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Advancing Biocentric Architecture Through Smart Building Application

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ABSTRACT

The research explores the use of biocentric architecture concepts on top with smart building applications to promote sustainable design practices. Biocentric architecture prioritized ecological equilibrium and human well-being. In recent years, the introduction of smart building technology has created new potential to improve biocentric design methods. The research focuses into how smart building technologies like Internet of Things (IoT) sensors, data analytics, and automated systems can be used to boost energy efficiency, improve indoor environmental quality, and increase occupant comfort within biocentric architectural frameworks. The research assesses the effectiveness of smart building techniques in supporting biocentric principles by conducting a thorough assessment of literature review and case studies, considering issues such as resource conservation, ecosystem integration, and user-centric design. The findings emphasize the potential synergies between biocentric architecture and smart building technology to create healthier, more sustainable buildings. This study contributes to the on-going environmentally conscious design practices by advancing biocentric architecture with smart building solutions. It also provides insights for architects, urban planners, and policy makers who want to create resilient and liveable cities.

1. Introduction

The building industry ranks among the top contributors to global energy consumption and greenhouse gas emissions. Innovations in building energy technologies are pivotal in improving the energy sustainability of built environment. Recent developments in energy and environmental systems for buildings signify a growing focus on addressing these worldwide challenges through

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extensive research and innovative approaches [17]. Buildings, responsible for 40% of global energy use and 33% of greenhouse gas emissions, must lead in addressing climate change through robust sustainability and smart initiatives. To this end, the building sector is increasingly adopting diverse sustainability measures aimed at improving energy and resource efficiency while minimizing environmental emissions. Digitalization is seen as a key enabler in advancing these efforts [12]. Information and communication technology (ICT) underpins most organizational processes, making its management crucial. Information systems (IS) encompass ICT, processes, data, documentation, and personnel. Stakeholders often question the quality and efficiency there is. To assess this, organizations conduct IS audits, independent analyses, and due diligence, identifying controls and compliance issues. Some have implemented quality management and IT service management systems to ensure effectiveness [16].

Smart building applications truly revamp biocentric architecture because they incorporate IoT and AI and use renewable energy sources to create green, health-inducing spaces. Green roofs, daylight harvesting, and natural ventilation combine nature with design, thereby reducing the environmental imprint of the buildings while enhancing well-being for the occupants. Real-time data monitoring allows for optimal use of energy and indoor air quality resources, which means even more efficient resource use. With a rising demand for sustainable living, the on-going fusion of technology with biocentric principles opens a pathway to more people-and -planet-centered architecture.

1.1 Research Background & Problem Statement

The pressure to meet global climate targets is increasing, with buildings responsible for 40% of global greenhouse gas emissions. Johnson Controls' paper, "The Smart Building of the Future," outlines how smart buildings equipped with AI, IoT, and cloud technologies will help achieve net-zero goals. These buildings integrate with human and environmental ecosystems, enhancing well-being, sustainability, and productivity. Johson Controls CTO Vijay Sankaran highlights the importance of reducing the carbon footprint through advanced building technologies. Key factors driving smart building trends include rising energy costs and changing occupancy patterns. AI and digital twins facilitate real-time data analysis and strategic improvements, supporting sustain and efficient building operations [27]. The main challenges to achieving urban sustainability are managing growth, providing housing, and addressing environmental concerns during rapid urbanization and unclear policies. ArcAI is a useful tool that strengthens resilience, improves urban planning, and encourages collaboration [17]. Moreover, the analysis identified three main challenges from the literature: perceived usefulness, concerns about consumer data privacy, and the lack of enterprise IoT applications in the country. This study is crucial for providing an initial understanding and uncovering the issues surrounding IoT and smart home technology within the community [11].

As we enter 2024, smart buildings are rapidly evolving, driven by advancements in technology and societal needs. These intelligent structures utilized artificial intelligence (AI) and Internet of Things (IoT) for responsive climate control, predictive maintenance, and personalized settings. Emphasizing sustainability, they monitor energy use and integrate ESG factors. Enhanced security features, health-focused designs, 5G connectivity, and cloud-based management systems are also pivotal. Smart building as a service (SBaaS) offers flexible solutions, while platforms like Siemens Building X, Honeyweel Digital Prime, and Schneider EcoStruxure optimized operations. These trends are transforming buildings into dynamic, sustainable, and user-centric environments, revolutionizing construction, and management [18]. Smart buildings, integrating advanced technology, are rising in Malaysia, said Kuala Lumpur Mayor Datuk Seri Kamarulzaman Mat Sallleh. Unlike traditional buildings, they use sensors and data for efficient management. At the MIPFM Smart Building

Conference 2024, he highlighted three key considerations: integration, cybersecurity, and people-centric design to meet occupant needs [19].

The Malaysian Institute of Property and Facility Managers (MIPFM) proclaims that technology advancements, artificial intelligence (AI), and data analytics will affect the transformation of real estates through smart buildings. Certification agencies like SmartScore emphasize the use of digital security and intelligent management systems in smart buildings for delivering enhanced user experiences. MIPFM president Ishak Ismail emphasized at the MIPFM Smart Building Conference 2024 that smart buildings, now a reality, improve comfort, productivity, sustainability, and urban resilience. Examples like Tun Razak Exchange showcase successful smart buildings. Rising sustainability demands, especially from younger generations, push developers to focus on eco-friendly features such as energy efficiency and waste reduction [20].

Aziz *et al.,* [11] explores IoT adoption in Malaysian smart homes, highlighting its potential revolutionize home technology. It identifies three main challenges: perceived usefulness, data privacy, and lack of enterprise IoT applications. Addressing these issues is crucial for improving IoT and smart home technologies, particularly for enhancing remote work and online education pos-COVID-19. Aziz *et al.,* [11] examines IoT adoption for smart homes in Malaysia highlighting challenges in security, privacy, and consumer data protection. Despite its benefits for flexible work-life-balance, IoT awareness is low, and enterprise applications are lacking. Government support for IoT, big data, and AI is crucial. The study suggests improving IoT use in online education and remote work, especially post-COVID-19.

At the same time, the research highlighted human comfort and wellbeing emphasized on the needs of humans as following Maslow's Hierarchy of Needs. Maslow's Hierarchy of Needs was used to outline eight stages of human needs. These were further grouped into 24 common needs across three dimensions: necessities, complimentary needs, and desired opportunities [21]. Maslow's Hierarchy of Needs is a psychological framework that arranges human needs into a hierarchical structure. Initially, it delineates five primary levels: physiological, safety, love/belonging, esteem, and self-actualization, portraying the progression of needs from basic survival to higher-order fulfillment [21].

