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A methodology for achieving sustainability in educational buildings through smart architecture

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Abstract:
Architectural research has increasingly focused on smart and sustainable buildings, leveraging advanced communication and information technologies to address future construction needs. The advent of self-operating software has introduced new design paradigms, particularly in educational spaces, where smart technologies have been integrated to keep pace with the rapid developments in science and education. These technologies create environments conducive to learning by making spaces more adaptable and interactive, enhancing students' ability to engage with their surroundings.

Despite the benefits of smart technologies, the concept of sustainability which emphasizes a return to nature and reduced reliance on technology to conserve energy has often been overlooked. This oversight has led to an overreliance on technological controls without adequately considering their potential negative environmental impacts, ultimately failing to meet the comfort requirements of architectural spaces. This research aims to improve the sustainability of educational buildings by exploring the design requirements for smart buildings and the application of these technologies within educational environments. Specifically, it focuses on integrating programmable smart technologies into HVAC systems to create an internal environment with dynamic heating, cooling, ventilation, and lighting. The objective is to achieve an optimal balance between student comfort and energy efficiency, thereby supporting the sustainability of educational buildings while maximizing economic and environmental benefits.

Keywords: Educational Buildings; Smart Architecture; Sustainable Building

A- Research Introduction:

Architecture accompanies humans throughout all stages of life, continuously striving to create comfortable environments and spaces. This goal has been increasingly realized through technological advancements, which have led to the integration of responsive and efficient systems within architectural designs. Educational buildings require highly effective and adaptable systems to accommodate diverse activities such as lectures, group work, and audio-visual presentations. The implementation of smart architecture concepts and systems in these spaces not only enhances comfort and safety for students

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and staff but also helps reduce and optimize energy consumption by leveraging the capabilities of smart technologies and materials.

B- The Research Problem:

Buildings generally contribute to at least 40% of energy consumption[1], with educational buildings being among the highest energy consumers. Despite continuous technological advancements, smart systems have proven their efficiency over the long term in terms of life cycle costs and their ability to reduce energy consumption[2]. With the worsening global energy crisis, it has become essential to implement these technologies in buildings. However, the concept of smart buildings and their systems is still seen as merely recreational in developing countries.

Thus, the research problem can be identified as follows: educational buildings consume significant amounts of non-renewable energy during construction and operation, and often neglect the use of smart technologies and systems within the buildings, despite their potential to conserve energy.

C- Research Objectives:

The research aims to design a technological methodology to activate the role of smart materials with the sustainability of the building to increase energy efficiency within the vacuum through the application of smart technology technologies which reduces energy consumption rates in educational buildings. To accomplish this overarching objective, the following specific goals have been established:

1. ☐ **Enhance Awareness and Adoption:** Foster greater awareness and commitment among architects to the crucial role of integrating environmentally compatible smart materials in reducing the environmental impact of interior spaces in educational buildings. This also includes promoting the increased use of glass surfaces in Egypt's hot, dry climate to maximize environmental compatibility and sustainability in these structures.
2. ☐ **Assess Local Impact:** Evaluate the impact of implementing smart materials on a local level, focusing on their contribution to achieving thermal comfort and climate adaptation in educational buildings, which in turn helps to reduce the consumption of non-renewable energy.

D- Research Hypothesis:

The design of an educational building's form, exterior envelope, and the relationships between its internal spaces significantly influence solar energy gain and the building's thermal load, thereby affecting energy consumption rates. The research proposes the hypothesis that implementing smart architecture in educational buildings can achieve comprehensive sustainability, optimize the functionality of interior spaces, enhance overall building performance, and conserve energy. This can be accomplished by designing the building's exterior envelope and internal facades of educational spaces using the latest advanced techniques and smart technological materials, ultimately contributing to sustainability and reducing energy consumption within the building.

E- Research Methodology:

The study employed a combination of inductive and analytical methodologies to establish a design methodology for educational buildings that effectively embody the principles of sustainability. The use

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[1] *Gyeong Yun, K. C. (2014). The influence of shading control strategies on the visual comfort and energy demand of office buildings. Energy Build.p70.*

[2] *Sinopoli, J. (2006). Smart Buildings. Spicewood Publishing. p12, p7.*

of contemporary intelligent technologies and the utilization of intelligent materials are responsible for the establishment of sustainable educational environments.

