INTELLIGENT DESIGN STRATEGIES FOR UNIVERSITY BUILDINGS: IMPLEMENTING GREEN ARCHITECTURAL INNOVATIONS

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Abstract
This study explores the application of systems thinking in green architecture across two leading universities in arid climates: King Abdullah University of Science and Technology (KAUST) and the American University in Cairo (AUC). Employing a comparative case study methodology, this research delves into the integration of sustainability strategies at multiple levels: individual components, building systems, and broader community and ecosystem interactions. Both universities exhibit robust approaches to material selection, employing advanced, reflective, and locally sourced materials to enhance energy efficiency and reduce environmental impact. Innovations in building design demonstrate significant energy savings through strategic use of natural lighting and state-of-the-art HVAC systems, tailored to the unique desert conditions of each location. Water management and waste reduction strategies reflect a deep commitment to sustainability, featuring advanced recycling systems and designs that support easy material recovery and reuse. The comparative analysis highlights how each university's adoption of local practices and technologies not only minimizes their environmental footprint but also embeds sustainability into the educational culture, influencing faculty and student practices. This research underscores the potential for scalable and adaptable green architecture strategies in similar environmental conditions, offering valuable insights for global applications in sustainable campus design.

Key words. *green buildings, systems thinking, university buildings.*

1. Context

Integration of green architecture with sustainable environmental design has become imperative for every society in order to address environmental challenges arising from fast urbanization and more so for hot climates (McLennan, 2004; UNEP, 2003). From just one more ecologic novelty, green architecture has grown into one of the serious disciplines within the area of architectural design that responds to a whole array of environmental, social, and economic challenges. A core idea in this model is that of system thinking, which views buildings as not standing alone but rather as part of a larger networked ecosystem (Marcos *et al.*, 2022). Systems thinking in green architecture is structured into three axes in order to enhance sustainability in building practices (Fig. 1) (Kibert, 2022):

- Individual Building Components: This area of interest investigates the comprehension and optimization of each building element, like materials, energy, water systems, or even waste management, with sustainability in mind.
- Building as a System: Views the building as an entity by itself, where it ensures all the subsystems, including HVAC and electrical systems, have the ability to work in harmony among them.
- Community and Ecosystem Level: Expands the perspective to include the interaction of the building with its broader environmental, economic, and social context, promoting wider ecological and community integration.

This study investigates the application of systems thinking in green architecture at

King Abdullah University of Science and Technology (KAUST), and The American University in Cairo (AUC), focusing on their innovative approaches to sustainability within arid climates. Opened in 2009 and stretched along the Red Sea coast, KAUST, which encompasses 36 square kilometers in Saudi Arabia, is built in an extreme desert climate and developed by HOK (Fig. 2) (HOK, 2009) On the other hand, the New Campus in Cairo, which was re-established in 2008, is set at 1.0522 square kilometers and integrates modern facilities of education within the traditional Egyptian architectural elements guided by Sasaki Associates (Fig. 3) (Sasaki, 2008). Both institutions are devoted to reducing their environmental impact with an educational framework that increases the sustainability literacy of the community through its sustainability practices. Indeed, while the understanding of systems thinking in green architecture is increasingly appreciated empirically, the little effective practice in hot climates is still present so far. This paper aims to fill this gap by examining how KAUST and AUC systematically think toward the sustainable outcome of reduced energy consumption, efficient water usage, and effective waste management. This will, in turn, highlight exactly where similar strategies can be repeated across the globe.

2. Materials and methods

The study uses a qualitative case study as the research method in order to focus on the application of systems thinking in green architecture at and American University in Cairo (AUC).

This choice of universities is informed by advanced sustainable infrastructures that seem to offer solutions to the challenges of arid climates. Data Collection: Data collection sources considered were mainly online materials, which included official university websites that had an all-inclusive entry on sustainability reports, architectural plans, among others. These sources provide details on design principles, methodologies of construction, and sustainability initiatives carried out on every campus.

Information was retrieved from some architectural websites and online databases, including the case studies and reviews related to campuses, giving an outside evaluation of the strategies about green architecture. Analytical Framework: The present study is undergirded by a conceptual system thinking approach as the framework that helps investigating the level of integration of sustainability practices within KAUST and AUC to their respective larger environmental, economic, and social ecosystems.

It includes identifying relationships between different elements of a building, such as energy efficiency systems, water conservation measures, use of sustainable materials, among others, in order to find their overall benefit for the sustainable objectives of the campuses.

