Energy Use Intensity Issues in Building Design within the UAE University: A Principal Component Analysis of Design Competencies Gap and Challenges

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Abstract

The United Arab Emirates (UAE) faces a significant challenge in the form rapid urbanization coupled with cooling systems consumption of up to 60% of the nation's total energy owing to extreme climatic conditions and climate change. The UAE's Architecture, Engineering, and Construction (AEC) industry must have a performance metrics and frameworks to manage significant energy consumption challenges and be an active part of the UAE's ambitious target of 2030 nearly Zero Energy Buildings (nZEBs). At present, the UAE's AEC industry relies on "Reference Building Method" (Performance Method) to compares their proposed building to a theoretical "Reference Building" (a baseline version of itself that comply with the codes minimum requirements) to judge building energy performance, which lacks the precision needed for the region's extreme climate.

The study deployed multivariate Principal Component Statistical Analysis (PCA) surveys to evaluate the 12 critical Energy Use Intensity (EUI) attributes for UAE University's building energy performance design analysis. The PCA maps the mental model of the emerging UAE AEC workforce to decide their actual EUI-design competencies. To improve the study's interpretability and make the factor loadings more distinct, the Rotated Component Matrix (or Varimax) rotation methods were used, and the 12 EUI attributes were categorized into two distinct clusters of competence for building design: Environmental Factors (sustainability) and Architectural Elements (physics).

The PCA revealed three critical flaws: first, the low communality score (0.44) for Smart Control proves the emerging UAE AEC workforce (comprising 94.2% building design students) views building automation technology as an additive 'future opportunity'; second, there is an attribute category error where Energy Efficiency is regarded as physical architectural components rather than as part of the "efficient system performance"; and, third, there is a severe siloing effect within the emerging workforce, where renewable energy integration and smart controls are treated as isolated environmental add-ons rather than being integrated with fundamental physical building operations.

The researchers recommend for curricular reform to UAEU design programs, technical integration of Smart Building Automation IoT training with HVAC management, redefining EUI variables to bridge the current design competency gap to shift focus from dynamic to real-world building design, operation, and maintenance competencies and reach the 2030 nZEB targets.

Keywords: Energy Use Intensity (EUI); Principal Component Analysis (PCA); UAE AEC Industry; Sustainable Design; nZEB.

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1. Introduction

1.1. Background and Context.

Analyzing the built environment in the United Arab Emirates, an often-observed challenging paradox appears: rapid urbanization continues to demand continuous infrastructure expansion, yet the region's extreme climatic conditions impose a severe energy penalty on these structures. Mechanical cooling systems alone account for 80-90% of the nation's total energy consumption, positioning the UAE as one of the most energy-consuming countries globally. [1]. Given the government's ambitious target of achieving zero-energy buildings (nZEBs) by 2030, the architecture, engineering, and construction (AEC) industry is approaching a necessary turning point.

Moving beyond baseline energy-reduction measures toward comprehensive performance strategies will likely require a fundamental shift in how professionals conceptualize sustainable development in dry environments. To manage this transition, tracking energy use intensity (EUI)—typically measured in kWh/m^2/year—becomes essential, although applying it effectively is rarely straightforward.

In the UAE context, EUI serves as a diagnostic lens, highlighting whether passive strategies, such as optimized building orientation and deep shading, effectively complement active systems, such as grid-tied solar photovoltaics [2][3][4]Refining this metric, however, poses distinct environmental and technical obstacles. The unrelenting heat loads and high moisture content in the air profoundly dictate architectural choices, often exposing the limitations of standard sustainability templates imported from milder climates. That is, international sustainability standards (like early versions of LEED or BREEAM) were originally developed for temperate, mid-latitude climates (e.g., North America and Europe). When these "templates" are exported to tropical or arid regions with high heat and moisture, they often do not account for the unique energy demands of dehumidification and extreme thermal loads. [5]

Sustainable methods in building design have reached a critical point at which current climate data shows an urgent push beyond simple reductions toward true net-zero or net-positive energy generation could be the most workable way forward to decouple the region's rapid growth from its historical reliance upon fossil fuels. [6], [7], [8]

1.2. Current Knowledge and Field Advances.

The UAE government has actively advocated for sustainability through the implementation of green building practices outlined in the UAE Vision 2021 and UAE Vision 2030 (often aligned with the UAE Green Agenda 2015-2030 and Abu Dhabi Economic Vision 2030). These frameworks underscore the significance of sustainable development, which aims to balance economic growth with environmental preservation [9]. The existing literature finds several factors that influence EUI, which can be manipulated through design elements and operational practices. These include building orientation and layout, which influence natural ventilation and can reduce cooling demand and solar heat gain, both crucial for energy efficiency, and which can impact the EUI.[10]; double-glazing and low-e coatings can improve thermal insulation and can contribute to energy savings by reducing heat transfer [11]; increasing insulation thickness generally improves thermal resistance and can reduce heat transfer, thereby lowering heating loads in buildings [12]; occupant behavior energy efficiency is a significant factor that can influence energy consumption patterns, including temperature settings and appliance usage[13]; and advanced controls can effectively lower EUI by managing HVAC loads more efficiently compared to traditional baseline controls, thus resulting in reduced operational costs and enhanced sustainability in building management [14].

The integration of Smart Building technologies with the IoT and building automation is a crucial element of current sustainable urban development. Multiple IoT-based strategies contribute to improved energy efficiency in buildings such as occupancy-based building automation, where IoT sensors are used to predict and detect occupancy patterns which lead to reduced energy demand and carbon emission, and anomaly detection and predictive maintenance which can significantly reduce energy usage in lighting as well as in HVAC management. [15]. Networked sensors and actuators provide real-time monitoring for remote surveillance and environmental adjustments (say, lighting and temperature) to improve safety, security, and comfort [16], [17]. HVAC system infrastructure is a major part of building energy used and as such is a critical priority for reducing energy usage. HVAC optimization with IoT-driven automation (occupancy-based control and predictive maintenance) is crucial for its efficiency [18]. Integrating solar and other renewable energy sources into building energy systems is a priority for the attainment of sustainability goals and net energy consumption reduction [19] [20]. Combining natural light harvesting with advanced lighting control technologies in building illumination can improve energy efficiency in buildings. [21].

The benchmarking approach adopted by the Emirates Green Building Council (EGBC) can serve as a compelling case study. They use Energy Use Intensity (EUI) to compare the performance of specific property types—namely, hotels, schools, and malls. Their plain goal is to equip these types of buildings with the comparative data they need to reduce carbon emissions and improve operational efficiency. Rather than relying on a simple industry average, the EGBC program categorizes buildings into best, median, and worst performers. This stratification is quite revealing. For instance, it reveals a massive performance disparity: the best-performing hotels consume up to 58% less energy per square meter than the worst. Highlighting such stark contrasts arguably creates a stronger empirical foundation to drive the retrofit market and inform local policymaking. [22]

1.3. Identification of the Research Gap.

Despite the clear mandates for sustainability and the availability of technological solutions, a significant deficiency stays in the regulatory and practical landscape. Currently, the UAE lacks specific energy performance frameworks or regulations for nZEBs. This regulatory void forces the industry to rely on “Reference Building Method” approach rather than fixed benchmarks, such as EUI, to analyze projects. Project performance is often evaluated based on the performance of other comparable “Reference Building” rather than proven, static standards[23].