1 Sustainable Buildings

1.1 Concept and Objectives of Sustainable Buildings

Sustainable building encompasses a range of concepts, which include: The concepts pertaining to sustainable building exhibit variation because of the diverse applications employed. In their publication titled "Green Architecture," Brenda and Robert provided a definition of sustainable architecture as a holistic approach to architectural design, wherein the conscientious consideration of all resources, encompassing materials and energy, is vital in order to attain a sustainable building.

Sustainable buildings can be characterized as structures that prioritize the effective utilization of energy, materials, and water resources, while also demonstrating a harmonious integration with the surrounding environment, hence optimizing the utilization of natural elements. The architectural designs, construction, operation, maintenance, and disposal of these structures are executed with a strong emphasis on environmental considerations. Their objective is to attain both functional and environmental efficiency through the provision of user comfort and the mitigation of environmental consequences associated with construction and usage. The primary goals of sustainable buildings encompass the attainment of integrated design and the establishment of harmonious functional relationships.

- The optimization of energy consumption, the strategic selection and usage of site capabilities
- The optimization of resource and energy utilization while minimizing adverse environmental effects.
- Ensuring the maintenance of indoor air quality and its compatibility with the surrounding environment Minimizing human exposure to hazardous and toxic substances [3]

1.2 Design Criteria for Sustainable Buildings

1.2.1 Site Considerations

The architectural design should be such that the building is compatible with the surrounding land, ensuring that its removal does not result in any alterations to the site, thereby preserving its original condition prior to construction. This criterion encompasses the interplay between the structure and its immediate surroundings, as well as its influence on ecological systems, as identified by the following factors:

- Examining the building orientation to maximize the utilization of solar and wind energy as depicted in Figure 1, then examines the influence of the surroundings on the architectural form and weight of the structure.
- Using locally accessible resources.
- Implementing shading techniques on northern facades to mitigate thermal loads[4].

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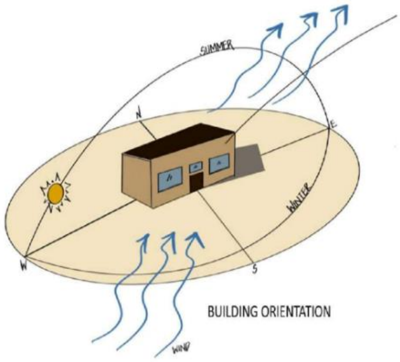
[3] *Marwa Atef Abdel Hadi, (2018), "Towards Sustainable Architectural Formation Using Photovoltaic Cells," master's Thesis, Department of Architecture, Faculty of Engineering, Mansoura University, p. 25.*

[4] *Shaaban, M., (2016), "Future Technology Effect on Learning Environment Design", M.Sc., Faculty of Engineering, Cairo University, P29*



Figer 1 shows the building orientation for optimal use of sunlight.

Source: Building Orientation | Download Scientific Diagram (researchgate.net) Accessed 20/5/2024

1.2.2 Form and Orientation

The geometric configuration of a structure plays a crucial role in determining the extent of shadowing to which it is exposed. According to the data presented in Figure 2, it can be observed that a square form experiences the lowest level of shading on both the facade and the roof components. The level of shading rises proportionally with the complexity of the structure's shape, with the building with an inner courtyard exhibiting the highest degree of shading.

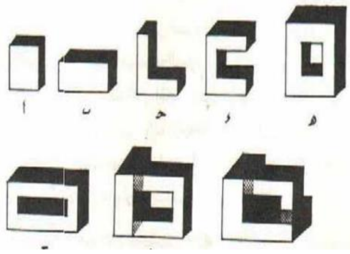


Figure 2 illustrates the impact of the building's shape on the amount of cast shadows.

Source: Osman Attman, green architecture technologies and material, 2007, p55 – 56 Accessed 15/3/2024

Regarding the orientation of the building, the following considerations are considered:

Therefore, it is more advantageous for a building that is oriented longitudinally to face east-west, as depicted in Figure 3. As a result, the southern facade experiences the highest level of heat penetration during the cold winter season, whilst the northern facade encounters the lowest level of heat transmission during the hot summer season.[5].

