

Architecture 5.0: Bridging the Human-Centric Gap in Industry 5.0 for Sustainable and Resilient Innovation in Architecture, Engineering, and Construction Sector

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Abstract—As the Architecture, Engineering, and Construction (AEC) sector evolves with technologies from Industry 4.0 such as Building Information Modeling (BIM), robotics, the Internet of Things (IoT), and big data, there is growing interest in transitioning toward Industry 5.0, also called as “Architecture 5.0.” This emphasizes on human-centricity, sustainability, and resilient innovation aligned with the United Nations-Sustainable Development Goals (UN-SDGs). However, the application of Architecture 5.0 within AEC sector remains very limited, particularly in addressing human-centered approaches. This review and thematic analysis determined 155 peer-reviewed articles from the Scopus database to assess current research trends and identify gaps. The analysis reveals that energy efficiency (38 occurrences), urban design (30), and project management (21) dominate the discourse, while critical areas such as decision-making (15), air quality (11), sensor integration (7), and deep learning (7) are significantly underrepresented. These findings present an imbalance in research efforts, suggesting the need for an expanded focus on technologies and strategies that prioritize human well-being, real-time feedback, and adaptive resilience. This paper offers a conceptual framework and actionable recommendations of Architecture 5.0 for policymakers, planners, designers, and other stakeholders to establish building and design codes and measures for the AEC sector toward a more human-centric, sustainable, and resilient future.

Keywords—Architecture 5.0, architecture, engineering, and construction, Industry 5.0, technology, SDGs

I. INTRODUCTION

The AEC sector is important to the well-functioning of thriving society as it facilitates all human life activities. However, the AEC has not fully developed into a sustainable solution, yet which remains an on-going problem with real-world consequences facing our future generation as the AEC sector accounts for 7% of all global carbon emissions. [1] While having no indication of

declining for the carbon emission rate, it calls for urgent needs for improvement within this aspect. Moreover, it required a significant portion of the world’s ecological footprint, which reduces the earth’s surface required for plant sequestering. Thus, it is clear why the widespread emergence of the sustainability trend is currently focused on reducing carbon footprints. As the most prominent building type overall is residential type which accounts for 81.3% [2], one of the issues facing sustainability of the AEC sector is single family housing which accounts for around more than half of total residential building types. This is inefficient for land build-up area [3–5]. Urban sprawl also increases the reliance of automotive vehicles for basic life tasks which increase energy usage and carbon emissions.

Recently, following the policy establishment of the United Nation-Sustainable Development Goals (UN-SDGs), there has been a growing emphasis on promoting sustainable human well-being. This shift highlights the importance of addressing the needs of both building users and workers, particularly in an era of diminishing human resources. For example, indoor air quality standards now discourage the presence of volatile organic compounds (VOCs), and building designs are encouraged to support healthy human activity, such as promoting stair use over elevators. Additionally, construction environments must prioritize worker safety, including minimizing exposure to harmful substances like fine particulate matters (PM2.5) and microplastics. A recent study [6] in the industrial sector highlights the integration of advanced real-time sensor systems to guide human interactions more efficiently. This sensor technology empowers project managers by providing real-time insights that support workstation redesign, task rebalancing, and other corrective measures aimed at enhancing both safety and operational efficiency in their workspaces.

The development of Industry 4.0 with past few decades primary focused on enhancing the efficiency of cyber-physical system through digital transformation, the Internet of Things (IoT), big data, and Artificial Intelligence (AI), often with limited consideration for social impact, human well-being, and overall sustainability [7]. In the other hand, the emerging paradigm of “Industry 5.0” aligns more closely with the UN-SDGs by emphasizing on the integration of human-centric and sustainable development. Despite this alignment, the AEC sector has struggled to fully adopt the principle of Industry 5.0 that leaves those of Industry 4.0. For instance, many small-scale design firms have yet to adopt Building Information Modeling (BIM), a technological development of Industry 4.0, due to budget constraints, steep learning curves, or concerns over usability. This slow adoption of Industry 5.0 within the AEC sector, especially compared to more streamlined industries like manufacturing, remains as AEC projects are inherently complex. To move the AEC sector forward, a broad improvement across all related parties is required. Therefore, a resilient AEC development involved both sustainable design and construction stakeholders utilizing adequate resources and energy while delivering the lowest environmental impacts and highest performance with the supports of resilient innovation and human centric management.