1.2 Literature Review

Multidisciplinary technological approaches in building design are essential for tackling the complexities of a VUCA world and addressing climate change. By combining advanced technologies, sustainable practices, and adaptive strategies, these methods offer innovative solutions to global challenges, fostering resilient, efficient, and environmentally responsible built environments for a sustainable future. Multidisciplinary technological approaches in higher education enrich learning by enhancing quality, fostering interdisciplinary expertise, and integrating advanced technology with theoretical knowledge. Emphasizing applications like cutting-edge building technologies, sustainability, and innovation, these strategies prepare students for future careers, promoting complex problem-solving and collaboration to address global challenges and advance human civilization [22].

Advancing biocentric architecture through smart building applications integrates living systems with cutting-edge technology to create harmonious, sustainable environments (Figure 1). This approach leverages IoT devices, AI, and data analytics to optimize energy efficiency, reduce carbon footprints, and enhance occupants' well-being. By monitoring and adapting to natural conditions, these buildings promote biodiversity and resource conservation. Smart systems manage climate control, lighting, and security while ensuring minimal environmental impact. This fusion biocentric design and smart technology aims to create resilient, self-sustaining structures that support both human health and ecological balance, addressing the urgent need for sustainable development.

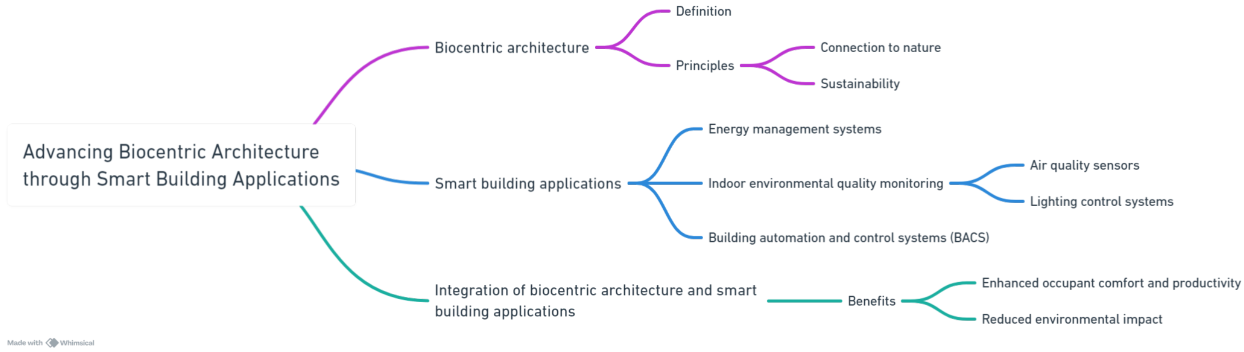

Fig. 1. Theoretical framework of advancing biocentric architecture through smart building applications (Source: Author, 2024)

Biocentric architecture prioritizes the integration of natural systems and living organisms within built environments. It embraces principles of sustainability, biodiversity, and ecological harmony, aiming to minimize environmental impact and enhance human well-being. By incorporating features such as green roofs, nature ventilation, and biophilic design elements, biocentric architecture seeks to create spaces that mimic and support natural ecosystems. This approach emphasizes the interdependence between humans and nature, promoting healthier, more resilient buildings that contribute positively to local ecosystems and global sustainability goals. Biocentric architecture represents a holistic and regenerative approach to design that honors the interconnectedness of all living things within the built environment.

The built environment should not harm the earth or drain its resources. In architecture, this idea is based on understanding life cycles, cultural changes, and how people interact. Although the term 'sustainability' is sometimes used as a buzzword, leading to 'greenwashing,' the global commitment to true sustainability has grown stronger. This shift, driven by innovative technologies and visionary leaders, has led to the creation of new buildings and masterplans that rethink our future. Sustainability now includes environmental, social, and economic aspects (Figure 2). For Killa Design, sustainability is a holistic approach that covers embodied carbon, renewable energy, water management, waste recycling, and green transportation. Their philosophy also integrates biocentric architecture and smart building applications, focusing on renewable energy, passive design, IoT systems, waste management, bioremediation, thermal comfort, and energy conservation (Figure 4) [7].

Another core principle of sustainable architecture is Life Cycle Design (LCD), a "cradle-to-grave" approach that considers the environmental impact throughout the entire life span of architectural resources, from their extraction to their return to nature. LCD is based on the idea that materials continuously transition from one stage of usefulness to another, maintaining their utility indefinitely. The life cycle of a building can be divided into three interconnected phases: pre-building, building, and post-building, as depicted in Figure 3. These phases, though not clearly delineated, are linked and can be used to develop LCD strategies focused on reducing a building's environmental footprint. Analysing each of these phases provides valuable insights into how the design, construction, operation, and eventual disposal of a building affect the larger ecosystem [2].

This principle by Aldo Leopold that ethics must protect the integrity, stability, and beauty of the biotic community essentially redefined ecological morality by positioning it from an ecocentric lens. Leopold's holistic framework-the first to recognize humans as equal constituents of the land community-serves as an anchor for sustainability discourse, despite continuous encapsulations and reinterpretations over the decades, because he emphasizes nature's intrinsic value (SCB 2020) [23]. Or Aldo Leopold conceptualized ethical conservation, entwining the benefits of resource management with the input of science, which in turn revolutionized the study of ecology. His value-driven approach inspired conservation biology, emphasizing ethics and restoring harmony between humanity and nature (Van Dyke, 2008) [24]. In detail on Earth ecosystem, Lovelock's Gaia hypothesis highlights life's role in Earth's atmospheric balance. Unlike lifeless Venus and Mars, Earth's reactive gases sustain a unique disequilibrium, emphasizing the need to align human activity with nature's self-regulating systems for ecological harmony [25]. Ecosystem approaches interlink health and biodiversity, facilitating principle-driven strategies via interdisciplinary dialogues across political, scientific, and philosophical spheres, streamlining adoption within local policy-making frameworks (Figure 5) [26].