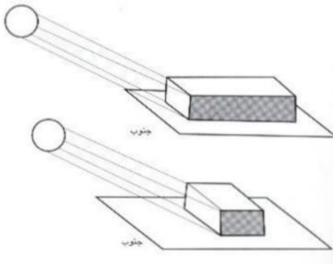


Figure 3 shows the effect of building shape on the amount of falling shadows.

. Source: http://www.arch.hku/research/beer/sustain.htm Accessed (20-12-2022)

The primary goal is to reduce the building's solar loading by carefully arranging it in a manner that minimizes the amount of surface area exposed to morning sunlight. It is advisable to strategically place

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[5] *Sara Abd El Baki Mahmoud, (2014) "Environmental Solution as Main Approach to Sustainable Neighborhood," Master of Science in Architecture, Faculty of Engineering, Ain Shams, university p 43*

larger sections towards the northern and southern regions, as these spatial orientations provide reduced visibility and are more prone to shadowing[6].

1.2.3 Water Efficiency

The attainment of maximum water efficiency can be accomplished by implementing sustainability concepts such as conservation, recycling, and reuse. This includes the utilization of non-potable water for the purpose of irrigating landscaping elements. Incorporating contemporary technologies in sanitary equipment employed within architectural structures and collecting and purifying rainwater for subsequent use.

1.2.4 Energy Efficiency

The construction industry comprises the extensive energy consumption associated with many stages of construction, including extraction, transportation, production, operation, destruction, and recycling. It has become crucial to prioritize the improvement of energy efficiency and the optimization of energy use in order to effectively respond to the growing energy demand and mitigate environmental consequences through the reduction of greenhouse gas emissions.

High energy efficiency can be attained by implementing[7]:

-Taking into account the direction, shape, and placements of apertures.

- Implementation of effective design strategies to mitigate energy consumption in heating and cooling operations.

- The implementation of contemporary insulation and cladding technology in architectural structures.

- This approach involves the utilization of renewable energy sources, specifically solar panels and wind turbines, for the purpose of power generation.

1.2.5 Material and Resource Efficiency

The strategy for material efficiency is achieved through[8]:

- Limiting the depletion of materials from limited sources and using manufactured or alternative materials.
- Reducing construction waste and relying on building deconstruction rather than demolition during the removal phase.
- Relying on local materials and reducing energy consumed in transportation and installation.
- Reusing and repurposing structural components.
- Designing buildings that are easily dismantled and reassembled to utilize and recycle materials.

1.2.6 Innovation in Design

This entails the use of novel approaches to design and construction, taking into account economic, social, and environmental factors during the building design process. The architectural design, implementation, and operation of the building incorporate sophisticated methodologies and strategies with

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[6] Marwa Atef Abdel Hadi, (2017), "Towards Sustainable Architectural Formation Using Photovoltaic Cells," master's Thesis, Department of Architecture, Faculty of Engineering, Mansoura University, 2018, p. 25.

[7] www.sustainabilti.com.what is sustainable development. (Accessed 20-4-2024).

[8] Franchetti, Matthew, (June 2019) "An Analysis of the Relationship between indoor Environmental Quality and Productivity", paper, The Air & Waste Management Association's 107th Annual Conference and Exhibition in Chicago

the objective of minimizing expenses associated with operation and maintenance. Hence, the implementation of this notion necessitates ingenuity and originality in design, which should progress through multiple stages outlined as follows:

- Embracing sustainability as a lifestyle in design.
- Moving towards conserving natural resources.
- Educating building partners to understand and implement sustainable design.

1.2.7 Waste Management

- Reducing waste in various stages of construction.
- Reusing buildings instead of demolishing them.
- Reusing construction waste and industrial waste in construction.
- Disposing of solid waste through burial or incineration.