Regarding sustainable design, past studies [8–11] integrate architecture, structure and building services to assess construction cost more accurately and to quickly evaluate the feasibility of constructing. While others emphasize the integration of design and building services with the aspects of energy efficiency and environmental performance, many aim to enhance operational performance [8, 12–14]. In sustainable construction, key areas of study include knowledge management, construction process management, risk management, cost, and schedule management [13]. Among these, identifying critical successful factors (CSFs) is essential for addressing project shortcomings. These CSFs, including technical competence, early collaboration, stakeholder and supply chain management, technical competence, and standardization, are particularly vital for Modular integrated Construction (MiC) [8, 14]. Additionally, effective risk management is crucial, as complexities in architectural design, supply chains, stakeholder coordination, and project delivery methods can significantly impact project outcomes [8, 13, 16]. In energy usage and building performance, research [17] has shown that integrated project delivery (IPD) offers superior energy efficiency, as early collaboration among owner, designer, and contractor enables energy-conscious design from the initial phase. However, despite its benefits, IPD remains less widely adopted than methods like Design-Bid-Build (DBB), Design-Build (DB), and Construction Manager at Risk (CMR), due to challenges related to risk-reward sharing, funds distribution, liability allocation, and contractor-related-issues. In resilient innovation, human-centric ecosystems using operator digital twins, combined with biometric data reflecting

physical, and mental conditions, enable managers to monitor performance while safeguarding workers’ physical and mental well-being [18, 19]. This approach has potential for integration into architectural construction environments. In human-centric management, supply chain management (SCM), which is a common source of construction project failures, can be improved through blockchain technology [20]. As noted in [21], blockchain’s ability to securely link information into immutable data chains helps prevent conflict caused by changes that often occur from the distorted communication among stakeholders. With enhanced transparency and smart contract-based financing, blockchain has the potential to significantly transform SCM.

Based on the knowledge gap stated, there is a need to comprehensively examine the Industry 5.0 adoption within our AEC sector (also called “Architecture 5.0”). The objective of this study is to identify the potential use case and enhancement from general Industry 5.0 developments as a benchmark AEC implementation. This review aims to provide insights and guidance on leveraging Architecture 5.0 to support sustainable development and human-centric activities.

II. METRODOLOGY

This review begins by introducing the emerging framework of Architecture 5.0, which is grounded in the principles of SDGs. This framework emphasizes human-centricity, sustainability, and resilient innovation [7]. Based on these foundations, 6 thematic research clusters have been identified: sustainability in design, sustainability in energy consumption, resilient innovation, and human-centric management. These clusters serve as targeted keywords, capturing a wide range of relevant issues and are specified to represent the field’s complexity, as overly broad terms may obscure nuances and hinder effective categorization.

The initial review reveals that each research theme within the Architecture 5.0 framework is associated with five identified clusters: 1) In sustainable design theme, studies frequently address aesthetics, urban design, user well-being, and clarity during early design stages; 2) In sustainability in energy consumption cluster, research centers on energy conservation and efficient energy use; 3) The resilient innovation theme is strongly associated with digital twin technologies and their potential to enhance worker and user well-being; 4) The human-centric management theme cover topics such as integrated practice, cryptocurrency-based payment systems, and interface management; and 5) The sustainable construction theme focuses on worker well-being and human action guidance.

