM), point clouds processing and field information modeling (FIM), into building and construction brings about significant changes. These technologies can help address issues of carbon emissions, energy consumption, and costs. By addressing these issues, they pave way for renovation and redevelopment scenarios.
Gao et al. (2023)	The integration of IoT technology into buildings can effectively reduce the consumption of energy and help provide efficacious and lasting solutions to issues of energy management.

Source: Author, 2023

It is quite obvious from the above that AI has been revolutionizing the field of architecture. Apart from those noted above, AI algorithms, such as decision trees and support vector machines (SVM), carry out predictions that allow for effective maintenance of equipment. Following effective predictions, potential equipment failures are detected and prevented. Effective maintenance allows for quality. AI generative designs proffer innovations. For this study, AI has been revolutionizing architecture in the following ways:

- Prediction, detection and mitigation of conventional risks, faults and anomalies
- Optimization and automation of operations and activities
- Increasing efficiency

- Maintaining, protecting, organizing, and building capacity, resilience, and sustainability
- Saving time, costs and resources, thereby preventing wastages
- Provision of large data for different purposes

The extent to which AI is revolutionizing is evident in the growing application of robotics, 3D printing, modularization, digital twin technology, analytics, and supply chain optimization to architecture by different organizations in the industry. Liu et al. (2022) prove that through accurate predictions and smarter decision-making in urban development, deep learning and machine learning serve as viable means of attaining green building designs and green cities. They add that multi-layer neuron structures enhance urban planning and building design, which optimize traffic flow, reduce energy consumption, and improve efficiency in green building. Consider the following table:

Table 2: Impact of Computer-Based Simulation Technologies on Architecture

Studies	Findings
Wang et al. (2023)	The application of Internet of Things (IoT) to building activities optimizes energy consumption. Using IoT for building and other architectural purposes entails applying optimization methods, such as particle swarm optimization (PSO), chaotic particle swarm optimization (CPSO), and fractional chaotic order particle swarm optimization (FCPSO). These methods are result-oriented in the optimization of building, with which smart buildings and green building principles are attained.
Prabhu et al. (2022)	The demand for large data is relatively high these days among organizations in the fields of building and construction, engineering, and informatics. IoT technology plays a crucial role in building and monitoring smart systems, as it allows for remote control of and access to structures from far and near.
Suryawinata and Mariana (2022)	Architectural practices are revolutionized by Virtual Reality (VR), an AI technology that has several constituent models. It provides architects and designers with interactive platforms for visual analytics of green building activities in real-time.
Gao (2021)	Computer-based simulation technologies play a critical role in architectural process.

	They simulate various scenarios, unveil the strengths and weaknesses of various design approaches, and enhance quality, sustainability, and efficiency as result of informed decisions by architects.
Jha et al. (2021)	AI and IoT are viable mechanisms for urban planning and building of sustainable smart cities. Smart devices connected to the internet produce large data for different architectural activities, creating intelligent systems for smart cities, smart healthcare, and secured environments.
Nadeem et al. (2021)	Eco-friendly activities are promoted by the integration of IoT into green buildings and natural resources are managed better.

Source: Author, 2023

Factors Militating against AI Integration into Architecture

The integration of AI into the field of architecture would have been higher than what it is currently borne not for some militating factors. These include cyber threats and crimes, financial challenges, threats to human wellbeing, AI safety and fairness, violations of ethics and human rights, data security threats, privacy invasion, and technological unemployment, to mentiuon but a few (Marsh, 2020; Yigit et al., 2018). Darwish (2017) emphasizes the cost implications of AI as the serious challenges of its adoption among organizations in the industry. AI needs voluminous data for high results and so its prime limitation is data (Cudzik & Radziszewskí, 2018). The reason is that the more the data, the better the results (Lukovich, 2023).

As Marsh (2020) and Picon (2020) rightly observe, in order to fully take advantage of the creative potentials of AI models, the fundamental 'otherness' of computers must be respected. These include the differences between machine elements and human characteristics. For example, where humans see walls, floors and roofs, machines may choose different ways of organizing its reading of the same components of a building. The need to affect a change to that end is what gave rise to this study. The essence is to contribute to increasing the adoption of AI by a larger number of organizations for architectural undertakings.

Also, by ascertaining the extent to which AI impacts and revolutionizes architecture, the study rouses deserving attention of individuals, organizations and governments to the adoption of AI for architectural activities. It also awakens their consciousness towards increasing AI adoption and addressing the concerns about its adoption. Taking full advantage of AI for architectural purposes requires making concerted efforts to ameliorate the challenges of its adoption. Once the constraints are addressed or lessened appreciably, there would be significant adoption of AI for architectural purposes. This is because many of the organizations in the industry that have not keyed into AI integration would likely do so.

Trabucco (2021) expresses hope that an increase in training of architects in universities would lead to a massive impact of AI technologies on disciplines that are yet to experience high(er) or the supposed integration of AI and its attendant prospects. Borglund (2022) points out that although the integration of AI into various areas of architecture affects creativity, exploring and controlling the processes of its implementation can ensure the desired applications of AI to engineering, architecture and construction. By so doing, significant change and prosperous future can be achieved in these fields as well as others. Similarly, Raza et al. (2023) advise designers, educators, policymakers, and researchers to uphold ethical considerations in the course of integrating as well as advocating the integration of AI into building, construction, engineering and education. Such considerations, they note, include preservation of creativity, collaboration, and ethical values that have to be emphasized to a large extent.

Conclusion

It is quite obvious that AI has been revolutionizing the architecture industry. As it impacts the industry, a lot of things are getting revolutionized therein. Activities, operations, systems, procedures, tasks, projects, scheduling and practices in architecture are getting innovated, optimized, transformed and seamless. The benefits of AI to architecture, as to other spheres, are evident in its impact on the industry. With AI in the industry, architectural undertakings are being digitalized, made seamless, easy, better, speedy, less expensive, stressful and time-consuming, and cost-effective. Therefore, the study concludes that since the impact of AI on architecture is appreciably high, the extent to which it is revolutionizing the industry is also significantly high amidst the current low extent of AI integration into the architecture sector.

The low extent is informed by attitude towards and perception of AI, high costs of AI models and resources, lack of technical-know-how, and slow institutional reception of AI. Stakeholders in architecture industry and political realm are charged to help increase the integration of AI into architecture. Doing so means increasing the current extent to which AI revolutionizes architecture. Increasing the integration can be achieved through wide awareness about the nitty-gritty of AI, tackling the concerns raised about AI usage, manpower re/training for AI technical-know-how, and provision, availability and accessibility of AI resources.

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