1.3 Thermal Treatments for Building Envelopes

The primary objective of thermal treatments for the building envelope is to mitigate the flow of heat between the interior and exterior spaces. These interventions are designed to enhance energy efficiency, optimize building comfort, and effectively manage internal temperature, hence resulting in reduced expenses in energy usage. Several key components significantly influence the heat transfer characteristics of the building envelope.[9]:

1.3.1 Attention to envelope design.

Architectural design plays a crucial role in promoting building sustainability and facilitating the integration of renewable energy sources for cooling and heating purposes, hence boosting environmental performance. This objective is accomplished by using design components that prioritize thermal comfort for inhabitants while minimizing energy use. Furthermore, it enables the incorporation of emerging technologies that are fueled by sustainable sources of energy, such as solar and wind power. One of the key elements of sustainable architecture design is the diligent examination of human behavior within the building context.

- Studying the environmental impact on the building envelope and interior spaces.
- Using clean energy sources such as solar and wind.
- Integrating design and the building envelope to conserve resources and support the economy.

1.3.2 Reducing heat transfer to and from internal spaces in the building through:

When choosing exterior colors for the building's surfaces, it is important to select light colors in hot parts during summer to enable effective reflection of sunlight, and dark colors in cold areas during winter to maximize solar absorption.[10].

1.3.3 Using External Shading Devices

The implementation of shading devices serves to mitigate solar radiation and facilitate cooling within a building, thus influencing the energy efficiency of the structure. Several significant benefits of utilizing external shade equipment include:

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[9] *Qasim, Dima Omar (2014)- "Sustainability in Traditional Architecture and its Applications in Contemporary Architecture" - Master Thesis - College of Architecture - Engineering Sciences Series Volume P (36) - Tishreen University.*

[10] *The German Energy Society, (2018)," Planning & installing photovoltaic guide for installers Architects and Engineers" Second edition, London, Earth scan, sterling, p13.*

- Harvesting solar energy through windows and saving energy.
- Reducing the costs of mechanical cooling equipment.
- The ability to reduce glare without closing windows, allowing some light to pass through, as shown in Figure4.
- Engineers address all building openings by reducing the thermal load inside or outside the building.

Figure 4 shows the arrangement of windows horizontally to allow light to pass through the Mercado.
Central del Carman building in France, Source: Building Orientation | Download Scientific Diagram (researchgate.net) Accessed 20/4/2024

1.3.3.1 Sunshades:

The primary function of sunshades is to mitigate the impact of excessive sunlight on the buildings outside surface and internal areas, particularly in situations where the ambient air temperature exceeds the optimal comfort thresholds for human occupants. The primary objectives of sunshades are to:

- Reduce electricity consumption resulting from the use of air conditioning due to high temperatures.
- Help control the level of daylight illumination inside the spaces.

1.3.3.2 Sunshades are divided into three main types:

- Vertical sunshades are used on east and west facades to provide greater protection from the sun and are designed based on the horizontal shadow angle, as in the following figure[11].

Figure5 shows the Vertical sun shading.
Source: https://danpal.com/vertical-sun-shading-plays-the-angles-for-inside-comfort/ Accessed 20/4/2024

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[11] *Mohammad Arif Kamal, "A Study on Shading of Buildings as a Preventive Measure for Passive Cooling and Energy Conservation in Building", International Journal of Civil & Environmental Engineering IJCEE-IJENS, December 2013, Vol:10, P19,* http://www.ijens.org/102406-5252%IJCEE.pdf *Accessed 8-7-2014.*

- Horizontal sunshades are used on south-facing facades and are designed based on the vertical shadow angle as in the following figure.

A figure6 showing the horizontal sun visors on the building.
Source: https://agsshade.com/vertically-mounted-horizontal-sunshades/ Accessed 20/4/2024

- Double sunshades are used on southeast and southwest facades and are designed based on both horizontal and vertical shadow angles[12].

1.3.4 Use of Insulating Materials for the Building Envelope

This entails the utilization of materials possessing thermal insulating characteristics, which aid in mitigating the movement of heat from the exterior to the interior of the structure and vice versa during the year. Ingress of thermal energy into the building occurs via many means such as roofs, walls, windows, and ventilation openings. The primary benefits associated with the utilization of thermal insulation include:

- The structure maintains an optimal temperature for a lengthy duration, thereby obviating the necessity of using air conditioning systems for prolonged periods.
- Thermal insulation serves the purpose of safeguarding and ensuring the structural integrity of a structure against dynamic weather conditions.
- It serves to decrease the required thickness of walls and concrete roofs in order to mitigate heat transfer influx into the structure.[13].