While the UAE federal government has approved high-level green building standards and net-zero strategies (such as the UAE Net Zero 2050 Strategy) [24], there is no single, mandatory federal mandate that specifically prescribes Energy Use Intensity (EUI) benchmarks for Nearly Zero Energy Buildings (nZEBs). Instead, compliance and specific performance thresholds are governed by Emirate-level codes.

In 2017, EGBC defined Nearly Zero Energy Buildings (nZEBs) in terms of a site Energy Use Intensity (EUI) target of less than 90 kWh/m²/year. EGBC offers certifications for buildings that meet this definition; however, it is important to note that these certifications are voluntary, not mandatory government requirements. This means that while they provide a framework for promoting energy efficiency and sustainability, compliance is not enforced by law[25]. The Dubai Green Building Regulations (Al Sa'fat) allow for flexibility in EUI compliance by enabling developers to compare the proposed building’s energy consumption against a “Reference Building.” This reference is a hypothetical structure that adheres to minimum elemental standards. Compliance with these regulations can be achieved if the proposed building uses less energy than the established baselines, rather than adhering strictly to a fixed EUI[26].

The Abu Dhabi Estidama Pearl Rating System also evaluates energy performance by comparing the design to a baseline model (Reference Building) derived from ASHRAE 90.1 standards. Where points are awarded for the percentage improvement over this baseline, which confirms the reliance on relative rather than absolute and static fixed EUI benchmarks [27] [28].

The updated 2024/2025 Al Sa'fat codes have tightened the requirements [29] but the core compliance mechanism is still the related improvement over a baseline (e.g., 15-20% better than the reference [30]) rather than a mandatory EUI cap (e.g., "must be under 110kWHr/m^2/year) for code approval. This reliance on relatives rather than absolute benchmarks is critical.

While there is a commitment to sustainable practices within the AEC industry, implementation is a different story indeed with ample barriers, such as insufficient technical knowledge among workers and professionals. Then, training and education programs for the workforce could ensure that AEC industry professionals developed the necessary competencies. These include areas like low carbon material selection and renewable energy integration, to facilitate better sustainable solutions implementations. [31]

It is essential for professionals to view environmental factors and architectural elements as integrated systems rather than separate skills to promote a holistic approach to sustainable design. This is to emphasize this integration can enhance both resiliency and efficiency in energy use within buildings and their surroundings[32] [33]. There is a need for an integrated understanding of energy-efficient design and the promotion of building integrated design concept in educational systems and the AEC industry must acknowledge the importance of developing this competency[34].

Furthermore, the extent to which "Smart Control and Automation" and "Renewable Energy Integration" are embedded in standard practice versus being viewed as "future opportunities" is not quantified. Addressing this gap is essential because achieving high EUI performance requires a multi-layered skill. That is, there is a need for comprehensive understanding of the integration of various competencies, including environmental and operational knowledge, for the holistic approach for enhancing energy efficiency in building design and operation. This perspective is crucial for the effective integration of renewable energy technologies and optimization of smart building designs. [35]

1.4. Research Objectives and Hypothesis.

The primary objective of this study is to clearly define EUI as an essential design factor for sustainability within the UAE context. This involves analyzing stakeholder prioritization of primary factors contributing to high or low EUI in building design, specifically within the UAE University Campus setting.

Objectives: To address the identified gaps, this research aims to:

- **Identify Challenges:** Pinpoint specific problems affecting the EUI benchmark, including reliance on fossil fuels, harsh climate conditions, and environmental impact.
- **Explore Opportunities:** Investigate factors that could enhance EUI benchmarks, such as continuous renewable energy development, energy efficiency initiatives, and the adoption of green smart building technologies.
- **Analyze Competencies**: Employ a quantitative multivariate approach using Principal Component Analysis (PCA) to evaluate twelve critical EUI attributes, ranging from HVAC systems to Smart Controls. This analysis seeks to identify the underlying latent structures of energy-efficient design.
- **Integrate Approaches:** Collaborate with design professionals to build integrated design approaches that ensure the adoption of sustainable practices in all phases of design.

Hypothesis: This study posits that while awareness of EUI factors exists, the current prioritization of these attributes by students and professionals is fragmented. The research hypothesizes that a

Principal Component Analysis will reveal distinct clusters of competencies—specifically separating Environmental Factors (e.g., Resilience, Water Efficiency) from Architectural Elements (e.g., Envelope Design, Lighting). Furthermore, the study anticipates that sophisticated interventions like "Smart Control and Automation" will statistically manifest as "future opportunities" rather than established practices, indicating a critical disconnect in current educational and professional frameworks.

By validating these latent structures, the study intends to provide a strategic roadmap for developing professional regulatory frameworks and educational curricula necessary to meet the UAE's sustainable development goals. This roadmap will support the transition from simple energy reduction measures to the comprehensive performance strategies required for the nZEB 2030 targets.

2. Literature Review and Integration

2.1. Theoretical Framework: EUI and the nZEB Paradigm.

The transition toward sustainability in the built environment is guided by the quantitative framework of Energy Use Intensity (EUI). Defined as the energy consumed by a building per square meter per year (kWh/m²/year), EUI serves as the primary metric for evaluating efficiency and operational performance. In the United Arab Emirates (UAE), the Emirates Green Building Council (EGBC) report posits that EUI provides essential insight into the effectiveness of design strategies, such as passive solar design and orientation, while serving as a benchmark for comparing buildings of similar typologies. [25]

This quantitative framework is critical for meeting the UAE government's strategic objectives. The UAE Green Agenda and Vision 2030 underscore the importance of sustainable development, aiming to achieve zero-energy buildings (nZEBs) by 2030 [9]. This target necessitates a change in thinking in the construction industry, moving from simple energy reduction measures to comprehensive performance strategies. The theoretical model guiding this transition is the concept of "Resource Efficiency," which entails optimizing energy, materials, and water consumption to minimize environmental impact. However, the literature indicates that achieving these "lofty goals" requires more than general efficiency; it demands a predictive understanding of how buildings perform over time, positioning EUI not just as a post-occupancy metric, but as an essential design factor. While EUI is important for assessing energy efficiency it does not adequately address the dynamic aspects of smart readiness and thus necessitate the need for the integration of more comprehensive metrics that includes both energy efficiency and smart technologies [36].

To operationalize these concepts, this study utilizes Principal Component Analysis (PCA) as a methodological framework. PCA reduces the dimensionality of large datasets to identify "latent structures" or underlying factors [37], [38]. By analyzing twelve verifiable attributes—ranging from HVAC systems to Smart Controls—PCA allows for the categorization of design competencies into distinct clusters: Environmental Factors and Architectural Elements. This statistical approach extends the theoretical framework by moving beyond a checklist of green attributes to understanding how these attributes are conceptually grouped and prioritized by AEC industry stakeholders.

