Keeping up with changing technologies: The nexus between architecture and engineering

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Abstract. Advancements in technology are fundamentally transforming architectural and engineering domains within the building and construction sector. This study investigates the intersection of both fields in assimilating emerging innovations by eliciting empirical perspectives from practitioners. Embracing a quantitative approach, a survey was conducted among 203 architects and 392 engineers within Enugu metropolis, Nigeria using proportionate random sampling. Results were analyzed using descriptive statistics, revealing insights into awareness, perception, and collaboration concerning emerging technologies. Findings revealed high awareness but uneven adoption of building information modeling tools, with 97.3% of architects employing them versus only 25.4% of engineers. Although virtual reality and cloud-based platforms showed promise for enhancing project coordination, actual usage lagged significantly, likely owing to systemic and attitudinal barriers. However, respondents strongly endorsed tighter, technologically unified partnerships to smooth industry transformation, necessitating digital literacy interventions, supportive policy and binding protocols bridging persistent digital divides stalling seamless innovation diffusion along construction value chains.

1. Introduction

The proliferating global population and urbanization trends are creating unprecedented demand for sustainable and resilient buildings and infrastructure [1]. This mounting pressure on the architecture, engineering and construction (AEC) sector to accommodate environmental and demographic changes has been assessed by various studies including Asmar et al. (2021) [2] and Hatmoko et al. (2022) [3]. It is estimated that two-thirds of the global population will live in cities by 2050 (UN, 2019), necessitating adequate and climate-conscious housing at rapid scale [4]. Various projections indicate that along with population growth in developing regions, there is accelerating migration to metropolitan areas bringing its own resource demands and threatening sustainability aims [5, 6]. The twin challenge of extensive growth and climate consciousness is steering the imperative for greener, smarter techniques that enhance productivity while lowering carbon footprints. The AEC industry thus faces heightening expectations to deliver positive societal change through upgraded technologies meeting accelerating safe housing needs. This backdrop informs the rationale for assessing opportunities and technological innovations to balance environmental and demographic pressures.

Advancements in technology are transforming the landscape of the building and construction industry, presenting both prospects and challenges for professionals in architecture and engineering. Given the swift pace of technological evolution, grasping the interplay between architects and engineers is vital for cultivating synergy and propelling innovation within the sector. The collaborative nexus between architects and engineers has become increasingly impacted by rapid technological advancements transforming building design and construction. while distinct responsibilities exist between the architects and engineers, their functions inherently overlap during building development requiring structured coordination - from initial space use plans to technical drawing approvals [7]. As Nawari (2021) [8] explains, this interdependency has become more pronounced with technologies like parametric modeling and 3D printing enabling codified design-analysis iterations. Memon et al. (2020) [9] observed, increase in innovations like automation, virtual reality, and data analytics has necessitated tighter coordination between architectural and engineering professionals. The seamless integration of new tools and methodologies is crucial for enhancing efficiency, accuracy, and collaboration across

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various stages of building projects. However, while recognition of technological potential persists, adoption gaps remain tied to financial, behavioral and systemic barriers [10].

Presently, awareness exists regarding technological innovations like IoT, robotic fabrication and life cycle analysis that carry noteworthy collaborative potential. Yet as Wong et al. (2018) [10] established, sizable gaps remain between technology theory and practical application within architectural and engineering domains. Moreover, research of Edum-Fotwe et al. (2001) [11] noted, ingrained behaviors steeped in discrete ways of working exacerbate barriers. In order to understand limiting factors to spur widespread adoption and implementation of emerging technologies within the study area, professional perception and awareness needs to be evaluated. This study delves into the nexus between architects and engineers in navigating these technological changes, aiming to elucidate their awareness, perception, and collaborative practices within the evolving digital ecosystem. By exploring the perspectives of practitioners, the research identifies areas of convergence and divergence in technological adoption and utilization. Through a quantitative research methodology, empirical insights were captured that can inform strategic interventions and facilitate smoother transitions towards a technologically advanced built environment to support and sustain the housing and urbanization pressure on the AEC sector.

1.1 The study area

Enugu Metropolis comprising of South, North and East local government areas is in Enugu State, southeast Nigeria (see figure 1). Enugu metropolis is the state capital and seat of administrative authority of Enugu State located on $06^{0}21^{0}$N and $06^{0}30^{0}$N latitude and between $07^{0}26^{0}$E and $07^{0}37^{0}$E longitude. In the early 1960s it was the regional headquarters of the Old eastern Nigeria region [12]. It has evolved from been a small coal mining camp to an urban area [13] housing currently over 1.1 million people [14]. The predominant ethnic group is Igbo which as Okosun et al. (2023) [15] highlighted, accounts for over 90 percent of the population. Enugu city has undergone rapid development and expansion in recent decades according to Okeke et al. (2020) [16] with burgeoning commercial activities and increasing immigration. The study area is most suited for this research because that is where the main central business district is located, and the bulk of Architects and Engineers operate from.