Comparative Analysis: This shall provide a comparison between the sustainability strategies that exist between KAUST and AUC and if they are effective. This comparative analysis sets out to underscore successful practices and the potential for areas of improvement by assessing how the systems thinking within the two universities can handle the peculiar challenges to their environment. Methodological Tools: In the collection of data, this research goes further to synthesize it through thematic analysis by categorizing information into topics related to key aspects of systems thinking in green architecture. In this sense, this methodology allows the articulation of how specific strategies are implemented and interconnected within the operational framework in the light of each university.

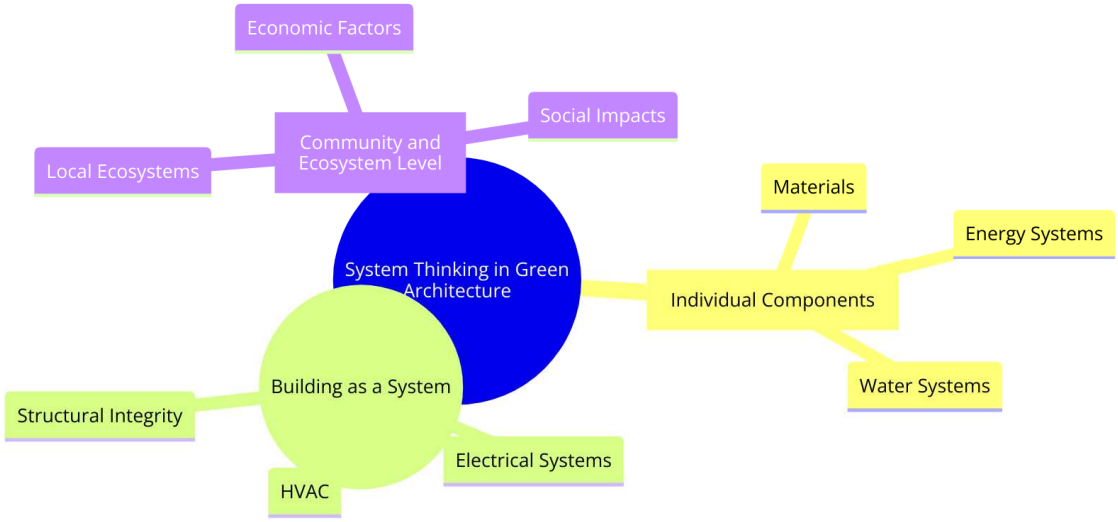

Fig. 1. *System Thinking in Green Architecture.*

Fig. 2. *King Abdullah University of Science and Technology in Saudi Arabia (KAUST).*

Fig. 3. *The American University in Cairo (AUC).*

3. Results and discussion

This section, therefore, is a summary of the findings resulting from the comparative case study analysis of King Abdullah University of Science and Technology (KAUST) and the American University in Cairo (AUC), given a system thinking framework in green architecture. Integration with the current literature and targeting a similar study against the sustainability strategies across different layers: Individual components, Building as a system, Community, and Ecosystem Level. The effectiveness of these strategies is categorized under Material Selection, Energy Efficiency, Water Management, and Waste Reduction, emphasizing the holistic approach to sustainability of the two institutions (Bucklain, 2020).

3.1. Individual components and material

Both KAUST and AUC have material selection strategies that have much lower environmental impacts. The university employs advanced building materials that reflect radiation from the sun, hence reducing the absorption of heat that is useful to them in a desert. On the other hand, AUC adopts locally sourced materials in order to minimize production and transportation energy (Koch, 2018; Ruwoko, 2024).

Both universities have followed recycled and reclaimed material approaches in their campuses in such a way that their institutions remain in tandem with the rest of the world on sustainability (Kibert, 2022).

3.2. Building as a system and energy efficiency

Both institutions have designed their infrastructure to harness natural lighting to the maximum. This significantly reduces their reliance on artificial lighting, thus reducing their indirect energy consumption. KAUST has some of the best HVAC systems, which have been optimized for use in a desert climate and, in turn, save 60% of the energy an ordinary HVAC system could consume (Knoll, 2014; Buildings-mena, 2009).

Similarly, AUC's strategic building orientation and high-performance insulation will significantly cut energy needs. Further campus-wide is the replacement of LED lighting, cutting the electrical consumption by more than 30% (Buildings-mena, 2008).

This level of integration with sustainability goals reflects in the practices in which even local architectural elements improve energy efficiency; for example, using regional construction techniques at KAUST or having green spaces and native landscaping at AUC in order to reduce the urban heat island effect (Architizer, 2008; Ruwoko, 2024).