2.2. The Climate-Energy Nexus: Alignment with Existing Knowledge. Existing literature consistently identifies the UAE's harsh climatic conditions as the primary barrier to energy efficiency. Research demonstrates that extreme temperatures and high humidity impose severe challenges on building performance. Specifically, cooling systems are contributing to about 40% of the average total electric load annually, which could increase to as high as 60% during summer periods. [39] [40].

2.3. Contrast: The Technological Disconnect. While this study aligns with the physical realities of the UAE climate, it presents a significant challenge to the prevailing narrative regarding technology adoption. Literature on future trends often frames Smart Building technologies and the Internet of Things (IoT) as imminent, transformative solutions that enhance connectivity and efficiency. Building automation systems can improved energy efficiency and operational effectiveness in smart buildings [41]. Occupancy-based controls and advanced technologies like AI-driven approaches in HVAC systems are effective methods for improving energy efficiency and user comfort by adjustment of airflow, temperature, and ventilation based on occupancy and user preferences [39].

While there are significant initiatives and advancement in the UAE regarding smart energy-efficient technologies, there is perception about smart technology as a niche specialization rather than a general competency. This understanding contributes to the knowledge gap and resistance in adopting these technologies and integration within the AEC sector [39]

Despite their theoretical importance, there are substantial research gap about building Smart Control and Renewable Energy Integration. While both solar renewable energy systems and smart building technologies contributes to the improvement of residential energy performance there is a lack of empirical evidence especially in small island energy systems [42].

2.4. Evidence Gaps: Regulatory Vacuums and Educational Silos. A critical gap identified in the literature is the absence of specific regulatory frameworks for nZEBs in the UAE. While the government advocates for sustainability, there are currently no fixed energy performance regulations or absolute EUI benchmarks [43].

The UAE AEC industry use comparative analysis for retrofitting and benchmarking , but new construction must adhere to absolute prescriptive and performance-based codes [44], [45]. Where prescriptive provisions are specific requirements that must be followed in building design and construction, such as material specifications and construction methods. Performance-related provisions involve expected outcomes and or performance statements that a building must achieve to ensure safety, efficiency, and compliance with the building regulations or standards [45], [46].

The reliance on EUI relative metrics in existing building is a known challenge. However, the UAE's Energy Strategy 2050 specifically targets a 42–45% increase in efficiency by 2030 through absolute improvements in individual and institutional consumption [47]. This target is part of the UAE's broader aims to balance the rising energy demand while sustaining natural resources. This aligns with the country's commitment to the Paris Agreement and its goal to reach net zero by 2050 [47].

Research confirms a "dynamic energy performance gap" where buildings do not perform as designed. This is often due to operational faults—like cooling waste—rather than a lack of EUI static standards leading to significant energy waste [48].

There is a need for a clear understanding of whole-building energy efficiency performance with multi-criteria technique as a measurable outcome which can help AEC emerging stakeholders to focus on achieving true energy efficiency versus optimization of physical attributes such as building envelope and lighting design. That is, recognizing energy efficiency as a vital goal can enhance professional design practices and overall building energy performance [49].

It is important to distinguish between operational outcomes, such as EUI and the physical elements for building's energy-efficient design. That is, there is a strong correlation exist between various building features and energy performance metrics and multicollinearity - a situation in multiple regression analysis where two or more independent variables are highly correlated with each other - can obscure the true impact of individual components. This lack of clarity may lead to misunderstandings about the effectiveness of energy-efficient strategies, highlighting the need for careful analysis to ensure informed decision-making [50].

As renewable energy marker evolves, related jobs become more specialized and required skilled professionals across various AEC fields. That is, there is a need for broader competency development within the AEC workforce as the industry advances [51].

There is a need for constructive collaboration between energy and environmental education with the focus on the integration of renewable energy education to ensure students can assess and evaluate energy solutions effectively at the onset of the building design tasks [52].

Challenges in renewable energy education, specifically with the lack of hands-on experiences coupled with its elective in nature, strongly suggest that there is a gap on how renewable energy is addressed within educational program [53].

It is crucial to improve the would-be AEC industry workforce's knowledge in STEM fields to prepare for changes in technological requirements and to enhance workforce mobility across their related sectors [51].

3. Methodology

3.1. Research Design. This research study follows a mixed-used approach the includes literature review, surveys and interviews, issues identifications, and recommendations.

To address the research objective of defining Energy Use Intensity (EUI) as an essential design factor within the UAE context, this study employs a quantitative multivariate approach. The primary methodological framework utilized is Principal Component Analysis (PCA). This design was selected to navigate the complex, multidimensional nature of sustainable building performance. Given that the UAE currently lacks specific energy performance frameworks for zero-energy buildings (nZEBs), the AEC industry relies on comparative case studies rather than fixed benchmarks. Consequently, a simple descriptive survey would be insufficient to understand the "latent structures" of design competency.

The PCA approach is well-suited to this inquiry because it effectively reduces the dimensionality of large datasets by transforming the original variables into a smaller set of orthogonal variables, termed Principal Components (PCs). This process enables the analysis and visualization of data while retaining as much variance as possible. This simplification aids in handling complex datasets [54], [55], [56] .

3.2. Population and Sampling Strategy. The target population for this study comprises the academic and professional community within the UAE University ecosystem, specifically those interacting with the built environment as users and future designers which for this study consider as the emerging AEC workforce.

3.2.1. Familiarity Profile. The sampling strategy included an assessment of the respondents' familiarity with EUI concepts to contextualize the PCA results.

3.2.2. Inclusion and Exclusion Criteria

- **Inclusion:** Participants were required to be active users of the UAE University buildings (students or faculty) to ensure their responses reflected local climatic and operational realities.
- **Exclusion:** Individuals who had no interaction with campus infrastructure or were unable to complete the familiarity assessment were excluded to maintain data integrity.

3.3. Instrumentation and Protocols. The primary data collection instrument was a structured survey designed to measure the prioritization and application of twelve verifiable EUI performance attributes. Participants rated these attributes on a scale from "Unaccounted" to "Established".

The Twelve EUI Performance Attributes: The study investigates twelve variables identified in the literature as essential for reducing EUI in the UAE's harsh climate. These attributes serve as the input variables for the PCA:

1. **Energy Efficiency:** Defined as energy conservation strategies or design efficiency.
2. **Building Envelope Design:** Competencies related to controlling solar radiation and air leakage, critical for mitigating heat gain.
3. **HVAC System:** Optimization of cooling equipment. This is a weighted variable given that cooling accounts for 40-60% of the region's energy consumption.
4. **Lighting Design:** Utilization of LED fixtures and maximization of daylighting to reduce internal heat loads.
5. **Renewable Energy Integration:** The use of solar or wind technologies to offset grid reliance.
6. **Smart Control and Automation:** Systems that adjust based on real-time occupancy data, representing the integration of IoT.
7. **Life Cycle Assessment (LCA):** Evaluation of environmental impacts from extraction through demolition.
8. **Indoor Air Quality (IAQ):** Management of ventilation and humidity, a challenging factor in the UAE's extreme climate.
9. **Water Efficiency:** Reduction of energy used for heating and pumping water.
10. **Adaptive Reuse Potential:** Strategies for repurposing existing structures to minimize embodied energy.
11. **Building Materials Selection:** Consideration of thermal properties and embodied energy.
12. **Resilience and Climate Adaptation:** Designing for climate variability and long-term durability.