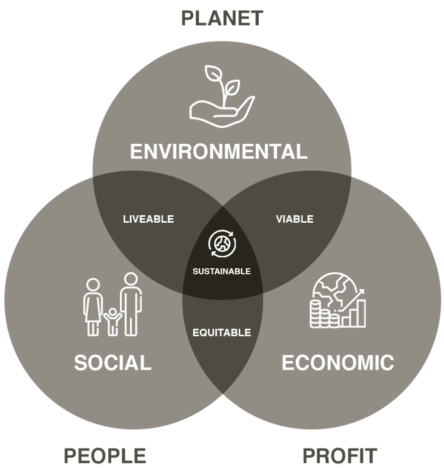

Fig. 2. The sustainable element [7]

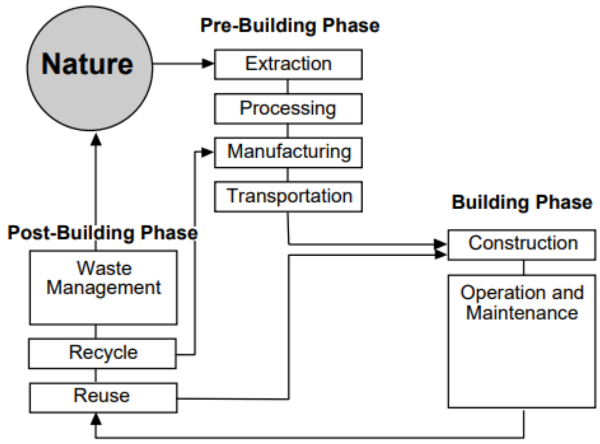

Fig. 3. The sustainable building lifecycle [2]

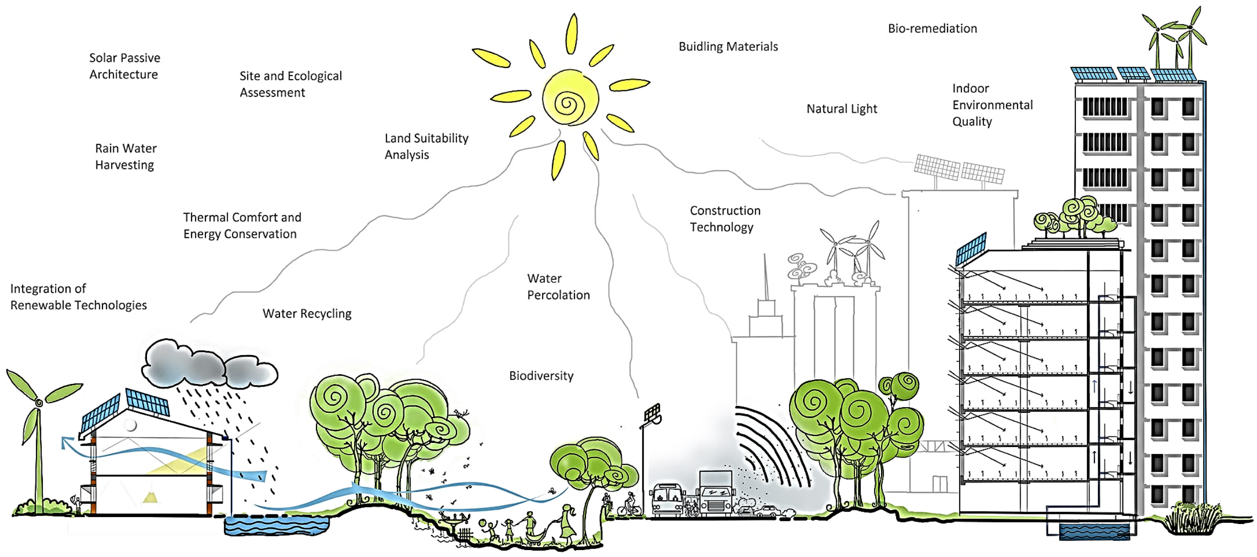

Fig. 4. The sustainable building lifecycle [7]

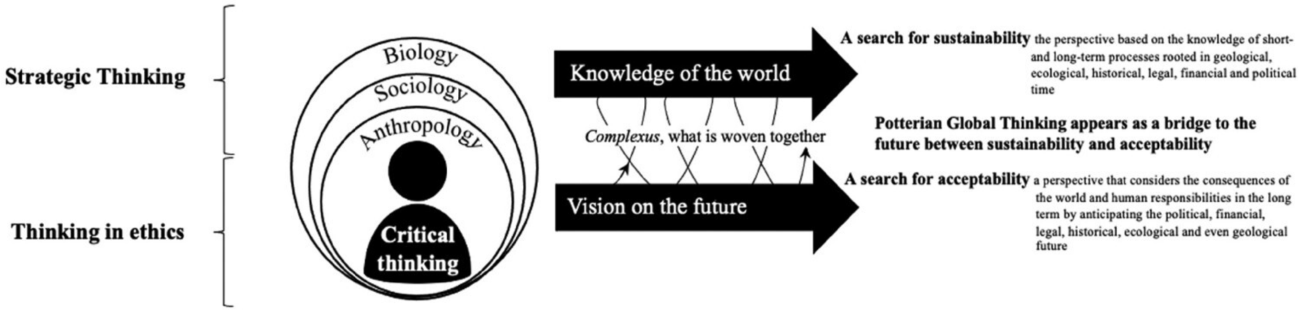

Fig. 5. Ecological model of the philosophical knowledge organization [26]

Smart building applications refer to the utilization of advanced technologies, such as IoT, AI, and data analytics, to enhance efficiency, sustainability, and user experience within buildings. These applications enable seamless integration and automation of various systems, including HVAC, lighting, security, and occupancy management. By leveraging real-time data and predictive analytics, smart building applications optimize energy usage, improve operational efficiency, and provide personalized services to occupants. They enable remote monitoring and control, proactive maintenance, and adaptive responses to environmental conditions, ultimately creating intelligent, responsive, and sustainable built environments for occupants and stakeholders.

Energy efficiency in building design aims to create environments that provide optimal comfort for occupants while minimizing energy costs. The goals of energy-efficient buildings are to enhance occupant comfort and reduce the consumption of energy sources, such as electricity and natural gas, used for lighting, cooling, and heating. Progress in energy efficiency is assessed by any actions taken by manufacturers or operators of energy products that lower energy usage per unit of production without compromising the level of output. Energy efficiency encompasses various aspects, including low energy consumption, energy-efficient fixtures, and renewable energy sources like wind, biomass, hydroelectric, and geothermal power [3].

To enhance health and productivity, office building managers should adopt the following recommendations: i) regularly monitor all pertinent Indoor Environmental Quality (IEQ) indicators to ensure they meet recommended standards; ii) address and eliminate identified indoor pollution sources; iii) implement effective ventilation and climate control strategies; and iv) offer opportunities for personalized adjustments to environmental conditions, aligning with the preferences of individual workers. Smart home energy management systems (SHEMSs) integrate electrical devices and energy systems into a unified communication network, enabling smart homes to be controlled by devices like smartphones and voice-activated controllers (Figures 6 and 7) [12].