These subtopics were used as refined keywords for the literature search, allowing for more focused and comprehensive retrieval of relevant studies compared to broader thematic terms. Research articles were sourced from Google Scholar and Scopus databases, using these search terms: (TITLE-ABS-KEY(“AEC industry” OR “building construction” OR “project delivery” OR “project success”) AND TITLE-ABS-KEY(“aesthetic” OR “well-

being” OR “interface management” OR “human action” OR “integrated practice” OR “cleared early design stage” OR “crypto payment” OR “conservation heritage” OR “sensors” OR “urban design”). The inclusion criteria for selected papers required a direct connection to the concept of Architecture 5.0, specifically addressing the integration of human-centric design, sustainability, and resilient innovation within the context of the AEC industry. The initial literature search yielded a total of 306 articles. Of these, 16 were review papers. After applying relevance and eligibility filters, 151 articles were excluded, resulting in 139 articles selected for in-depth analysis. The final set of 135 selected articles underwent both qualitative and bibliometric analysis. Bibliometric analysis is particularly well-suited for managing large datasets and offering a comprehensive overview of research trends, while also enabling the identification of emerging or underexplored themes in literature [22, 23]. The analysis was conducted using the Bibliometrix package within RStudio, supported by the Biblioshiny add-on, which offers a user-friendly interface. This tool [24] was used to examine key elements such as Keyword Plus, and thematic evolution.

III. REVIEW ANALYSIS AND DISCUSSION

A. Research Clusters

As mentioned, the analyzed articles were categorized into five thematic clusters: (1) sustainability in design, (2) sustainability in construction, (3) sustainability in energy consumption, (4) resilient innovation and building performance, and (5) human-centric management, as given in Table 1.

Within sustainability in design cluster, sub-topic includes design decision support, urban design, aesthetic design, innovative design, and predesign phase. For example, a decision support for choosing a partition wall which enables 3–11% cost savings through optimized masonry designs and integrating with BIM for automated validation. The tool enhances efficiency in architectural decision-making [25]. While in urban design, a study analyzes how courtyard geometry and urban porosity in Mediterranean cities inform sustainable planning. The findings link aspect ratios and densification to microclimate mitigation, offering data-driven insights for enhancing thermal comfort and energy efficiency [26].

Within sustainability in construction cluster, sub-topics include construction decision support, reversible construction, and material reuse. For example, The SLAM-IMU coupling-based positioning system enables real-time worker tracking through wearable cameras (Intel RealSense D435i) mounted on workers' chests, which capture 3D environmental data while IMU sensors (accelerometer/gyroscope) track motion which maintains accuracy in GPS-blind zones like underground sites. Integrated with BIM, it enhances safety via dynamic hazard mapping and optimizes labor efficiency, reducing resource waste which aligns with sustainable construction goals [27].

Within sustainable energy consumption cluster, research highlights the development of smart, sustainable

energy management systems for residential buildings. It introduces a total sustainable performance index to optimize life cycle costs and emissions, recommending a mix of 2–3 locally available renewable energy sources (e.g., solar and wind) combined with IoT-driven real-time management. The study highlights the efficiency gains of microgrids (20–100 houses) and emphasizes adaptive, human-centric solutions, supporting Architecture 5.0's vision of intelligent, eco-friendly, and responsive built environments [28].

TABLE I. RESEARCH CLUSTERS AND SUB-CLUSTERS IN ARCHITECTURE 5.0

Research cluster	Sub-cluster
Sustainability in design	Decision support for design Urban design Predesign Aesthetic design Innovative design
Sustainability in construction	Construction decision support Reversible construction Material reuse
Sustainability in energy consumption	Energy consumption analysis New energy source Energy reduction
Resilient innovation and building performance	Safety BIM Green design Smart innovation Climate change Sensors
Human-centric management	Blockchain technologies Cost analysis Project management Interface management Workplace well-being

Within resilient innovation and building performance cluster, one notable example is the integration of LIDAR drone mapping system with Faster CNN, representing smart innovation in sustainable construction by enabling automated, high-accuracy damage detection (95.88% accuracy) in buildings, roads, and bridges. Drones equipped with LIDAR sensors capture 3D point clouds, while the Faster CNN algorithm processes this data to identify cracks, corrosion, and structural defects without manual intervention. This system reduces inspection time by 70% compared to traditional methods and integrates with BIM for real-time maintenance prioritization. Its scalability and adaptability to GPS-denied environments make it ideal for smart cities, enhancing infrastructure resilience and reducing lifecycle costs [29].