3.4. Data Analysis Plan. The data analysis strategy employs Principal Component Analysis (PCA) in SPSS. The protocol follows a four-stage process: Data Preparation, Factor Extraction, Interpretation, and Validation.

3.4.1. Correlation Matrix and Adequacy. The first step is to generate a Correlation Matrix to measure the strength of linear relationships among the twelve (12) EUI related-variables. Where the Correlation Coefficient measures the strength and direction of the linear relationship between two variables, and which ranges from -1 to +1. That is, a negative one (-1) indicates a perfect negative correlation, 0 indicates no correlation, and +1 indicates a perfect positive correlation [56].This step is vital to verify that the variables are sufficiently intercorrelated to warrant factor analysis.

3.4.2. Factor Extraction: Explained Total Variance Table.

The Correlation Matrix focuses on relationship between variables while the Total Variance Table focuses on how well factors explained variable variance. This separation information is vital for understanding the contribution of each factor to the total variability of the dataset.

3.4.3. Factor Extraction: Eigenvalues and Scree Plot.

To determine the number of underlying components to retain, the study utilizes the "Kaiser-Guttman Criterion" and Scree Plot analysis [57].

- **Eigenvalues:** Factors with eigenvalues greater than 1.0 are retained, as they explain more variance than a single original variable.

- **Scree Plot:** This visual tool plots eigenvalues against the number of factors. The retention threshold is determined by the point at which the curve shows an "elbow," indicating that subsequent factors capture mostly noise [57].

3.4.4. Factor Extraction: Communalities Table and Analysis.

Communalities are calculated to assess the proportion of variance in each attribute explained by the extracted components. High communalities (close to 1.0) indicate that the attribute is well represented, while low communalities (close to 0) suggest that the attribute is disconnected from the underlying factors [58]. This metric is used to identify "knowledge gaps"; for example, a low communality score indicates that it is not well integrated into respondents' core competency profile.

3.4.5 Factor Extraction: Component Matrix Table

The Component Matrix Table is used simply for mathematical verification by identifying the original axes of maximum variance wherein variables often have complex “cross-loadings” across multiple components. This makes the variable difficult to name or explain them. This table can show the relationships between the original variables (attributes) and the principal components (PC) where each cell in the matrix contains the loading (or weight) of an original variable on a specific principal component that can help in the understanding of which of the original variables contribute most to each concerned principal component [55].

3.4.6. Factor Extraction: Component Rotation (Varimax).

To improve interpretability, the extracted components undergo orthogonal rotation using the Varimax method. The unrotated Component Matrix often presents complex cross-loadings that are difficult to interpret. The Varimax rotation simplifies this structure by maximizing high loadings and minimizing low ones, making it clearer which variables "belong" to which component [55], [57], [58].

- **Interpretation Criteria:** Attributes are categorized based on their loading patterns. High positive loadings indicate a strong contribution to a factor, while high negative loadings indicate an inverse relationship or a distinct, opposing category.
- **Categorization Strategy:** Based on the rotated matrix, the twelve attributes are grouped into "Environmental Factors" (associated with PC1) and "Architectural Elements" (associated with PC2). This distinction enables the development of the "multi-layered skill set" framework.

3.4.7. Validation: Biplot Visualization

The analysis concludes by validating the factor structure through a biplot visualization. This visual confirmation ensures that the statistical grouping aligns with theoretical expectations for this study. By plotting both the observations and the variables in the same space, biplots can provide insights into how well the PCA has summarized the information from the dataset [59].

3.4.8. Schematic Diagram: Block Diagram Visualization

In PCA statistical analysis, the design schematics diagram (block diagram) at the end of the study is especially important after the validation of rotated matrix (varimax method). This is used to communicate the full picture of how the original large data sets (attributes) were reduced to few and significant Principal Components (PCs).

4. Results and Analysis

4.1. Respondent Demographics and EUI Familiarity.

The data collection process yielded a sample heavily weighted toward the emerging workforce in the Architecture, Engineering, and Construction (AEC) sector. The analysis reveals a homogeneous group, with 94.2% of respondents identified as students, primarily in the 17–25 age range. This demographic profile is critical to interpreting the subsequent Principal Component Analysis (PCA), as it reflects the "mental model" of the academic body and future professionals rather than that of established industry veterans.

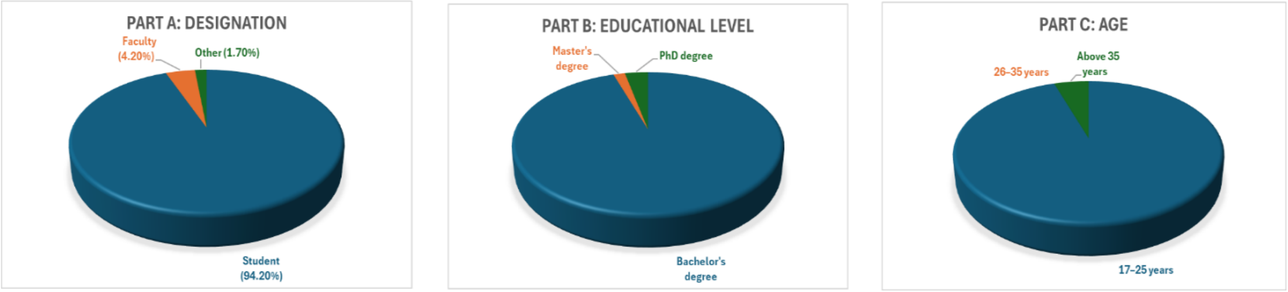

Figure 1. Survey Respondent's Demographics (Part A to C)

Regarding familiarity with Energy Use Intensity (EUI), the data indicate that deep expertise is rare within this population; only 21.7% described themselves as "Very Familiar" with EUI. The vast majority (66.7%) reported being "Somewhat Familiar," while 11.6% were "Not at all Familiar.” This distribution is critical to the analysis, as it suggests the study captures a "surface-level awareness" rather than established expert competence, necessitating a statistical method (PCA) capable of detecting how these developing professionals conceptually organize their limited knowledge.