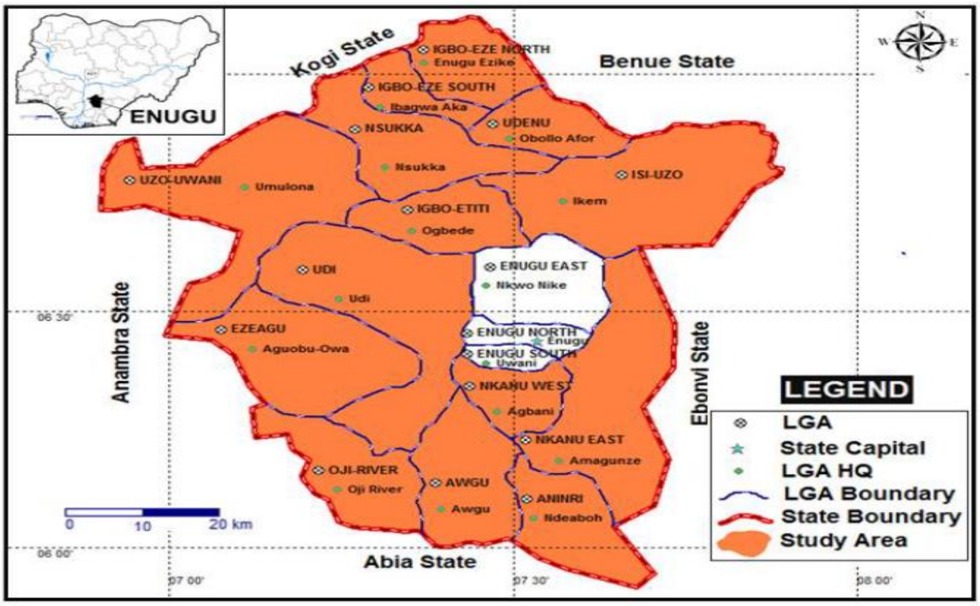

Figure 1: Map Enugu state showing Enugu Metropolis (Source: State ministry land and survey Enugu,2010)

Enugu South is bounded to the north by Enugu North and to the south by Nkanu west local government areas. It comprises of the following district; Awkunanaw, Akwuke, Amechi, Ugwuaji, Obeagu, and Amechi-Uwani with coordinates 6°24′N 7°30′E. The LGA is also rich in agriculture.

Enugu North is bounded in the north by Enugu East Local Government with Nkwo-Nike as its headquarters, in the South by Enugu South with Uwani as its headquarters, in the West by Udi local Government with Udi as its headquarters and west by Nkanu east Local Government with Agbani as its headquarters. The LGA is made up of four main district areas Amaigbo Lane, Onuato, Umunevo and Ihenwuzi with coordinates 6°28′N 7°31′E

Enugu East is bounded to the north by Isi-Uzo and Igbo-Etiti Local Government Areas, to the south by Enugu north Local Government Area, to the east by Nkanu east Local Government Area and to the west by Udi Local Government Area.

Enugu East is made up three zones/districts: Nike-Uno, Ugwogo and Mbuli Ndljodo with coordinates 6°32′N 7°32′E. Its headquarters are in the town of Nkwo Nike.

2. Literature Review

2.1 Technological advancements transforming architectural and engineering practices

New innovations are fundamentally reshaping architectural and engineering practices by empowering professionals with advanced tools, methodologies, and insights thereby influencing how professionals conceive, design, and construct the built environment. According to Norman (2017) [17], Emerging technologies are rapidly developing innovations that could significantly impact various industries and society. These technologies, often in their early stages, include artificial intelligence, biotechnology, nanotechnology, robotics, 3D printing, quantum computing, and renewable energy. They can bring transformative changes, create new opportunities, and address complex challenges in areas like healthcare, transportation, energy, communication, and environmental sustainability. As they evolve, they can reshape industries, disrupt traditional business models, and drive economic growth and social progress [18]. Some examples of emerging technologies that are influencing the architectural and engineering sector include:

- **Building Information Modeling (BIM):** BIM is a digital representation of the physical and functional characteristics of a building. It allows architects and engineers to work collaboratively on a single, integrated model, enabling better coordination and communication throughout the design and construction process.
- **Virtual Reality (VR) and Augmented Reality (AR):** VR and AR technologies are increasingly being used in architecture and engineering to create immersive experiences that allow stakeholders to visualize and interact with designs in a virtual environment. This can aid in design reviews, client presentations, and public engagement.
- **Digital Fabrication and 3D Printing:** Additive manufacturing technologies such as 3D printing are being used to create complex architectural and structural components with greater precision and efficiency. This can enable innovative design solutions and more sustainable construction methods.
- **Advanced Simulation and Analysis Tools:** Engineers are utilizing advanced simulation software for structural analysis, energy modeling, and environmental performance assessment. These tools help optimize building performance and inform design decisions.
- **Internet of Things (IoT) and Smart Building Technologies**: IoT devices and sensors are being integrated into buildings to collect data on occupancy, energy usage, and environmental conditions. This data can inform design decisions and enable the creation of more efficient, responsive, and sustainable buildings.
- **Artificial Intelligence (AI) and Machine Learning:** AI and machine learning are being used to analyze large datasets and automate certain design tasks, such as pattern recognition, optimization, and predictive modeling. This can help architects and engineers make more informed design decisions and streamline repetitive tasks.
- **Sustainable Design Tools:** There are a variety of software tools that enable architects and engineers to assess the environmental impact of their designs, including daylighting analysis, energy modeling, and life cycle assessment tools. These tools help in creating more sustainable and eco-friendly buildings.
- **Robotics in Construction:** Robotic technology is being used in construction for tasks such as 3D printing of building components, automated bricklaying, and site assembly. This can lead to faster construction times, reduced labor costs, and increased precision in building processes.
- **Advanced Materials and Nanotechnology:** Advances in materials science and nanotechnology are leading to the development of innovative construction materials with enhanced properties, such as self-healing concrete, lightweight composites, and smart materials that can adapt to environmental conditions.
- **Cloud-Based Collaboration Platforms:** Cloud-based platforms are enabling architects and engineers to collaborate on projects in real-time, regardless of their physical location. This facilitates seamless communication, document sharing, and project management among multidisciplinary teams.
- **Drones and Aerial Imaging:** Drones are being used for site surveying, aerial imaging, and monitoring construction progress. They provide a cost-effective and efficient way to collect data and generate 3D models of sites, aiding in the design and construction process.
- **Additive Manufacturing:** Additive manufacturing technologies are being used to create complex architectural components and prototypes, as well as to explore new possibilities in form, structure, and materiality.

2.2 The Interdependency Between Architects and Engineers

The collaboration between architects and engineers is crucial in the design and construction process, as they bring distinct expertise to translate design concepts into functional, structurally sound buildings.

- **Design Integration:** Architects are responsible for conceptualizing and visualizing the overall aesthetic and functional aspects of a building, considering factors such as spatial layout, aesthetics, and user experience. While engineers focus on structural integrity and regulatory compliance. Integrating architectural and engineering considerations ensures design objectives are met without compromising stability or performance.

- **Technical Expertise:** Architects rely on engineers to provide technical insights and solutions to complex design challenges. They analyze structural, mechanical, and electrical aspects of designs, identifying potential issues and proposing practical solutions. By collaborating closely, architects can refine and enhance design concepts while maintaining design integrity.
- **Innovation and Problem-Solving:** The collaboration between architects and engineers foster innovation and problem-solving in the design and construction process, combining their strengths to tackle complex design and engineering problems creatively and effectively.
- **Communication and coordination:** Effective communication and coordination between architect and engineer is crucial for accurately conveying design intent and translating it into actionable plans. They must collaborate closely throughout the design and construction process, exchanging ideas, feedback, and information, ensuring alignment and coherence towards common goals.
- **Continuous Learning and Improvement:** The interdisciplinary collaboration between architects and engineers fosters a culture of innovation and knowledge sharing in the design and construction industry. This interdisciplinary approach promotes a holistic approach to design and problem-solving, driving innovation and excellence in architectural and engineering practices.

2.3 Tools designed to improve collaboration between architects and engineers

There are several software tools that are specifically designed to improve collaboration between architects and engineers. some examples include:

- **BIM Software:** BIM platforms such as Autodesk Revit, Graphisoft ArchiCAD, and Trimble Tekla Structures enable architects and engineers to work on a shared digital model of a building. BIM software allows for the collaborative creation, management, and exchange of design and construction data, facilitating coordination and communication between disciplines.
- **Collaboration and Project Management Platforms:** Tools like Autodesk BIM 360, Procore, and PlanGrid provide cloud-based platforms for project collaboration, document management, and communication among project team members. These platforms allow architects, engineers, contractors, and other stakeholders to share project information, track revisions, and coordinate tasks in real time.
- **Virtual Design and Construction (VDC) Software**: VDC tools like Synchro PRO and Navisworks facilitate multidisciplinary coordination by combining 3D models from different design disciplines, enabling better identification of conflicts and constructability issues, thereby fostering a collaborative environment between architects and engineers.
- **Cloud-Based File Sharing and Collaboration Tools:** Platforms like Autodesk A360, Dropbox, and Box provide cloud-based file sharing and collaboration capabilities, allowing architects and engineers to share design files, drawings, and documentation with each other and with project stakeholders in a secure and accessible manner.
- **Communication and Visualization Tools:** Software such as Bluebeam Revu and SketchUp enables architects and engineers to annotate, mark up, and collaborate on design drawings and models. These tools facilitate real-time communication, design reviews, and feedback exchange between the two disciplines.
- **Project Information Management Systems**: Newforma and Deltek PIM are project information management platforms that offer document control, email management, and workflow automation, enabling architects and engineers to efficiently manage project documentation and communication, ensuring all team members have access to the latest information.
- **Integrated Design and Analysis Software:** Tools such as Autodesk Fusion 360 and ANSYS Discovery Live enable architects and engineers to perform integrated design and analysis tasks within a single software environment. These tools allow for seamless collaboration between architectural design and engineering analysis, enabling real-time feedback and iteration on design concepts.
- **Design Review and Markup Tools**: Bluebeam Revu and Adobe Acrobat Pro DC are software that enable architects and engineers to collaborate on design documents and drawings, promoting interactive reviews and feedback exchange between the two fields.
- **3D Visualization and Rendering Software**: Lumion and Enscape are visualization tools that enable architects and engineers to create high-quality 3D visualizations and renderings of building designs, enhancing communication and collaboration between disciplines in refining project visual aspects.
- **Augmented Reality (AR) and Virtual Reality (VR) Platforms:** AR/VR tools like Unity 3D and Unreal Engine offer immersive environments for architects and engineers to collaborate on building designs, enhancing understanding and coordination between architectural and engineering elements through visualization and interaction in virtual space.

2.4 Diffusion of innovation theory and change management frameworks

The Diffusion of Innovation theory, developed by Everett Rogers in 1962, offers insights into how new ideas, products, or technologies spread and are adopted within a social system. This theory is particularly relevant in understanding the process of change management within organizations and societies. It extensively assesses technology assimilation, underscoring the influence of factors like relative advantage, complexity, compatibility and trialability alongside external variables. Some key concepts of the diffusion of innovation theory are;

- **Innovations:** Innovations refer to new ideas, products, or technologies that are perceived as novel and potentially beneficial by individuals or groups within a social system. These innovations can range from tangible products to intangible concepts or practices.
- **Adopters:** Adopters are individuals or groups within a social system who choose to accept and implement an innovation. Rogers categorized adopters into different segments based on their willingness to adopt new ideas, including innovators, early adopters, early majority, late majority, and laggards.
- **Diffusion Process**: The diffusion process describes the spread of an innovation through a social system over time. It typically follows a bell-shaped curve, starting with a small number of innovators and early adopters, followed by the majority of adopters, and finally reaching saturation as laggards adopt the innovation.
- **Communication Channels: Communication** channels are the means through which information about an innovation is disseminated within a social system. These channels can include interpersonal communication, mass media, social networks, and formal organizational channels**.**

The adoption of technology in Africa and Nigeria faces unique challenges due to socio-economic, cultural, and infrastructural factors. Despite the potential of innovations, assimilation faces hurdles. A holistic approach is needed to address infrastructure issues, improve affordability, enhance digital literacy, consider cultural and socio-economic factors, foster supportive policies, and promote entrepreneurship. This approach can unlock technology's transformative potential for inclusive growth, improved livelihoods, and development in Africa.

3. Research Method

The research embraces quantitative methodology, employing exploratory inquiry to capture the nuances and lived experiences within the nexus of architects and engineers amidst a backdrop of evolving technologies. The study adopted a questionnaire survey research design. It was considered the most suitable for this research because it will help the researcher to collect pragmatic data on the changing technologies in the building industries from two specific viewpoints, which are architects and engineers in the study area. The research population for this study consists of practicing architects and engineers (structural, mechanical and electrical) who are actively involved in the predesign and design stages of construction of a building. The participants will be selected from sampling frame consisting of the 203 Architects registered by the Architects Registration Council of Nigeria (ARCON) as of 2023 within Enugu metropolis and 392 Engineers registered by the Council for the Regulation in Engineering In Nigeria (COREN) as at 2023 in the study area. Details of the sampling frame are available in table 1.