1.4 Impact of the Building Envelope on Energy Consumption:

The architectural structure known as the building envelope functions as a crucial link between the interior space and the external environment that encompasses the building. The building envelope is a crucial factor in mechanically air-conditioned buildings as it effectively mitigates the burden on air conditioning systems, hence resulting in reduced operational expenses for the building. The fundamental principles of climate-responsive design can be succinctly summarized as follows.:

- Limiting heat gained from surrounding heat sources.
- Retaining thermal energy within the internal space.

Numerous architectural scholars have established a set of technical criteria that, when implemented in the construction of the building envelope, effectively attain thermal comfort in buildings without air conditioning systems, while concurrently diminishing the cooling burden in buildings equipped with air conditioning systems. Consequently, the subsequent reduction in energy consumption throughout their operation leads to a decrease in both construction and running expenses during the full lifespan of the structure.[14].

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[12] *John Carmody and Kerry Haglund, "External Shading Devices in Commercial Building", Centre for Sustainable Building Research, University of Mansoura International, site:* http://www.csbr.umn.edu/download/AMCA*. Pdf, Accessed 5—2023.*

[13] *Wael Ahmed Shaaban Abo Neama, (2016) "Applying Sustainability Principles on Architectural Design Concepts in Egypt to Enhance Building Performance," Lecturer in Architectural department, Faculty of Fine Arts, Helwan University, Zamalek, Cairo, Egypt.*

[14] *Sara Abd El Baki Mahmoud, (2014) "Environmental Solution as Main Approach to Sustainable Neighborhood," Master of Science in Architecture, Faculty of Engineering, Ain Shams, university p 43*

2 Smart Buildings

2.1 Origin and Evolution of Smart Buildings

The emergence of smart buildings can be attributed to technical advancements and the growing need for buildings that offer operational efficiency, enhanced comfort, and sustainable practices. The chronological progression of intelligent architectural design can be shown in the subsequent table.[15]:

Time Period	Definition
Ancient Era	The ancient Egyptians tried to use technology in buildings and temples to provide thermal comfort in the architecture of ancient Egypt and Greece.
Middle Ages	Novel engineering methodologies were devised, encompassing the use of domes and architectural arches, thereby offering distinctive resolutions for the purposes of ventilation and illumination within residential structures.
Industrial Revolution	The utilization of technology in buildings experienced a notable surge subsequent to the onset of the Industrial Revolution. This included the incorporation of mechanical systems like steam cylinders and elevators, which resulted in enhanced performance and thermal comfort.
Twentieth Century	Due to technical progress and growing dependence on computers and networks, numerous intelligent architectural solutions have evolved to accomplish conservation objectives and establish centralized management and operation systems for buildings.
Modern Era	In contemporary architectural design, buildings have included sophisticated smart technologies, encompassing smart lighting systems, temperature regulation, security measures, entertainment systems, and integrated communication systems. These technological advancements have been implemented to enhance both comfort and efficiency within the built environment.

Table1 Showing the Evolution of Smart Buildings
Source: Prepared by the Researcher

The advent and progress of computers have facilitated the integration of this contemporary technology into building control systems. These systems were designed with a primary emphasis on the provision of lighting, heating, and cooling in order to establish an optimal atmosphere for persons. Now, the utilization of the internet, artificial intelligence, and big data analytics is prevalent in the realm of smart buildings, where these technologies are being employed to enhance facility management, security, and comfort systems. Further advancements in this domain are anticipated[16].

2.2 Definition and Characteristics of a Smart Building

The Japanese believe that a smart building relies on four aspects: receiving and sending data, supporting building efficiency administratively, ensuring the comfort of the occupants, and providing more services at lower costs. Additionally, it includes rapid response and flexibility for changes, with systems for

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[15] *Sinpoli, J. (2019). Smart building systems for architects. Owners and builders, Oxford, Uk: Elsevier press an imprint of Elsevier.p33.*

[16] wang, S. (2010)," Intelligent Buildings and Building Automation", Spon Press – an Imprint of Taylor & Francis Group, Oxon, USA.

ventilation, air conditioning, smart lighting using fiber optics, and an automatic fire extinguishing system. A smart building can be defined as follows:

A smart building is characterized by the integration of several environmental systems, encompassing energy consumption, temperature regulation, lighting, and sound management. This refers to the capacity to electronically program the building in accordance with shifting environmental conditions and modifications, employing contemporary technical methodologies[17].