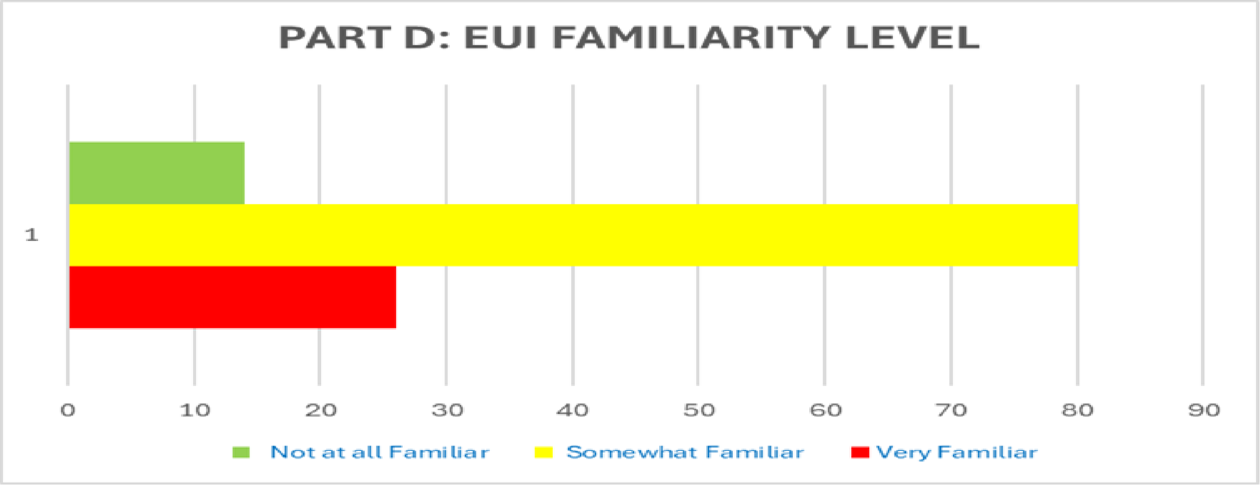

Figure 2. Part D: EUI Familiarity Level

4.2. Correlation Matrix Analysis and System Interdependencies.

The Correlation Matrix, Table 1 below, provides the initial insight into how stakeholders in this study perceive relationships among building systems. A notable finding is the strong correlation between "Lighting Design" and "HVAC System". The evidence indicates that UAE professionals and students correctly understand the thermodynamic relationship between artificial lighting and cooling loads. That is, it is a test of whether designers treat buildings as a single connected system rather than separate part.

This suggests that the fundamental "building physics" competency—understanding that lighting generates heat, thereby increasing cooling demand—is present among the UAEU respondents.
Furthermore, "Renewable Energy Integration" shows moderate-to-strong correlations with "Smart Control and Automation" (0.48) and "Life Cycle Assessment" (0.55). This clustering suggests recognition of a "Holistic Design Approach," in which advanced sustainability measures are viewed as an interconnected ecosystem rather than isolated interventions.

Table 1. Correlation Matrix for the PCA Factor Analysis

		1	2	3	4	5	6	7	8	9	10	11	12
		Energy Efficiency	Building Envelop Design	HVAC System	Lighting Design	Renewable Energy Integration	Smart Control and Automation	Life Cycle Assessment	Indoor Air Quality	Water Efficiency	Adaptie Reuse Potential	Building Material Selection	Resilience and Climate Adaption
1	Energy Efficiency	1	0.45	0.42	0.45	0.38	0.28	0.5	0.32	0.24	0.34	0.37	0.34
2	Building Envelop Design	0.45	1	0.46	0.4	0.32	0.25	0.19	0.32	0.25	0.3	0.32	0.21
3	HVAC System	0.42	0.46	1	0.57	0.5	0.38	0.42	0.4	0.38	0.45	0.38	0.46
4	Lighting Design	0.45	0.4	0.57	1	0.36	0.27	0.43	0.19	0.21	0.3	0.33	0.38
5	Renewable Energy Integration	0.38	0.32	0.5	0.36	1	0.48	0.55	0.28	0.49	0.52	0.41	0.49
6	Smart Control and Automation	0.28	0.25	0.38	0.27	0.48	1	0.45	0.42	0.46	0.4	0.37	0.46
7	Life Cycle Assessment	0.5	0.19	0.42	0.43	0.55	0.45	1	0.36	0.48	0.55	0.54	0.58
8	Indoor Air Quality	0.32	0.32	0.4	0.19	0.28	0.42	0.36	1	0.54	0.57	0.44	0.46
9	Water Efficiency	0.24	0.25	0.38	0.21	0.49	0.46	0.48	0.54	1	0.62	0.54	0.53
10	Adaptie Reuse Potential	0.34	0.3	0.45	0.3	0.52	0.4	0.55	0.57	0.62	1	0.45	0.66
11	Building Material Selection	0.37	0.32	0.38	0.33	0.41	0.37	0.54	0.44	0.54	0.45	1	0.63
12	Resilience and Climate Adaption	0.34	0.21	0.46	0.38	0.49	0.46	0.58	0.46	0.53	0.66	0.63	1

Overal Implications of the Correlation Matrix result:

- **Holistic Design Approach**: This lead to more sustainable and efficient buildings by simulatenously considering multiple design factors.

- **Integrated Systems:** Integrating HVAC, lighting, and renewable energy can lead to maximized efficiency and address sustainability issues.

- **Sustainability Focus:** Enhancing a building's sustainability can be achieved with strong emphasis on life cycle assessment, renewable energy integration, and smart controls in building designs.

- **Resilience and Adaptation:** Buildings can adapt to changing climate conditions and extend their useful lives by selecting of appropriate materials and designing for resiliency.

4.3. Explained Total Variance Table Analysis.

The "Explained Total Variance" table, shown in Table 2 below, indicates that the first two Principal Components (PCs) explained 57.72% of the total variance in the data.

* Component 1: 46.64% variance.
* Component 2: 11.08% variance.

Table 2. Explained Total Variance of the PCA Factor Analysis

Component	Total	% of Variance	Accumulated %
1	5.6	46.64	46.64
2	1.33	11.08	57.72
3	0.89	7.41	65.12

4	0.74	6.14	71.26
5	0.65	5.38	76.64
6	0.58	4.81	81.45
7	0.57	4.72	86.17
8	0.42	3.52	89.68
9	0.4	3.29	92.98
10	0.32	2.7	95.68
11	0.31	2.57	98.25
12	0.21	1.75	100

That is, the first two PCs explained approximately 58% of the total variance in the data, suggesting they capture most of the information in the original variables. The last eight PCs explain only 42% of the total variance in the data, which suggests that they mostly capture noise or minor details in the original variables. Thus it is possible to reduce the dimensionality of the dataset from 12 attributes to 2 or 3 principal components without losing significant information.

The first principal component is likely to capture the most critical factors influencing Energy Use Intensity in buildings. Identifying and understanding these key drivers can aid in targeted improvements. Therefore, significant efforts and resources can be focused on the first few principal components to achieve the maximum impact on reducing EUI.

The Scree Plot result from this study visually confirmed that there are two factor above the eigenvalue of 1.0 we can assumed two (2) factors is enough for the continuation of the study. This indicates that these two components capture most of the critical information about EUI competencies, while subsequent factors represent statistical noise.