The sample size to be selected for investigation is determined by using the Yamane (1967) sample size formula given in the Equation:

$$n= N/\mathrm{N}1 + N(e^2)$$

Where n is the minimum sample size for the sample, N is the population size of 595 practicing Architects and Engineers (structural, mechanical and electrical) as obtained from the sample frame and e is the precision level which is 0.05 significance level at a 95% confidence level. Therefore, the sample size is:

$$n= 595/1+595(0.05^2) = 239.12$$

Formula for distribution ratio.

$$X_n = P/N$$

where X is the unknown size of the subset of the sample size, P is the population of the variables, n is minimum sample size for the sample, N is the population size of 595 practicing Architects and Engineers (structural, mechanical and electrical) as obtained from the sample frame.

Table 1. Sample size proportion according to professions

Profession	Sampling frame	Sample size	Percentage
Architects	203	82	34.12
Structural Engineers	157	63	26.39
Mechanical Engineers	133	53	22.35
Electrical Engineers	102	41	17.14
Total	595	239	100

The instrument used in data collection for this study was a structured questionnaire which have four sections. The first section captures the socio-demographic information of the respondent and their practice-based tools. Section two elucidate on their awareness of emerging technologies in the practice of architecture and engineering within the study area. Section three captures the perception of the knowledge of respondents concerning technological advancement in the construction industry while the last section expatiates on relationship between Architects and Engineers in coping with changing technologies in the construction industry. To achieve the objectives of this study, results were analysed using descriptive statistics and presented using tables, charts, and text.

4. Results

A total of 239 structured questionnaires was administered to Architects and Engineers, including those specializing in structural, mechanical, and electrical disciplines, aiming to capture a comprehensive and informed perspective on the topic. Of these, 217 questionnaires were returned fully completed, accounting for 90.80% of the total distributed. The response rate based on professional discipline is detailed in Figure 4.

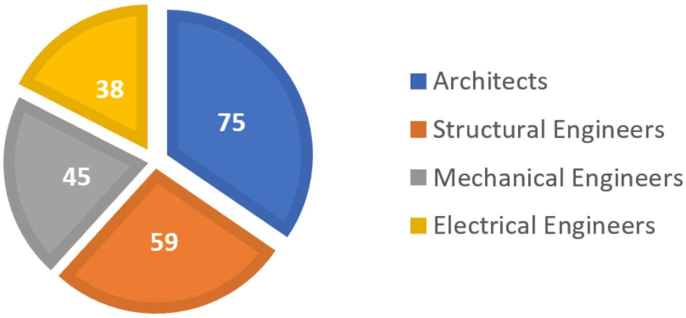

Fig. 2. Response based on profession.

According to Figure 2, Architects accounted for the largest share of responses at 34.56%, trailed by Structural Engineers at 27.19%, Mechanical Engineers at 20.74%, and Electrical Engineers at 17.51%. The collective responses amounted to 217, providing a comprehensive perspective across various professions. Survey research acknowledges the influence of gender, age, educational attainment, and professional background on individual perceptions of various aspects of life. Therefore, the personal characteristics of the participants in this study were analyzed, as outlined in Table 2.

Table 2. Socio-demographic characteristics of respondents (n = 217)

Characteristics	Frequency	Percent (%)
Gender		
Male	193	88.94
Female	24	11.06
Age Groups (years)		
20 years and below	0	0
21 – 40 years	37	17.05
41 – 60 years	130	59.91
> 60 years	50	23.04
Level of Education		
HND/B.Sc.	89	41.01
M.Sc.	108	49.76
PHD	20	9.21
Scale of Operation		
Small	18	8.29
Medium	114	52.53
Large	85	39.17
Years of Practice		
0-5 years	42	19.35
5-10 years	37	17.05
10-20 years	60	27.65
20 years and above	78	35.95

In the context of the research topic on technological change and the nexus between architects and engineers, this profiling data provides helpful background on the sample characteristics that may influence responses. The table 2 shows a high percentage of male respondents (88.9%) indicates the dominance of men in these professions in the study area. Prior research suggests gender can influence attitudes towards technology adoption. Therefore, capturing the data from both gender breakdown sets context. Over a Half of respondents (59.91%) were aged 41-60 years, indicating a demographic leaning towards very experienced professionals versus 17% young talent. Perceptions on building technological fluency and overcoming legacy ways of working may vary by age. However, the sample set represented legally competent adults capable of providing reliable empirical construction industry perspectives. With 41.01% educated to the bachelor's level, a high proportion do have postgraduate training. Approximately 9.21% held PhDs. Higher educational attainment levels signify a capable study sample. 39.17% of respondents operated large-scale firms and 8.29% work in small sized establish. Although 52.53% are engaged on a medium scale this data shows a good mix of work environment to capture vary perspective. Over a third (35.95%) have over 20 years' experience, while another portion (27.65%) have 10-20 years. Length and type of exposure to tools over evolving careers could impact views. This extent of professional maturity across the respondent's domains indicates comprehensive understanding of procedural subtleties, communication protocols, collaboration tools, administrative considerations etc. underpinning building and construction initiatives. Figure 3 shows the usage of various BIM software tools among the different professions sampled in the study area.