One of the most important features of a smart building that enables the realization of smart architecture values and achieves an intelligent architectural building is:

Automation	Virtuality	Sustainability
The aim is to enhance the capacity of architectural settings to autonomously adapt to both internal and external factors, thereby satisfying user preferences, optimizing performance, minimizing operating expenses, ensuring user satisfaction, and increasing productivity. This objective is accomplished by adopting the theoretical framework of automation as a systematic approach and utilizing technological apparatus and sophisticated communication devices as means to realize this notion.	Efficient usage of sophisticated communication technology and the global information network, rapid information sharing techniques, and virtual reality data visualization. The primary objective of this initiative is to provide physical spaces that can effectively accommodate various services, facilitate remote activities, and facilitate the shift towards non-material alternatives. This concept entails the incorporation of virtual habitats into the cosmic community of the information age, hence replacing conventional physical visited surroundings.	The objective is to establish an urban setting that can effectively uphold its environmental obligations and adhere to the principles of conservation and sustainability. The aforementioned objectives are accomplished by the utilization of sustainable, renewable, and ecologically benign energy sources, which contribute to the attainment of environmental efficiency, intergenerational consumption equity, ecological harmony and integration, localized needs satisfaction, and engagement with global concerns.

A table2 showing the characteristics of the smart building.

Source: Adapted by the researcher

One of the key characteristics of a smart building is:

- The building engages with the surrounding environment via automated technologies that facilitate its ability to adapt to both internal and external situations and fluctuations. The building has the capability to adjust the opening and closing of its façades in response to climatic circumstances, as depicted in Figure (7). Additionally, it is equipped with a central computer system that saves pertinent information.

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[17] *Addington, M & Schodeck, D. -" Smart Materials and Technologies for the architecture and design professions "- Architecture Press- an imprint of Elsevier- Linacre House- Jordan Hill- Oxford- UK-2004*

Figure7 shows the building's response to climatic changes for a restaurant in Beijing, China .Source: ACE Cafe 751 / dEEP Architects | ArchDaily, Accessed26/5/2024

- Managing consumption costs by controlling all parts of the building throughout the day.
- The building determines the most effective way to provide a suitable and comfortable environment for users through automation, management, and decision support systems.
- Employing sophisticated control systems to attain optimal practical and economic efficiency while minimizing energy use.
- The building effectively addresses user requirements by implementing sophisticated communication systems that provide rapid links with the external environment through the utilization of computers, fiber optics, and various wired and wireless communication modalities.

2.3 Smart Building Design System

Smart buildings are specifically engineered to leverage contemporary technology in order to optimize the efficiency of infrastructure and offer optimal comfort to occupants within the area. In order to enhance performance and facilitate interaction with users and the surrounding environment, they depend on a fusion of integrated technologies and systems. Smart buildings enhance energy efficiency, provide intelligent control and management, and increase security and safety, playing a significant role in improving quality of life and environmental sustainability. The essential criteria for the design of intelligent buildings encompass:

1. Smart materials and their properties
2. Smart envelopes that serve as a link between the external world and the building's internal space
3. Smart systems for building management

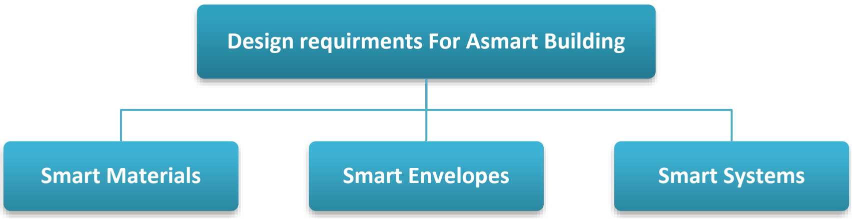

Figure8 Showing the Components of a Smart Building
Source: Researcher

2.3.1 Smart materials

Smart materials can be characterized as materials that exhibit reactive behavior in response to external stimuli through the incorporation of actuators and electrical components into its structure. Smart materials exhibit the ability to generate advantageous outcomes in reaction to diverse stimuli, rendering them well-suited for utilization in a wide range of architectural applications.[18].