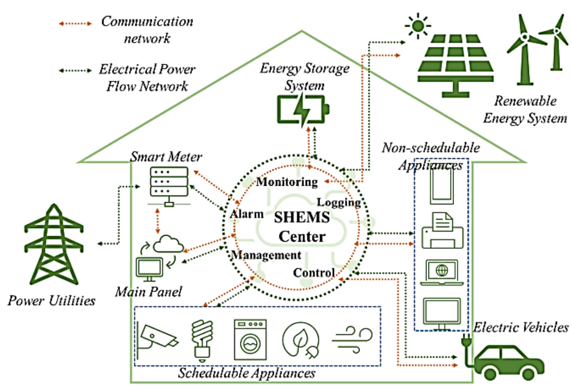

Fig. 6. The architecture structure of a typical SHEMS model [13]

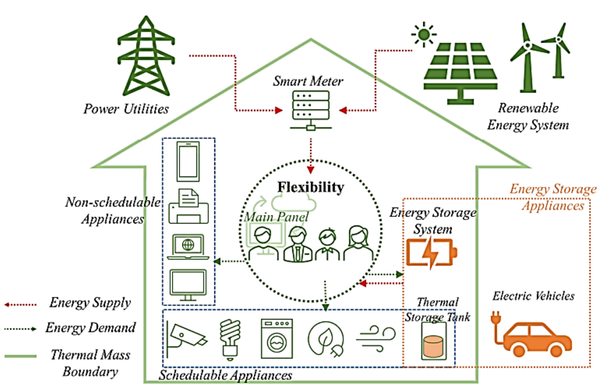

Fig. 7. Alternatives energy sources for a smart home/building’s flexibility energy usage [14]

Optimization techniques in systems engineering enhance sustainable building by improving design efficiency, resource management, and performance through integrated methods and technologies for better environmental and economic outcomes. Within systems engineering, optimization technique advancements have significantly improved the case of solution and have become a meaningful application by which very robust solutions have been provided to previously unsolved and complex problems. Recent research indicates how versatile these methods can be in such applications, not limited to parameter estimation in nonlinear systems or economic load dispatch in power systems. Thus, optimizing techniques are about to take the frontline in future innovations and improvements in the context of urban planning, architectural design, and sustainable architecture [4]. Efforts into the optimization techniques in systems engineering for energy-efficient buildings lean toward the multidisciplinary principles of thermodynamics, chemical engineering, and computational modelling to help develop a holistic picture of the issues involved and to develop exemplary solutions. The work manifests an emphasis toward a renewable energy source, hence sustainable energy practices [5]. These findings reveal that Building Information Modelling (BIM), the Internet of Things (IoT), and Big Data have all been significant forces within the last five years, while digital twins and smart robotics have emerged as leading drivers of construction sustainability. These technologies identified in the digital twin primarily have application areas in integration and collaboration, optimization, simulation and decision-making, monitoring and control, and training. Extensive research has been conducted on digital twins to optimize and monitor construction infrastructure for sustainable outcomes [6].

A systematic study has been conducted by reviewing existing applications and prospect of these 13 major important digital technologies in the construction industry-sensors, Building Information Modelling (BIM), Building Management Systems (BMS), smart meters, 3D printing, robotics, big data analytics, Internet of Things (IoT), machine learning, artificial intelligence, digital twins, blockchain, and cybersecurity (Figure 8) [8].The study shows that digital technologies are transforming buildings into more integrated, flexible, energy-efficient, and sustainable spaces by optimizing resources, improving operations, and reducing environmental impact. For example, sensors enable real-time data collection, BIM supports sustainability assessments, and AI improves energy management. These technologies could boost energy efficiency in the building sector by 30%–50% by 2040. However, challenges such as high initial costs, privacy and security risks, and a lack of customer awareness and skilled workers remain. Supportive policies and regulations are essential for fostering the adoption of these technologies [8].

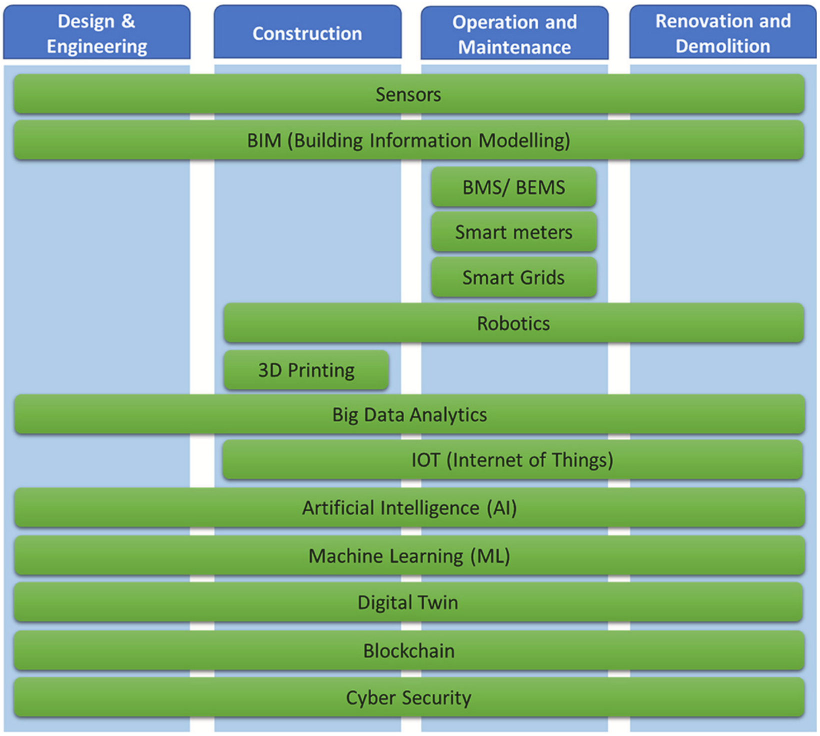

Fig. 8. Application domains of different digital technologies across a building's lifecycle (8)

2. Methodology

Architectural research intertwines design and research methodologies, highlighting their complementary nature. Design processes are informed by research, which can provide insights at various stages, from initial concept development to final artifact creation. Conversely, the design process generates numerous questions and challenges that necessitate further inquiry, fostering a continuous cycle of exploration and innovation. Research methods in architecture include qualitative approaches such as case studies, ethnographic studies, and participatory design, as well as quantitative techniques like surveys and statistical analysis (Table 1). These methods collectively enhance understanding, drive creative solutions, and validate design decisions, emphasizing the reciprocal relationship between research and design in advancing the field [1].