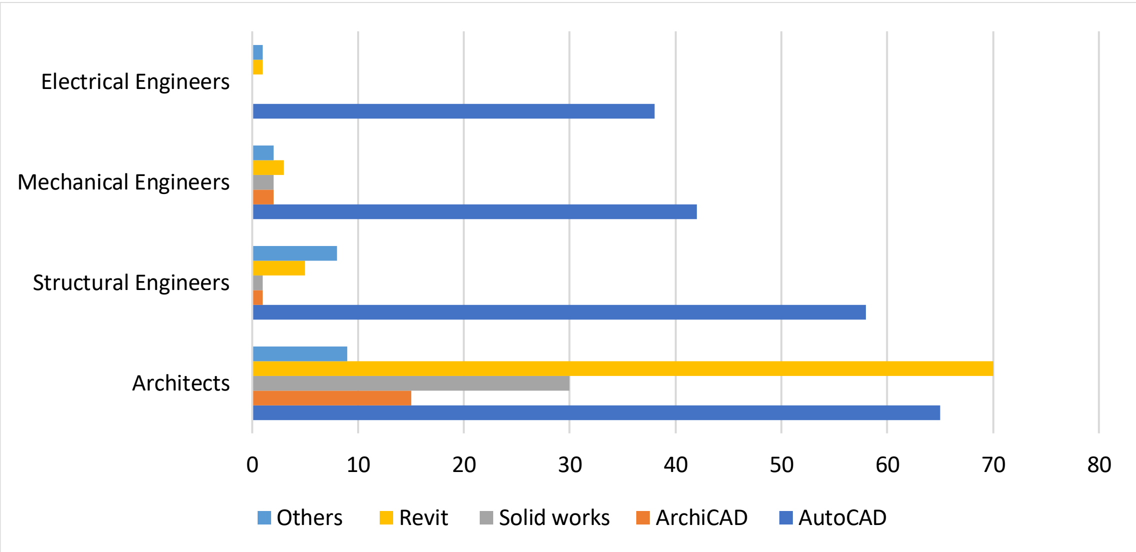

Fig. 3. Response based on the use of building information modelling tools.

This breakdown indicates that some professional use more than one software, however the usage of at least one BIM software tool is very high for architects at 97.3%, but significantly lower for all engineering disciplines - only 25.4% for structural, 20% for mechanical and 5.3% for electrical. The cumulative totals highlight that while specific tools show some variability, BIM adoption generally, has been much more extensive among architects versus engineers.

Table 3. Response based on the use cloud-based collaboration platforms**.**

Profession	**Procore users**	**AutoDesk BIM 360 users**	**Others**	**None**	**Total**	**Percentage of None**
Architects	0	7	0	68	75	90.67%
Structural Engineers	0	8	0	51	57	86.44%
Mechanical Engineers	0	2	0	43	45	95.56%
Electrical Engineers	0	1	0	37	38	97.37%

Table 3 shows the usage of cloud-based collaboration platforms among the professions. None of the respondents use Procore. Usage of Autodesk BIM 360 is 7 out of 75 architects (9.3%), 8 out of 59 structural engineers (13.6%), 2 out of 45 mechanical engineers (4.4%) and 1 out of 38 electrical engineers (2.6%). The table 3 also shows the percentage with no usage is high - 90.7% for architects, 86.4% for structural, 95.6% for mechanical and 97.4% for electrical. This demonstrates that while awareness of these cloud platforms exists, actual usage levels are very low across all disciplines. Over 90% of respondents do not leverage these technologies for collaboration currently.

Table 4. Awareness of emerging technologies in the practice of architecture and engineering.

Profession	BIM/ advance simulations	Cloud Based Collaboration Platform	3D Printing	Virtual reality & Augmented reality	Robotics & Artificial Intelligence	IOT & smart building technologies	Drones & Aerial Imaging
Architects	75	75	52	40	50	70	65
Structural Engineers	59	59	47	29	47	46	42
Mechanical Engineers	45	45	33	33	30	35	37
Electrical Engineers	38	38	27	17	24	36	20
TOTAL	217	217	159	119	151	187	164

From table 4 it is evident that the Awareness of building information modeling (BIM) and cloud platforms is uniformly high across all groups - architects, structural, mechanical and electrical engineers. This signals a broad recognition of these technologies' potential. However, awareness levels are lower for innovations like 3D printing (73.27%), virtual/augmented reality (65.43%), robotics (69.59%) and smart buildings. And drilldowns into specific groups show engineers lag architects. This knowledge gap could inhibit effective collaboration and integration. Architects demonstrate the highest levels of awareness of most emerging technologies. This likely reflects greater early adoption necessitated by design demands. Uptake lags on the engineering side, though they are crucial partners for successful implementation. For innovations still maturing like robotics and 3D printing, even architect awareness hovers around 50-70%. So, there are opportunities across the board for improving technological literacy to support collaboration.