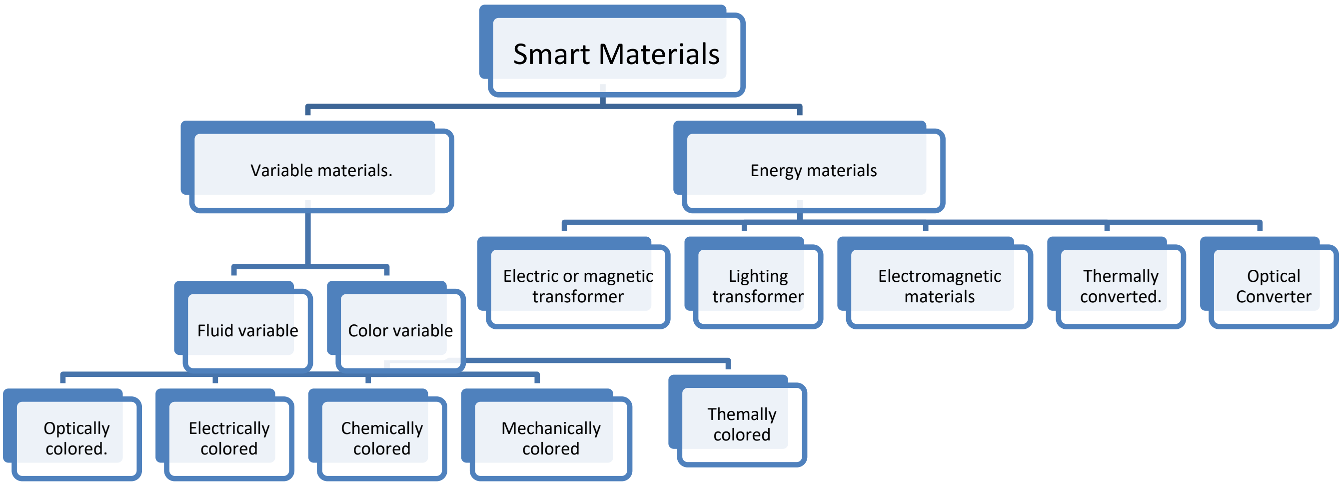

Figure9 Showing illustrating the types of smart materials.
Source: Researcher

Smart materials refer to synthetic materials that possess the ability to perceive and react to their immediate surroundings in a predetermined and desired manner. Biomaterials has the ability to rapidly alter their physical characteristics, including shape, color, and viscosity, in reaction to both natural and artificial stimuli. Additionally, they may exhibit corrective behaviors in some instances. The integration of diverse components, including sensors, processors, and microcomputers, facilitates the attainment of this functionality. Table 3 presents an overview of the attributes exhibited by smart materials.

Characteristics of Smart Materials	Explanation
Ability to change and transform	Adapts to surrounding conditions after the stimulus is removed
Responsiveness	Instantaneous response to external stimuli and data analysis
Sensitivity and adaptability	Can change their physical properties and behavior (such as shape, color, and viscosity) in response to internal or external stimuli
Ability	to operate through electronic systems
Remote control	Capability to be controlled remotely
Lightweight with high durability	Easy to replace and substitute
Self-assessment and self-repair capability	Can repair damaged parts caused by environmental conditions

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[18] *Mayssa Moffeq Alobeidi, Abdula Abdulrhman Alsarraf, (2018), "The impact of the use of smart materials the facades of contemporary building", Published paper, International Journal of Engineering and Technology, Vol 7, No 4, P 59. (Accessed 15-4-2024)*

Self-diagnosis	Possess self-diagnostic capabilities to identify and correct malfunctions by comparing current performance with previous performance
Energy sensing capability	Can store energy during high temperatures and release it when temperatures drop