Within human-centric management cluster, one study explores blockchain-enabled smart contracts and robotic reality capture technologies to automate construction payments, enhancing transparency and efficiency. For Architecture 5.0, this human-centric approach integrates real-time progress data with decentralized payment systems, reducing delays and fostering trust among stakeholders. By linking physical progress (via UAVs/UGVs) to financial transactions, it ensures accuracy and accountability, aligning with human-centric management goals. Future work includes hybrid contracts to balance automation and human judgment [30].

B. Keywords Plus

The total 135 articles were analyzed with Keywords Plus, an automatic function in the Bibliometrix software that can analyze the frequently appearing words from title or abstract to interpret it to a more conclusive keyword. This revealed that energy efficiency, urban design, project management, cost analysis, and decision-making themes

are the top 5 most frequently reported themes (see Figs. 1a and 1b).

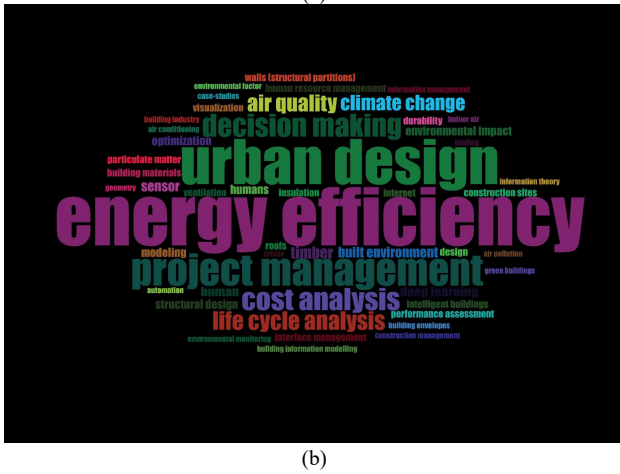
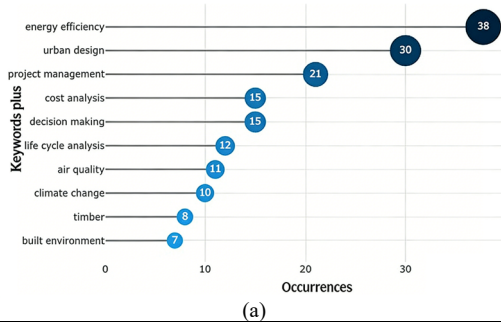


Fig. 1. Keywords Plus occurrences of Architecture 5.0 in the AEC: (a). Frequency of top keywords; (b). A visual representation.

C. Thematic Evolution

The thematic evolution serves as a key component in bibliometric analysis, using data gathered such as publishing year and abstract to analyze keyword overlap and plot the evolution with k-means clustering. Fig. 2 reveals 4 major thematic shifts from 2016–2022 to 2023–2025 which mark a significant post-pandemic transition. The first thematic shift reflects a move from a focus on safety to the internet. This suggests that safety concerns are increasingly addressed through internet-based security. For example, leveraging Wi-Fi Channel State Information (CSI) and deep learning, researchers have developed a passive indoor safety warning system that detects when workers approach restricted areas or floor openings without requiring them to wear sensors. This system utilizes internet-enabled Wi-Fi devices to collect and transmit real-time data, which is analyzed using advanced algorithms to trigger immediate alarms. The approach enhances safety by providing continuous, non-intrusive monitoring, even in low-light conditions, while minimizing deployment time and costs. Such innovations demonstrate how IoT and machine learning can synergize to create smarter and safer workplaces [31, 32]. The second shift illustrates narrowing research regarding decision making and public health to project management. This trend implies a reduced emphasis on the welfare of individuals for both on-site workers and the public, and a growing focus on efficiency and managerial control within project execution. The third thematic evolution moves