Table 1
Matrix of the primary differences between design and research [1]

Facets of difference	Design	Research
Contribution	Proposal for artifacts (from small-scale to large-scale interventions	Knowledge and/or application that is generalizable (in diverse epistemological terms)
Dominant Processes	Generative	Analytic & Systematic
Temporal Focus	Future	Past and/or present
Impetus	Problem	Question

This study uses a qualitative approach, including literature reviews and case studies, to evaluate smart building techniques supporting biocentric principles. Observations and unstructured expert interviews provide insights into green and smart buildings in Malaysia, identifying trends, challenges, and practical examples of sustainable architectural integrations. Unstructured interviews are informal and don't follow a set structure. They involve casual conversations where interviewers take brief notes and try to remember the responses. This method is often used in field observations, especially when there's limited research available on the topic [9]. The main benefit of using a case study observational research (CSOR) approach is that it combines observation with other data collection methods in case study research (CSR), with a focus on observation. This helps to gain a deeper understanding of the subject being studied.

To further clarify the understanding of the research, it also involves structured interviews with 16 professionals from the fields of architecture, sustainability, and smart technologies. The scholars give accounts of different criticism in terms of resource conservation, ecosystem integration, and user-centric design. The interviewers would receive in-depth information on the best practice, the innovative solutions, and the possible constraints in the application of smart building technologies in a biocentric framework. The method carefully combines literature analysis with case study reviews and interviews with experts to ensure a thorough and in-depth investigation of the topic. It not only reflects the current state of biocentric architecture but also provides practical inputs to further the use of applications for intelligent buildings and develop sustainable and integrative building practices. Concurrently, case study research is gaining increased attention from qualitative researchers as it embodies a flexible approach using several methods and designs. However, much flexibility has been the cause of its interpretation since, according to other critics, it is not such a reliable method of research [15].

3. Results

3.1 Biocentric Architecture

Biocentric architecture, also known as indoor-outdoor architecture (IOA), emphasizes merging indoor-outdoor spaces create functional, aesthetically pleasing, and eco-friendly designs (Table 3). This approach is rooted in six biocentric principles: eco-friendliness, harmonious environments with traditional linkages, sustainable design through technology, reduced energy consumption, enhanced human happiness, and the incorporation of green elements. Biocentric architecture seamlessly blends with nature by integrating natural elements such as lights, plants, and sustainable materials, aiming to create comfortable, harmonious environments that benefit occupants' well-being while promoting the surrounding ecosystem. Figure 9 shows elements of biocentric architecture that's has been studied by the researchers.

In Malaysia, architecture reflects a strong sense of tradition, with elements like intricate wood carvings and batik patterns showcasing the country's diverse cultural background. Locally sourced materials such as wood and bamboo are used to fuse traditional and contemporary design concepts. Biophilic architecture, which integrates native plants and greenery, enhances the connection to local heritage creates a tranquil atmosphere that aligns with nature's beauty. The role of technology is essential in improving the sustainability of the interiors for office designs. On the other hand, effective interior design practices constitute a clean approach of creating places that feel safe, soothing safe havens for exercise in health and wellness. Fine interiors are meant to stimulate a happy mood and promote the heritage of space, such as an open ambiance, connecting with people in security. Interior elements like sunshine and dwelling plants can increase relaxation among the attendees, enhance concentration, and promote rest all of which will eventually lead to comfort and sustainability within the interiors. Architects include space layouts, shades of color, lighting strategies, material selections, furniture design, plant integration considerations, views and construction procedures. The aim of biocentric and biophilic practice is thereby ensuring maximum comfort, well-being, and joy of occupants through notions of natural light, ventilation, climatic, and privacy conditions.

Studies show that principles based on the biocentric approach will work wonders in the human psyche and health. Where the environment is rich in natural elements such as plants and wood, stress is minimized, anxiety levels are lowered, and happiness is maximized. There is more of an appeal to nature augmentation using biophilic designs, which in their totality, yield productivity enhancement and excellent mental health. Biocentric designs are concerned with energy conservation by optimizing the available natural light, having insulating materials that regulate temperature indoors, and adopting energy-efficient furniture paired with intelligent technology systems. Thus, biocentric architecture constructs spaces in which the physiology, ecology, and biogenicism between the natural and the man-made are comforted and sustained, making them propitious for the human and planetary worlds.

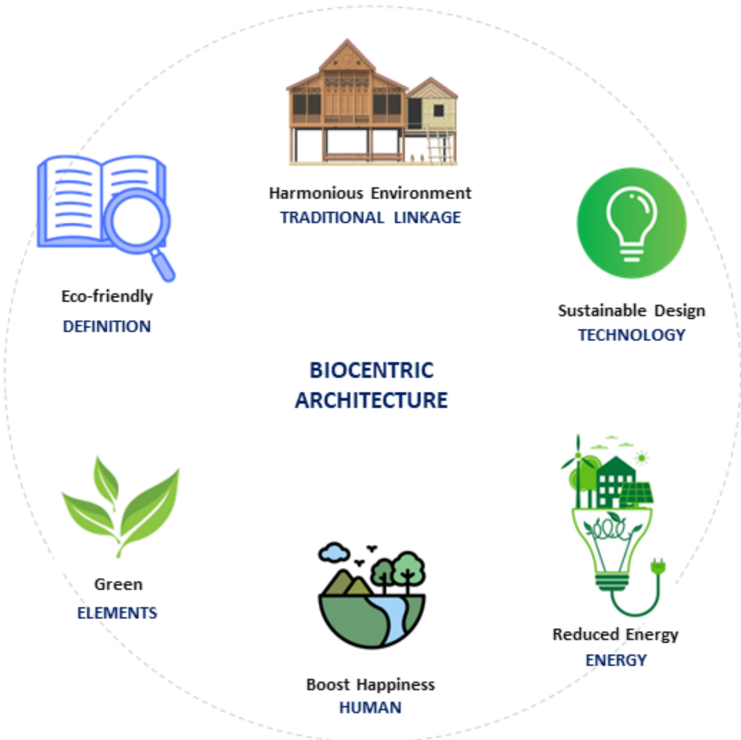

Fig. 9. Characteristics of biocentric architecture (Indoor-outdoor architecture) (Source: Author, 2024)

3.2 Smart Architecture and Architectural Intelligence (ArcAI)

Key challenges in achieving urban sustainability include managing urban expansion, providing affordable housing, balancing environmental concerns with development, addressing climate change impacts, preserving cultural heritage, and managing population growth. Malaysian cities face rapid urbanization, resource strain, inequality, and unclear policies that hinder effective sustainable development. Collaboration across government agencies is crucial. ArcAI, or architectural intelligence, can revolutionize sustainable urban development by enhancing the resilience of buildings and infrastructure to climate change and disasters. It aids in decision-making and scenario planning, optimizing layouts for efficiency and liveability. ArcAI personalizes environments for occupant well-being and fosters efficient collaboration among urban planners and architects. AI applications like GIS and BIM offer tools for efficient spatial analytics and urban prototyping, potentially transforming sustainable design practices in Malaysia, though ethical and privacy considerations must be addressed. Integrating ArcAI into urban planning and design processes offers benefits such as increased efficiency, accuracy, projection capabilities, and enhanced collaboration (Figure 10). It optimizes layouts for efficiency and occupant well-being, improves resource management, and revolutionizes public services. However, challenges include skill requirements, initial costs, and ethical considerations regarding data privacy and inclusivity.