3.3. Community and ecosystem level water management

Moreover, innovative water management systems at KAUST incorporate waste-water treatment for irrigation, which is considered an essential requirement in arid areas (Archdaily, 2009; Architizer, 2008). Similarly, AUC focuses on a sustainable water use need for a complete breaking from the impacts on localized water. These stretch beyond the campus to embrace sustainability in order to have an effective integration of the operations of a university with surrounding ecological and community systems (Aucegyp, 2023).

3.4. Waste reduction

On the other hand, KAUST and AUC have adopted strong policies toward waste reduction, with the promotion of material reuse and recycling. The level of commitment in the practice and sustainability of waste practices is high, as depicted in on-site waste management protocols, e-waste programs at AUC, and electronic waste programs at KAUST. Deconstruction design is more for ease in material recovery, a practice that underscores the life-cycle approach in building and construction materials (Hegazy *et al.*, 2021; Archdaily, 2009).

3.5. Comparative analysis

KAUST will more often take advantage of the most recent technological solutions since they have a larger budget, and their infrastructures are newer. For instance, in architecture, AUC combines modern efficiencies with traditional regional practice (Koch, 2018). An example of this nature of systems thinking approaches is that each institution will conform and scale their strategies in ways uniquely identified with their sustainability goals to the local conditions and resources. This highlights the ways of architectural strategies KAUST and

AUC are very efficient with detailed insight and numerical data. This is advanced integration that sees KAUST high-performance envelopes and smart HVAC systems, with 50% less energy use (HOK, 2009; Architizer, 2008). AUC integrates both the modern and traditional practices that include the heavy use of thermal mass materials and strategic orientation that is a temperature control practice in order to minimize the use of energy (Ruwoko, 2024; Sasaki, 2008). These examples are clear proof of systems thinking applied in architecture. They are an indication of how sustainability is nested in every corner of campus design and operation, allowing great savings in energy, and making this model of sustainability adaptable in various regions facing similar environmental challenges.

4. Conclusions

This research has effectively been synthesized from the application of systems thinking in green architecture at two most eminent universities, King Abdullah University of Science and Technology (KAUST) and American University in Cairo (AUC). It is expected that some strong findings in relation to sustainability strategies across individual components, integration of building systems, and broader community and ecosystem impacts holistically framed within both layers of systematic thinking emerge from such a comparative and analytic exercise. It provides deep analysis of the sustainability with detailed specifics of material selection, energy efficiency, water management, and waste reduction that underscore both universities' strong commitment toward sustainability catered to own particular environmental and cultural contexts as described below:

- Material Selection and Use: Both KAUST and AUC have adopted innovative and sensitive approaches for minimizing significant environmental impacts through the use of local materials. Sandstone is the building material used in the AUC from local sources (Aucegypt, 2024) and on the other hand use of advanced materials designed for the harsh desert climate at KAUST (Architizer, 2008) are both adaptive strategies that equally support sustainable building practices worldwide.
- Energy Efficiency: The institutions have, in fact, exhibited serious energy efficiency due to architectural and system designs that allow in much natural lighting and reduce consumption. Systems like KAUST's Smart HVAC or AUC's insulated buildings with strategic orientation are just underlying high efficiency regarding the management of energy consumption within respective arid climates (Buildings-mena, 2008, 2009).
- Water and Waste Management: The latest in water management systems and waste reduction has been introduced by both KAUST and AUC. They depicted the best proactive approach towards resource conservation and reduction in the environmental footprints (Architizer, 2008; Aucegyp, 2023).
- It is more human in their strategy: a commitment to sustainability that ranges beyond the campus and extends into communities and ecosystems within its reach. This shall be integrated into the local architectural and construction practices, with modern sustainable technologies being harmonized with traditional practices, so that modern sustainable technologies are enhanced and popular among the local community. This approach not only enhances sustainability but also fosters a sense of community involvement and responsibility.
- Comparative Insights and Scalability: A brief comparison of KAUST and AUC confirms that, although both deploy modern advances in sustainable technologies, deployment itself stands witness to their diverse environmental, budgetary, and sometimes even cultural environments. This shows that the strategies for sustainability with similar models can be emulated in another

region where there is a similar challenge. The following discussion explores the reflective role that systems thinking plays in green architecture; particularly, the architectural setup of educational institutions located within difficult climatic regions. These are evident in KAUST and AUC, where through the application of systems thinking in architectural designs, both institutions have managed to align sustainability goals with a vision to further reduce the environmental footprint while enhancing educational and community well-being. Further studies may look toward exploring the implementation of these practices in other climatic zones and may be implemented by other types of institutions to further validate their adaptability and efficacy of systems thinking in the global sustainability effort.

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