from climate conditions and energy efficiency to intelligent buildings. This indicates a convergence of climate-responsive systems and energy-efficient technologies under a unified concept of smart buildings. For example, one study integrates Wireless Sensor Networks (WSNs) for real-time environmental monitoring (e.g., temperature and humidity), indirectly supports climate-responsive construction by enabling adaptive resource allocation and hazard mitigation. While energy efficiency is not a primary focus, the system’s optimization of construction processes and resource management could reduce energy waste [33]. The fourth theme highlights a subtle shift in focus from energy efficiency, human factors, and ventilation of air conditioning towards air quality. This suggests that current research increasingly prioritizes indoor environmental quality, particularly in reducing PM2.5 and microplastics, over general energy-saving strategies [34–39]. After reviewing the trend and research gaps, the summary can be outlined in Fig. 3.

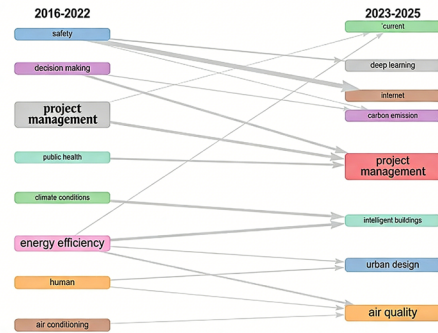


Fig. 2. Thematic evolution of Architecture 5.0.

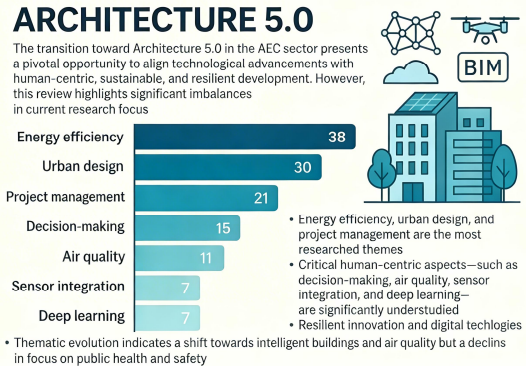


Fig. 3. Research Priorities and Gaps in Architecture 5.0.

IV. CONCLUSION

The transition toward Architecture 5.0 presents a pivotal opportunity to align technological advancements with human-centric, UN-SDG, and resilient development. However, this review highlights significant imbalances in current research focus, with energy efficiency, urban design, and project management dominating the discourse, while critical areas like decision-making, air quality, sensor integration, and deep learning remain underrepresented. Addressing these gaps is essential to fully realize the potential of Architecture 5.0 in fostering well-being, adaptive resilience, and real-time feedback systems. The key findings can be listed:

- Energy efficiency (38 occurrences), urban design (30), and project management (21) are the most researched themes.
- Critical human-centric aspects, such as decision-making (15), air quality (11), sensor integration (7), and deep learning (7), are significantly understudied.
- Resilient innovations and digital technologies (e.g., BIM, blockchain, and drones) show promise but require broader integration.
- Thematic evolution indicates a shift toward intelligent buildings and air quality but a decline in focus on public health and safety.

The findings underscore the need for policymakers, designers, and industry stakeholders to prioritize human well-being, sustainability, and social innovations and eventually establish building and design codes and measures. By adopting the Architecture 5.0 framework, the AEC sector can advance toward a more sustainable, resilient, and human-centered future for ultimately supporting the UN-SDGs while mitigating environmental impacts.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

S.T. and L.P. wrote the main manuscript text; S.T. Investigation; L.P. Conceptualization; all authors had approved the final version.

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