Stakeholders view ArcAI as an effective resource management tool, yet some aspects remain unexplored. Architects and designers embrace its potential for innovation and performance optimization. Community residents see it to address urban challenges like housing affordability and transportation. Government and investors recognize its value for sustainable development and informed decision making. Critical factors influencing ArcAI adoption in urban development projects include technological availability and maturity, reliability, scalability, and interoperability. Government support through policies and incentives, data privacy regulations, and public-private partnership are vital. Stakeholders' roles in education, development, consultancy, and public perception also impact adoption and implementation success. ArcAI-driven smartscapes can enhance future cities by optimizing air quality, noise levels and access to amenities. Although evidence is limited, studies show AI's potential in coordination, resource analysis, improving quality of life through data. In Malaysian cities, ArcAI could enable self-regulating buildings, streamline traffic, and improve waste management for cleaner, more efficient urban living. Figure 10 shows sustainable smartscapes conceptual framework through ArcAI integration in urban design that's has been explored by the authors.

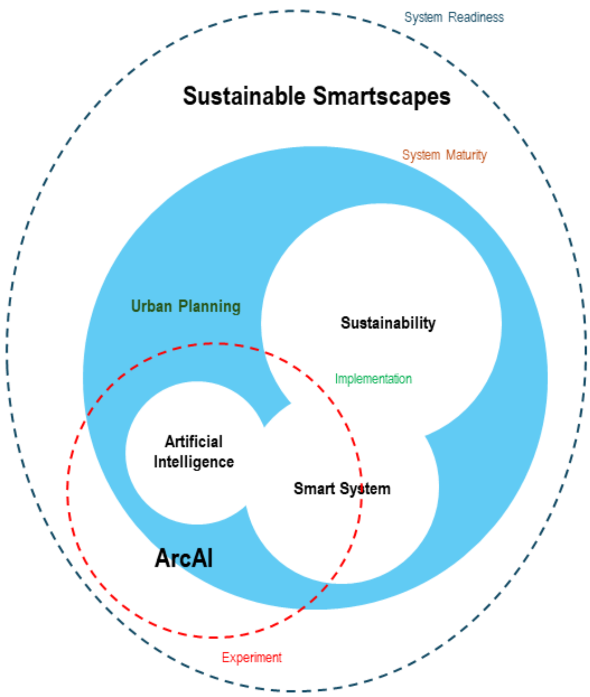

Fig. 10. Sustainable smartscapes conceptual framework through architectural intelligence (ArcAI) integration in urban design (Source: Author, 2024)

3.3 Case Study (Observation, Document Collection & Unstructured Interviews)

The Exchange TRX, a 70-acre development in Kuala Lumpur, includes 26 buildings with over 21 million sq. ft of Gross Floor Area (GFA) for office, residential, hotel, retail, F&B, and cultural spaces as shown in Figure 11 – Figure 15 and Table 2. Conceived in 2010 to be Malaysia's premier financial district, it opened on 29 Nov 2023. The design integrates sustainable architecture and green spaces, promoting a vibrant, eco-friendly community. Jointly developed by Lendlease Corporation and TRX City, and designed by Grimshaw, GDP, DP Architects, and Leonard Design Architects, it features a mix uses and is accessible via the Tun Razak Exchange MRT Station. Figure 16 – Figure 19 show indoor photos of The Exchange TRX in Kuala Lumpur which is practising smart system and applying biocentric design for the building.

Fig. 11. The Exchange TRX' master plan (Source: Landart Design Sdn Bhd)

Fig. 12. The green roof of The Exchange TRX (Source: theexchange.my)

Fig. 13. Establishing an effective and efficient ecological corridor (Source: Landart, 2024)

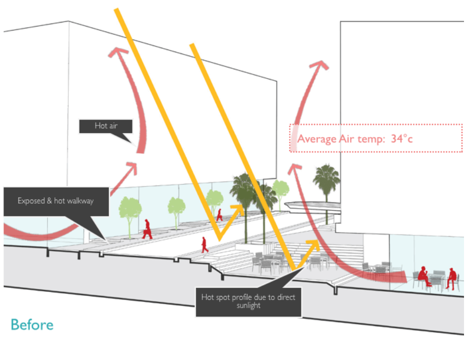

Fig. 14. Before (Source: Landart, 2024)

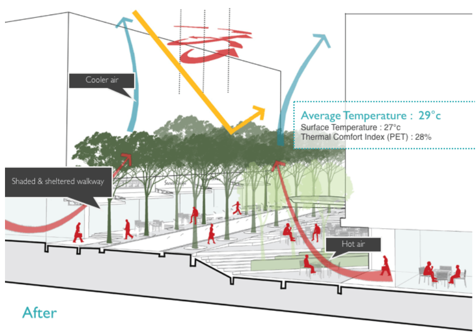

Fig. 15. After (Lobby) (Source: Landart, 2024)

Highlighting the integration of biocentric architectural principles and ecological biodiversity within the urban natural ecosystem, Tun Razak Exchange (TRX) demonstrates the merging of excellent connectivity, iconic public spaces, and sustainable design, establishing Malaysia's first international financial district (Figure 11 – Figure 15). As a forward-looking development grounded in sustainability, TRX is the first in Malaysia to attain a provisional Green Building Index (GBI) certification at the neighbourhood level.

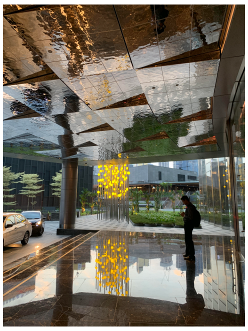

Fig. 16. The Exchange TRX' interior (Main Entrance) (Source: Author, 2024)

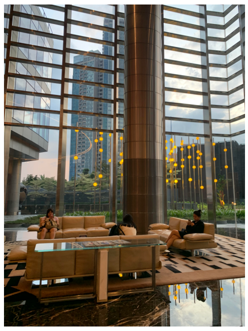

Fig. 17. The Exchange TRX' interior (Lobby) (Source: Author, 2024)

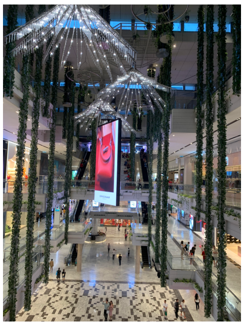

Fig. 18. The Exchange TRX' interior (shopping mall) (Source: Author, 2024)