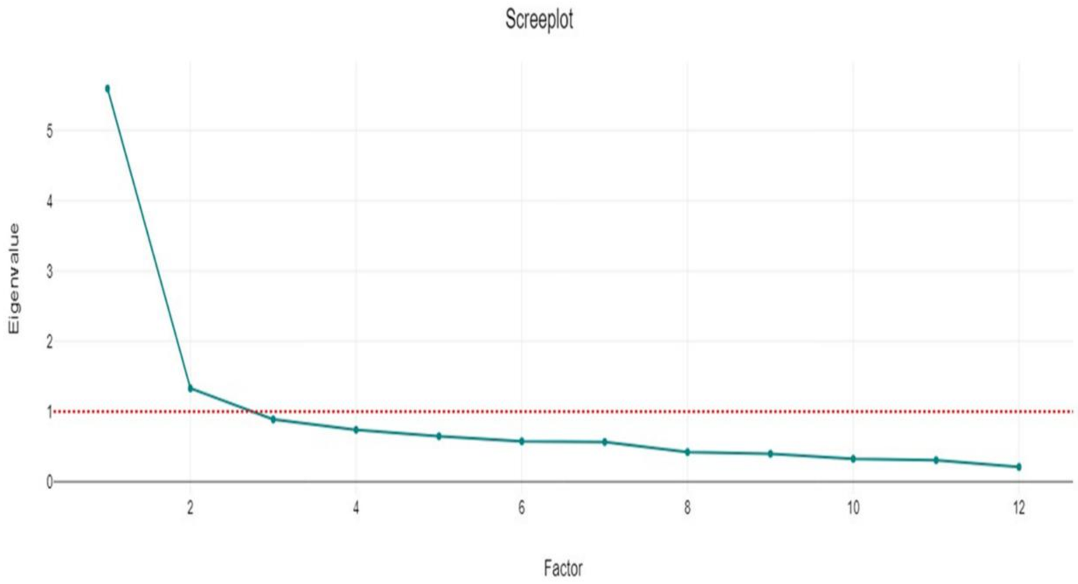

Figure 3. Scree Plot of the PCA Factor Analysis

4.4. Communalities Table Analysis: Proportion of Variance in Each Attributes.

Some key points to note from the communality table results are as follows:

- The highest communalities value in the table is for “BUILDING ENVELOPE DESIGN” at 0.79. This attribute was strongly associated with the extracted components, explaining 79% of the variance.

- The lowest communality value is the “SMART CONTROL & AUTOMATION” which is 0.44, indicating that 44% of the variance in this attribute is accounted for by the factors.

- The strong correlation between “LIGHTING DESIGN” and “HVAC SYSTEM” awareness suggests that UAE professionals correctly understood the thermodynamic relationship between artificial lighting and cooling loads. This indicates a high level of technical competency regarding the cross-system energy impacts.

Table 3. Communalities Table of the PCA Factor Analysis

		Extraction
1	Energy Efficiency	0.58
2	Building Envelope Design	0.79
3	HVAC System	0.62
4	Lighting Design	0.70
5	Renewable Energy Integration	0.58
6	Smart Control and Automation	0.44
7	Life Cycle Assessment	0.74
8	Indoor Air Quality	0.76
9	Water Efficiency	0.70
10	Adaptive Reuse Potential	0.68
11	Building Materials Selection	0.54
12	Resilience and Climate Adaptation	0.70

4.5 Component Matrix Table: The Un-rotated Matrix with Complex “Cross-Loadings”.

The Component Matrix Table, shown in Table 4 below, that most attributes have high positive laodings that indicates a strong contribution to PC1.This suggest that they collectively contribute significantly to the overall variance in the EUI of buildings.

Table 4. Component Matrix Table of the PCA Factor Analyis

		Component	
		PC1	PC2
1	Energy Efficiency	0.61	-0.45
2	Building Envelope Design	0.52	-0.53
3	HVAC Ssystem	0.7	-0.34
4	Lighting Design	0.58	-0.56
5	Renewable Energy Integration	0.72	-0.01
6	Smart Control and Automation	0.64	0.17
7	Life Cycle Assessment	0.75	0.06
8	Indoor Air Quality	0.65	0.25
9	Water Efficiency	0.72	0.41
10	Adaptive Reuse Potential	0.77	0.27
11	Building Materials Selection	0.72	0.15
12	Resilience and Climate Adaptation	0.78	0.25

4.6. Rotated Component Matrix: The Dichotomy of Design Competencies.

This is study analyzed 12 EUI complex set of design skills as a PCA attributes and found to naturally split into two distinct clusters using Varimax rotation.

Cluster 1: Environmental Factors (PC1). This component includes attributes with high positive loadings, representing complex, holistic sustainability measures:

- Water Efficiency (0.82)
- Adaptive Reuse Potential (0.79)
- Resilience and Climate Adaptation (0.78)
- Life Cycle Assessment (0.65)
- Smart Control and Automation (0.62)
- Renewable Energy Integration (0.58)

Cluster 2: Architectural Elements (PC2). This component is characterized by negative loadings, grouping fundamental physical building attributes:

- Lighting Design (-0.79)
- Building Envelope Design (-0.73)
- Energy Efficiency (-0.72)
- HVAC System (-0.69)

This separation suggests that respondents view "Holistic Sustainability" (PC1) and "Fundamental Building Physics" (PC2) as distinct domains of knowledge 11. While PC1 encompasses the broader environmental impact and future-proofing of the structure, PC2 focuses on the immediate, tangible systems that drive operational energy consumption.

The Rotated Component Matrix for this study is shown in Table 5 below.

Table 5. Rotated Component Matrix of the PCA Factor Analysis

		Rotated Component	
		PC1	PC2
1	Energy Efficiency	0.24	-0.72
2	Building Envelope Design	0.12	-0.73
3	HVAC Ssystem	0.38	-0.69
4	Lighting Design	0.15	-0.79
5	Renewable Energy Integration	0.58	-0.42
6	Smart Control and Automation	0.62	-0.23
7	Life Cycle Assessment	0.65	-0.39
8	Indoor Air Quality	0.68	-0.17
9	Water Efficiency	0.82	-0.08
10	Adaptive Reuse Potential	0.79	-0.22
11	Building Materials Selection	0.67	-0.29
12	Resilience and Climate Adaptation	0.78	-0.24

Table 6 below shows PC1 of the Rotated Component Matrix from highest to lowest positive loadings.

Table 6. PC1 of the Rotated Component Matrix from PC2 from highest to lowest positive loadings

		PC1
9	Water Efficiency	0.82
10	Adaptive Reuse Potential	0.79
12	Resilience and Climate Adaptation	0.78
8	Indoor Air Quality	0.68
11	Building Materials Selection	0.67
7	Life Cycle Assessment	0.65
6	Smart Control and Automation	0.62

5	Renewable Energy Integration	0.58
3	HVAC System	0.38
1	Energy Efficiency	0.24
4	Lighting Design	0.15
2	Building Envelope Design	0.12

Table 7 below shows PC2 of the Rotated Component Matrix from highest to lowest negative loadings.