Table 5. Perception of the knowledge of Architects and Engineers concerning technological advancement in the construction industry.

Perception of respondents	SA	A	N	D	SD	Mean	OMS	Rank
Have technological advancements significantly improved the efficiency and accuracy of construction process	110	72	11	24	0	4.24	4.05	3rd
The integration of virtual reality and augmented reality has enhanced the visualization and communication process	26	70	81	40	0	3.38		7th
Building Information modelling has improved quality of project delivery	128	59	30	0	0	4.45		1st
The adoption of 3D printing technology revolutionized the prototyping and fabrication of architectural and engineering components	70	110	36	1	0	4.15		4th
The implementation of advanced software for structural analysis and simulation has enhanced the design and performance evaluation of building structures	66	108	22	16	5	3.99		5th
The development of smart building technologies has transformed the way professional design and integrate building systems for improved efficiency.	33	128	45	11	0	3.84		6th
Cloud-based project management and collaboration platforms have improved design and document sharing among project teams	76	128	10	3	0	4.28		2nd

From table 5, the perceptions of architects and engineers regarding the knowledge and awareness of technological advancements in the building and construction industry highlights that the high rankings for efficiency/accuracy improvements and cloud-based platforms indicate a broad recognition of already-established technologies positively impacting the industry. This sets a promising baseline for further technological integration. However, lower scores for innovations like virtual/augmented reality and smart buildings reveal gaps in understanding and adoption of emerging tools with significant collaborative potential. As Wang et al. (2022) [19] observed, gaps persist between technology theory and practical application within construction fields. Critically, building information modeling (BIM) ranks the highest in terms of improving project quality and coordination. This corroborates the promising role of BIM highlighted in the previous section. It underscores the value design integration tools bring for communication when leveraged effectively. Indeed, BIM scores higher than technologies like 3D printing that are revolutionizing modeling but have more fragmented usage currently across teams.

Table 6. Perception of the relationship between Architects and Engineers in coping with changing technologies in the construction industry.

Perception of respondents	SA	A	N	D	SD	Mean	OMS	Rank
Architects and Engineers are effectively collaborating to integrate new technologies into the design and construction industry	29	72	81	35	0	3.44	3.80	6th
The adoption of Building Information modelling will improve communication and coordination between architects and Engineers.	110	62	21	24	0	4.19		2nd
The implementation of advanced software for structural analysis and simulation has improved the collaboration between Architects and Engineers	56	80	23	40	18	3.53		5th
The use of virtual reality and augmented reality enhances the visualization and communication of design concepts between Architects and Engineers	22	46	108	36	5	3.2		7th
Cloud-based project management platforms will facilitate better communication and collaboration between Architects and Engineers in construction projects	128	58	25	5	0	4.41		1st
The changing technologies in the construction industry have necessitated a stronger collaboration between architects and engineers for successful project delivery.	46	66	82	25	10	3.69		4th
The development of smart building technologies influence the way Architects and Engineers work together in building systems for improved efficiency.	74	105	31	7	0	4.13		3rd

Table 6 shows the perceptions regarding the relationship between architects and engineers in coping with changing technologies in the construction industry indicates that respondents rank collaboration on cloud platforms as the most helpful for enabling communication and coordination between the groups, validating arguments on technological integration. However, virtual/augmented reality ranks lowest, suggesting these visualization tools have yet to bridge substantial divides perhaps due to implementation costs. Building information modeling emerges as a clear success story - ranked 2nd - for its role in improving cross-disciplinary partnerships. Smart building technologies also score highly (3rd). IoT and automation can propel more unified workflows between architects and engineers. Interestingly, tighter mandated partnerships in response to industry changes rank 4th. Resistance to such imposed models could impede organic technology assimilation across divides.

5. Discussion

The findings indicate that building information modeling (BIM) tools have become widely recognized within the architect-engineer dynamic as greatly enhancing project coordination, supporting previous scholarly research. However, looking closer, significant discrepancies exist between the groups regarding usage proficiency—over 90% of architects employ BIM versus only 6% of engineers. This reveals a substantial knowledge and skills gap in technological fluency between the disciplines, hindering integrated adoption. Reasons may relate to differences in training emphasis, barriers to workflow disruption, and communication challenges in the absence of a common digital language. The uneven BIM proficiency levels between architects and engineers mirrors research by Memon et al. (2020) [9] showing over 80% of architects perceive themselves as experts in BIM versus under half of engineers. They note this tech-fluency divide causes coordination problems, corroborating the skills gap challenges highlighted in the results. Strategies for aligned BIM education could draw on recommendations in Abdirad (2021) [20] for integrated curricula.