Fig. 19. The Exchange TRX' interior (Mall) (Source: Author, 2024)

Table 2
The Exchange TRX information (Source: Author, 2024)

Building Name	Tun Razak Exchange (TRX)
Land area	70-acres
Master Plan	The master plan encompasses 26 buildings with over 21 million square feet of Gross Floor Area (GFA), distributed across office, residential, hotel, retail, F&B, and cultural spaces.
Gross Floor Area	Retail floor: 1,300,000 sq. ft (120,000 m^2), No of floor: 4, Parking: 3 levels
Address	Persiaran TRX, Tun Razak Exchange, 55188 Kuala Lumpur
Owner	LQ Retail Sdn Bhd (joint venture between Lendlease and TRX)
History	The Exchange TRX was conceived as Malaysia's premier financial district, initiated in 2010, aiming to create a global business hub.
Opening date	29 Nov 2023
Design Concept	The Exchange TRX integrates sustainable architecture, mixed-use development, and green spaces, fostering a vibrant, connected, and eco-friendly urban community.
Design & Architect	Grimshaw (Master plan), GDP, DP Architects, Leonard Design Architects
Developer	The Exchange TRX is jointly developed by Lendlease Corporation, a globally integrated real estate group based in Australia and TRX City Sdn Bhd, the master developer of the Tun Razak Exchange.
Contractor	The project adds to IJM Construction's current work in TRX which include HSBC Malaysia and Affin Bank's new headquarters as well as TRX Residences. The second contract for The Light City's Mezzo residential tower includes the construction of a 34-storey, 456-unit high-end luxury condominium.
Engineer	EDP Consulting Group Sdn. Bhd.
Building Types	Mix used development, shopping mall and complex, residential, office buildings

Public transit access	Tun Razak Exchange MRT Station
Green Certification:	Platinum (Township) from Green Building Index (GBI); Gold (LEED 2009 Core and Shell (63 points) Oct,30,2023

The Exchange TRX integrates biocentric architecture through several key features. It includes green spaces such as rooftop gardens, green roofs, and vertical gardens, promoting urban biodiversity and air quality. Native plants species support local ecosystems and reduce water consumption. Sustainable materials like recycled and reclaimed resources, along with low-VOC paints, are used to minimize environmental impact. Energy efficiency is achieved with high-performance insulation, double-glazed windows, and renewable energy sources like solar panels. Biophilic design incorporates natural elements, organic forms, and patterns to enhance occupant well-being. These features ensure the TRX building promotes community and environmental health without causing harm (Table 3).

Table 3
The Biocentric Architecture Characteristics (Source: Author, 2024)

Biocentric Architecture		
No.	Characteristics	Description
1.	Green Spaces and Urban Biodiversity	• Rooftop Gardens and Green Roofs: Promote urban biodiversity and provide insulation. • Vertical Gardens: Enhance air quality and aesthetics while providing habitat for urban wildlife. • Native Plant Species: Use of indigenous plants to support local ecosystems and reduce water consumption.
2.	Natural Ventilation and Lighting	• Vertical Gardens: Enhance air quality and aesthetics while providing habitat for urban wildlife. • Native Plant Species: Use of indigenous plants to support local ecosystems and reduce water consumption.
3.	Sustainable Materials	• Recycled and Reclaimed Materials: Use of sustainable building materials to reduce environmental impact. • Low-VOC Paints and Finishes: Improve indoor air quality by reducing volatile organic compounds.
4.	Water Conservation	• Recycled and Reclaimed Materials: Use of sustainable building materials to reduce environmental impact. • Low-VOC Paints and Finishes: Improve indoor air quality by reducing volatile organic compounds.
5.	Energy Efficiency	• High-Performance Insulation: Reduce energy consumption for heating and cooling. • Double-Glazed Windows: Enhance thermal insulation and reduce energy loss. • Renewable Energy Sources: Solar panels and other renewable energy technologies integrated into the building design.
6.	Biophilic Design	• Natural Elements: Incorporation of water features, indoor plants, and natural materials to create a connection with nature. • Organic Forms and Patterns: Design elements that mimic natural shapes and patterns to enhance occupant well-being.
7.	Healthy Element	• Designer integrates the TRX building with natural environments to enhance community and environmental health and well-being, ensuring the creation of buildings and spaces that cause no harm.

The Exchange TRX incorporated smart architecture through several advanced features. Building Management Systems (BMS) offer centralized control and automation for HVAC, lighting, and security (Table 4). The climate adaptation and resilience design of TRX emphasizes passive design principles (biocentric architecture) and uses Internet of Things (IoT) devices, such as smart sensors, to collect and analyse real-time data on occupancy, temperature, light, and air quality (Figure 20). Artificial intelligence (AI) and data analytics enable predictive maintenance and energy optimization. Advanced security systems use biometric access control and AI-enhanced surveillance. Sustainable technology includes smart meters for precise energy and water usage tracking and intelligent waste management systems. Enhanced connectivity is provided through high-speed internet and 5G network. User-centric design offers adaptive workspaces and digital interfaces for easy interaction.

Table 4
The Smart Architecture Characteristics (Source: Author, 2024)

Smart Architecture		
No.	Characteristics	Description
1.	Building Management Systems (BMS)	• Centralized Control: Comprehensive systems for monitoring and managing HVAC, lighting, and security. • Automation: Automatic adjustment of systems based on real-time data to optimize performance and efficiency.
2.	Internet of Things (IoT)	• Smart Sensors: Devices that collect data on occupancy, temperature, light levels, and air quality. • Real-Time Data Analysis: Continuous monitoring and analysis of building performance data.
3.	Artificial Intelligence (AI) and Data Analytics	• Predictive Maintenance: AI-driven systems that predict equipment failures and schedule maintenance proactively. • Energy Optimization: AI algorithms that adjust energy use based on patterns and external conditions.
4.	Advanced Security Systems	• Biometric Access Control: Use of facial recognition and other biometric technologies for secure access. • AI-Enhanced Surveillance: Intelligent surveillance systems that detect and respond to security threats in real-time.
5.	Sustainable Technology Integration	• Smart Meters: Precise tracking of energy and water usage. • Waste Management Systems: Intelligent systems for optimizing recycling and waste disposal processes.
6.	Enhanced Connectivity	• High-Speed Internet: Robust infrastructure supporting seamless connectivity and smart device integration. • 5G Networks: Enhanced connectivity for IoT devices and building systems.
7.	User-Centric Design	• Adaptive Workspaces: Flexible and customizable work environments based on user preferences. • Digital Interfaces: Mobile apps and interfaces for easy interaction with building systems and services.