Table 7. PC2 of the Rotated Component Matrix from highest to lowest negative loadings

		PC2
9	Water Efficiency	-0.08
8	Indoor Air Quality	-0.17
10	Adaptive Reuse Potential	-0.22
6	Smart Control and Automation	-0.23
12	Resilience and Climate Adaptation	-0.24
11	Building Materials Selection	-0.29
7	Life Cycle Assessment	-0.39
5	Renewable Energy Integration	-0.42
3	HVAC System	-0.69
1	Energy Efficiency	-0.72
2	Building Envelope Design	-0.73
4	Lighting Design	-0.79

4.7. Biplot Visualization Validation:

To better visually understand these loadings, a biplot from this rotated matrix results is shown below in Figure 4.

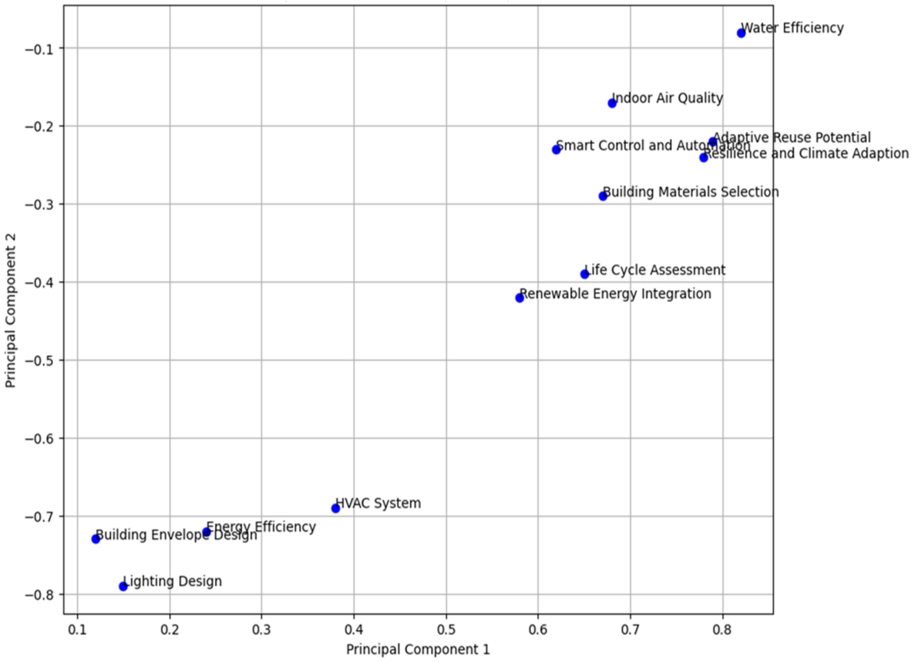

Figure 4. Biplot of the Rotated Principal Components

Therefore, the Rotated Component Matrix table revealed that most attributes had significant loadings on either Principal Component 1 (PC1) or Principal Component 2 (PC2).

That is, PC1 (Positive) is about "Holistic/Complex Sustainability" (focusing on water, lifecycle, smart systems) while PC2 (Negative) concerns "Fundamental Building Physics" (focusing on envelope, HVAC, lighting).

4.8. Schematic Diagram: Data Reduction to Structural Insight Visualization

Then, the PCA schematic diagram for this study is:

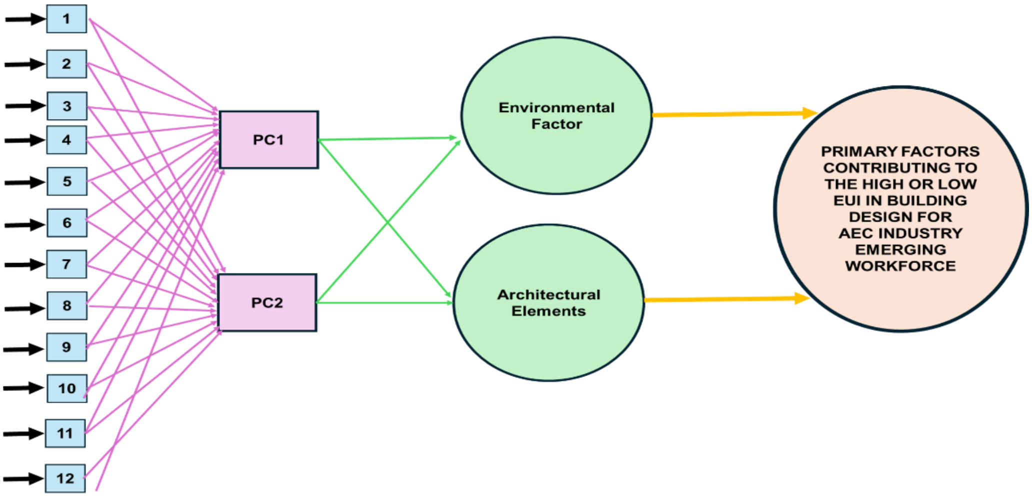

Figure 5. The Study's PCA Schematic Diagram

4.8. Critical Analysis: The Technological and Conceptual Gaps.

While the descriptive data shows a logical grouping of attributes, a critical examination of the Communalities and Rotated Component Matrix (Varimax) reveals significant gaps in the current competency profile of the UAE's AEC emerging workforce.

4.8.1. The "Additive" Nature of Smart Technology.

A primary concern emerges from the analysis of "Smart Control and Automation." Despite the theoretical importance of IoT and automation in the era of the Fourth Industrial Revolution, this attribute recorded the lowest communality score (0.44) among all 12 variables. This statistic indicates that 56% of the variance in this attribute is unaccounted for by the extracted factors, suggesting it is the least understood or integrated factor among the respondents.

Although "Smart Control" loads onto PC1 (Environmental Factors), its low communality indicates it is statistically unrelated to the core design competencies. The data suggests that stakeholders currently view smart technology as a "future opportunity" or an optional enhancement rather than a standard, essential driver of performance. Given that cooling loads account for 40-60% of energy consumption in the UAE, the failure to view automation (which optimizes these loads) as a fundamental competency is a critical barrier to achieving nZEB targets.

4.8.2. The "Energy Efficiency" Category Error.

The analysis reveals a conceptual misalignment regarding "Energy Efficiency." This attribute loaded strongly on PC2 (-0.72), clustering tightly with Envelope Design and Lighting. Critically, "Energy Efficiency" is an outcome or a goal, whereas Envelope and Lighting are the *methods* used to achieve it.

The clustering of the goal with the methods indicates a potential "multicollinearity" or category error in the respondents' mental model. It suggests that stakeholders function as if "Energy Efficiency" is a physical component of the building—a proxy variable for the architectural elements—rather than a distinct operational performance metric. This lack of distinction between *design strategies* and *performance outcomes* complicates the transition to absolute EUI benchmarking, as it implies a focus on "efficient parts" rather than "efficient system performance."

4.8.3. The Siloing of Renewable Energy.

Renewable Energy Integration" loaded onto PC1 (0.58) but showed negligible interaction with PC2 (-0.01). This orthogonality indicates that renewable energy is viewed exclusively as an environmental/sustainability issue, entirely separate from the building's architectural and mechanical operations (PC2).