Additionally, awareness levels of innovations like cloud-based platforms, 3D printing, and virtual/augmented reality are uniformly high among respondents, demonstrating technological cognizance. However, only 7-8% have actually adopted these systems within collaborative projects. This signifies that despite recognizing the latent potential, real-world implementation is lagging likely due to change resistance, lack of supportive infrastructure, and siloed working styles. New technologies often disrupt existing hierarchies and protocols, creating natural inertia. Moreover, engineers may prioritize functional concerns over experiential ones emphasized by architects, complicating unified buy-in. The lag in adopting innovations despite recognition of benefits resonates with barriers identified across diffusion of technology theories [10]. Rogers (2003) [21] found change resistance, financial constraints and social norms hamper uptake and Behzadan & Kamat (2009) [22] showed willingness outstrips capability for new visualization tools in

engineering/architecture. Purposeful innovation hubs on campuses outlined in Schön et al. (2014) [23] could enable unified immersion.
Critically, both groups strongly endorse that adapting to industry changes necessitates tighter technologically unified partnerships to deliver successful outcomes. This signals acknowledgement that fragmented, isolated responses are insufficient and integrated strategy vital. It also gives credence to arguments that communication ecosystems and knowledge networks focused on problem-solving through emerging solutions can catalyze progress. Center points could involve computational design hubs, digitally enabled value chains, and cross-cutting consortiums. The endorsement for tighter integration between architects and engineers aligns with comparative research on effective interdisciplinary collaboration in construction projects [7, 24]. Sanderson notes mutual understanding of disciplines' contributions is vital but often lacking, while pooled expertise can enhance outcomes. Formal mechanisms can facilitate this according to Enegbuma et al. (2022) [25] who propose binding partnership frameworks. Therefore, while positive orientations exist, there remain tangible capability and application gaps between intention and practice. Streamlined training programs, flexible procurement routes that encourage novel techniques, and dedicated funding avenues for research into technology-enhanced collaboration could bridge these divides.
The comparatively high overall mean score (OMS) of 4.05 for Perception of the knowledge of Architects and Engineers concerning technological advancement in the construction industry quantitatively indicates the broad recognition of these established technologies' benefits. However, the lower OMS of 3.8 for collaboration levels and adoption points to lingering hurdles in transitioning emerging tools into practical coordination, aligning with Ogunsiji et al.'s (2022) [26] BIM analysis. Ajayi et al. (2017) [27] also showed that over 75% of Nigerian built environment professionals feel these technologies improve project coordination. However, uneven BIM adoption rates revealed in the results highlight skill gaps impeding integration. Notably, while awareness is moderately high, actual usage of newer solutions trails potential as indicated by comparatively lower scores. Studies on African countries including Ghana [28], Zambia [29] and Tanzania [30] also underscore persistent implementation gaps tied to inadequate technical capabilities and unfamiliarity hindering adoption despite eagerness. The expressed need for stronger external interventions around technology-spurred industry shifts resonates with findings from South Africa highlighting increasingly binding partnerships between architects and contractors to improve project delivery [31]. In essence, the findings illustrate that while awareness is moderately high for some areas, unfamiliar innovations lag in understanding, even though their immersive and data-rich capabilities could enhance architect-engineer collaboration. This lends further support to the digital knowledge divide highlighted as a barrier, necessitating structured interventions alongside cultural shifts to maximize technological readiness and coordination.

6. Conclusion

Technological progress has undoubtedly impacted architectural and engineering practice over the years. The current study aims to investigate the intersection of architecture and engineering in adapting to evolving technologies within the construction industry through empirical insights from practitioner surveys within Enugu metropolis. The major findings from this research shows:

- Uneven adoption rates of BIM across architects and engineers reveal knowledge gaps.
- High awareness but low actual usage of emerging innovations due to change resistance
- Agreement that tighter, technologically unified partnerships are vital for progress.
- Quantitative data shows moderate tech readiness but lagging collaboration levels.

However, the study is limited by lack of qualitative insights that could reveal subtler barriers and opportunities. Its key contribution to knowledge includes the provision of empirical perspectives on digitization across architect-engineer dynamics, framework for strategic interventions to smooth technology transitions and comparative assessment of innovation diffusion gaps within construction field. As technological disruptions continuously shape design, engineering and building processes, overcoming impediments stalling widespread coordinated adoption is vital for fully leveraging advancements to enhance quality, sustainability and productivity outcomes.

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