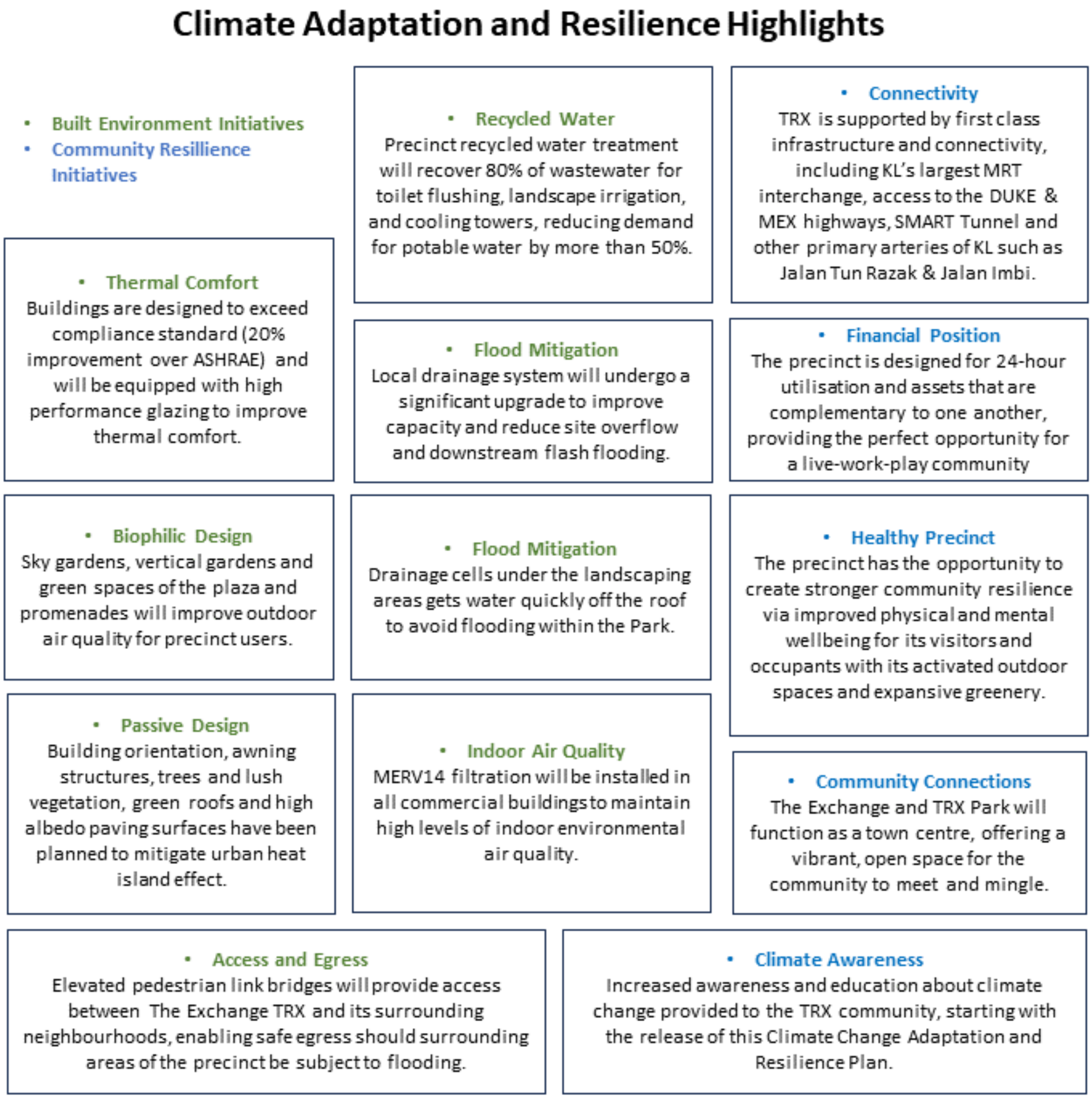

Fig. 20. Climate adaptation and resilience highlights (Source: thexchange.my, 2024)

Indoor-Outdoor Architecture (IOA) or biocentric architecture is indeed one avenue through which the indoors and the outdoors are combined with the aid of sustainable and eco-friendly designs involving natural elements such as light, vegetation, and locally sourced materials. This approach grounded on six core principles such as ecological stewardship and energy efficiency looks up to strong environmental synergy with occupant well-being. The smart architecture complements such principles by making full use of innovative technologies as AI, GIS, and BIM to solve the future urban sustainability issues of resilience and efficient resource utilization. Take for instance the Exchange TRX in Kuala Lumpur as a representation of such concept where bio-centric models seamlessly blend with intelligent systems for healthy individuals as well as ecosystems.

4. Conclusions

Incorporating interior and exterior spaces using indoor-outdoor-centric principles would be eco-friendly when designing with nature in mind. The composition of biocentric architecture follows the six guiding principles of ecological stewardship and energy efficiency because they point toward symbiosis and increased wellness from human consideration. These pillars are being joined by smart architecture, which adopts technologies such as Artificial Intelligence (AI), Geographic Information Systems (GIS), and Building Information Modelling (BIM) to make gains over urban sustainability problems by improving the readiness of buildings against future phenomena and better resource management. To illustrate this, The Exchange TRX in Kuala Lumpur will have an administration that combines biocentric approached with clever systems to produce that type of sustainable environment for humans' health while maintaining an ecological balance. The study used data mining, literature reviews, case studies through observation, unstructured and structured interviews with experts to identify issues and gather data. The future of smart buildings lies in integrating AI and biocentric design to enhance safety, sustainability, and harmony with nature. AI enables predictive analytics for crisis management, adaptive energy systems, and carbon-negative buildings, while promoting biosphere interaction. Guided by the Gaia Hypothesis and Land Ethics, buildings can mimic natural systems, support biodiversity, and foster resilience. This vision ensures sustainable development, blending technology and ethics for a healthier planet and future generations. This research advances biocentric architecture with smart building solutions, offering insights for architects, urban planners, and policymakers. Further research and development are needed in sustainable smartscapes and Architectural Intelligences (ArcAI). Areas like volatility, uncertainty, complexity, and ambiguity (VUCA), digitalization, advancement and development ArcAI, and Collaborative Robots (Cobots) are pivotal for future studies.

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Knowledge Contribution
The research highlights integrating biocentric architecture and smart systems to create sustainable, energy-efficient environments aligned with ecosystems. Leveraging AI, GIS, and BIM, it addresses urban sustainability through crisis prediction, resource optimization, and resilient, carbon-negative designs. Guided by the Gaia Hypothesis and Land Ethics, it fosters biodiversity and ecological harmony. Advancing ArcAI and Cobots offers solutions for VUCA challenges, ensuring sustainable, human-centered urban landscapes for future generations.

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