This "siloed" perspective is problematic. In an nZEB context, renewable generation must be intimately coupled with HVAC and lighting loads to balance demand. The statistical separation suggests that the current educational or professional framework treats renewables as an "add-on" to offset carbon emissions, rather than as an integrated power source that informs the initial architectural design and mechanical specifications.

4.9. The Role of Visuals in EUI Competency Analysis.

In the field of sustainable building design, the transition from qualitative "green" concepts to quantitative performance metrics is challenging. The visualizations generated in this study—specifically the Scree Plot and the Biplot—are not merely decorative but serve as essential tools for translating abstract statistical relationships into actionable educational strategies.

4.9.1. The Scree Plot as a Decision Threshold.

The Scree Plot (Figure 3) provides sufficient evidence to justify reducing twelve complex variables to two manageable focal points. By identifying the "elbow" where eigenvalues drop, the visual confirms that the vast complexity of sustainable design can be distilled into two primary curricula tracks: Environmental Factors and Architectural Elements. This visualization prevents "analysis paralysis" by focusing regulatory and educational efforts on the factors that drive 58% of the variance, rather than dispersing effort across statistically insignificant attributes.

4.9.2. The Biplot as a Competency Map.

The Biplot (Figure 5) shows the spatial separation between the two clusters. By plotting the attributes on the PC1 and PC2 axes, the visual exposes the "distance" between current practices. For example, the spatial distance between "HVAC System" (bottom left) and "Smart Control" (top right) visually quantifies the disconnect discussed in critical analyses.

For policymakers and educators in the UAE, this visual serves as a "gap analysis" map. It visually demonstrates that to move from current practice to nZEB performance, the industry must bridge the gap between the negative quadrant (Physics) and the positive quadrant (Holistic/Smart Systems). Without this visual representation, the "siloing" of skills remains an abstract concept; with the biplot, it becomes a clear, measurable distance that curriculum design must traverse.

5. Conclusion and Recommendations

5.1. Conclusion

The transition to nearly zero energy buildings (nZEBs) by 2030 in the United Arab Emirates represents a formidable challenge, necessitating a fundamental shift in how the Architecture, Engineering, and Construction (AEC) industry prioritizes design competencies 1, 2. This study utilized Principal Component Analysis (PCA) to quantify the latent structures of these competencies among the emerging workforce. The evidence indicates that while the foundational understanding of building physics is present, critical gaps remain in the integration of advanced technologies.

The Dichotomy of Competence. The analysis indicates that stakeholders conceptualize sustainable design through two distinct lenses: **Environmental Factors** (Principal Component 1) and **Architectural Elements** (Principal Component 2). The strong negative loadings on PC2 (e.g., HVAC: -0.69, Lighting: -0.79) suggest that the "hardware" of building performance—the physical systems—is well-understood as an interconnected ecosystem. Stakeholders correctly recognize the thermodynamic relationship between artificial lighting and cooling loads, demonstrating a solid grasp of the region's physical realities.

The Digital Gap: Smart Systems as "Future Opportunities". However, the data reveals a concerning disconnect regarding the "software" of sustainability. "Smart Control and Automation" recorded the lowest communality score (0.44) among all twelve attributes. This statistic suggests that more than half of the variance in this attribute is not accounted for by the current competency model. Despite the theoretical availability of Internet of Things (IoT) solutions, the emerging workforce views these technologies as "future opportunities" rather than standard, essential drivers. Given that cooling systems account for 40-60% of the UAE's total energy consumption, the failure to integrate automation—which is essential for optimizing these loads—represents a significant barrier to achieving the nZEB targets.

The Conceptual Misalignment of Efficiency. Furthermore, the clustering of "Energy Efficiency" with "Architectural Elements" (Envelope/Lighting) rather than as a distinct outcome reveals a category error in the professional mindset. Stakeholders view efficiency as a physical component to be installed, rather than an operational metric to be monitored. This "multicollinearity" complicates the transition from comparative case studies to absolute Energy Use Intensity (EUI) benchmarks, as it suggests a focus on efficient parts rather than efficient performance.

5.2. Strategic Recommendations

To bridge the gap between current awareness and the technical competence required for 2030, this study proposes the following strategic interventions. These recommendations move beyond the generic call for "more research" to offer specific, actionable directions.

Recommendation 1: Curricular Reform—From Additive to Foundational. Educational institutions must restructure curricula to treat "Smart Control and Automation" and "Renewable Energy Integration" as foundational skills, on par with structural engineering or thermodynamics. Currently, the low communality scores indicate these are treated as "additive" features—optional enhancements applied to a design.

- **Action:** Architectural studios and engineering courses must integrate modules on smart grids and automation from the onset of the design process, ensuring these competencies evolve from a niche perspective to a general requirement for the entire UAE AEC workforce.

Recommendation 2: Technical Integration—Coupling IoT with Cooling Loads. Curricula and professional training must explicitly link smart technology to the UAE’s specific climatic challenges rather than teaching it as a general IT concept.

- **Action:** Coursework should focus on applying centralized control systems to manage HVAC loads, which consume up to 60% of building energy. Students must demonstrate competency in using real-time occupancy data to dynamically adjust cooling and lighting, moving beyond static design models to dynamic operational management.

Recommendation 3: Methodological Refinement—Disentangling Goals from Methods. Future iterations of this study must refine the variable definitions to resolve the "multicollinearity" observed between "Energy Efficiency" and architectural elements.

- **Action:** The variable "Energy Efficiency" should be renamed to a specific actionable attribute, such as "Operational Maintenance" or "Energy Monitoring". This distinction will clarify whether stakeholders value monitoring energy as distinct from envelope design, thereby reducing the conceptual overlap identified in the Rotated Component Matrix.

Recommendation 4: Expansion of Scope—From Academic to Professional. While this study provides a robust profile of the academic and emerging workforce, the findings should be extended to established professionals to validate if the "siloing" of renewable energy and smart controls persists at the senior level.

- **Action:** Replicate the PCA methodology with a sample of licensed AEC professionals in the UAE. This will determine if the "knowledge gap" in automation is a product of university education or a broader industry-wide systemic issue.

5.3. Critical Questions for Future Inquiry

The findings of this study raise several critical questions that must be addressed to ensure the viability of the UAE's sustainable development goals:

1. **The Automation Threshold:** If "Smart Control" remains a niche competency with low integration (0.44 communality), can the UAE realistically achieve "Net Zero" status solely through improvements in building envelope and passive cooling?
2. **The Operational Gap:** Does the conceptual conflation of "Energy Efficiency" with physical "Architectural Elements" lead to a "performance gap" where buildings are designed efficiently but operated inefficiently?
3. **The Silo Effect:** How can professional licensing bodies incentivize the cross-pollination of skills, ensuring that architects possess a working knowledge of renewable integration (PC1) and engineers possess a nuanced understanding of envelope design (PC2)?

By addressing these questions and implementing the outlined recommendations, the UAE construction industry can transition from a reliance on comparative case studies to the rigorous, data-driven EUI benchmarks necessary for a sustainable future.

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