Table3 illustrates the characteristics of smart materials.
Source: Researcher

2.3.2 Smart Systems

Smart systems within buildings are classified as

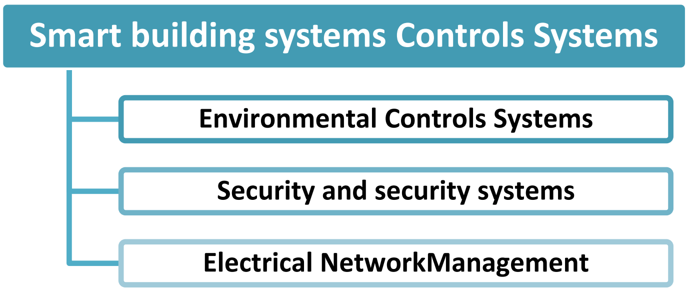

Figure10 illustrates the classification of smart systems within buildings.
Source: Researcher

2.3.2.1 Environmental Controls Systems:

Environmental control systems include several subsystems:

1. **Heating, Ventilation, and Air Conditioning (HVAC) Systems:** These systems are linked to building automation and management systems that help improve indoor air quality. They monitor and adjust temperatures according to user needs, regulate humidity, and control the temperature and airflow speed within rooms.
2. **Building Energy Management Systems (BEMS):** This system coordinates between HVAC systems and lighting control systems through energy management programs to reduce building energy consumption and minimize electrical costs while maintaining a safe and comfortable environment for space users[19].

2.3.2.2 Security and Safety Systems:

One of the key considerations in smart buildings is the provision of security and privacy, while ensuring little disruption to user mobility. This represents a level of integration within the system architecture employed for the safeguarding and management of elevators and emergency alarm systems across diverse environments. The structural integrity of the building is assessed by deploying sensors strategically positioned throughout the building, as depicted in Figure11. The integration of these sensors can be facilitated either during the design phase via simulation programs or post-construction as integral components of management and maintenance automation systems. These systems facilitate the detection of structural flaws by quantifying the maintenance requirements of the structure, monitoring the structural soundness, detecting vibrations in mechanical apparatus, and monitoring temperatures in electrical panels across the entire building[20].

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[19] *Dewidar, K., Mahmoud, A., Magdy, N.& Ahmed, S. (2010). “The role of intelligent facades in energy. First international conference on sustainable buildings and the future International Conference on Sustainability and the Future”: Future Intermediate Sustainable Cities (FISC), Cairo, Egypt, p 25.*

[20] *Abdeljalil, Wijdan Diaa, (2016). "The Role of Smart Materials in Adaptive Facades," Research Paper, Journal of the Arab Universities Union for Engineering Studies and Research, Issue 2, Volume 22, p. 106.*

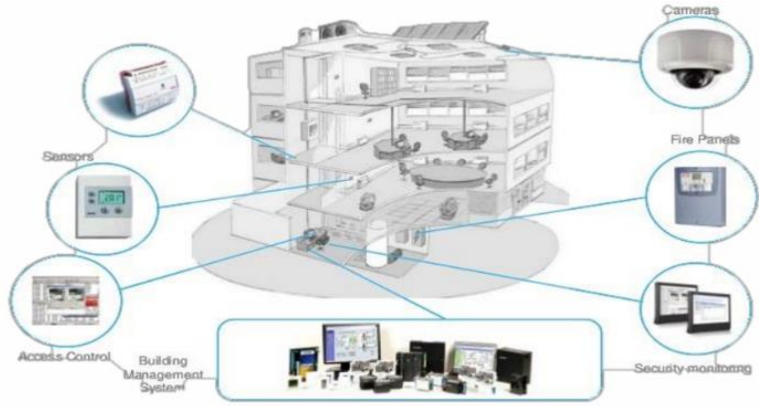

Figure11 illustrates management and monitoring operations through devices.
Source: https://partnerhvacr.id/automation-system, Accessed 16/5/2024

2.3.2.3 Electrical Network Management:

Electrical Network Management Systems include the following systems:

1. **Lighting Systems:** The efficacy of this technology is contingent upon the specific characteristics of the building space and the careful choice of lighting systems that effectively integrate with natural illumination, hence promoting energy conservation. The management and control of lighting are centralized through user-oriented sensor systems facilitated by software. The energy consumption management system employs photocells or sensors to monitor occupancy and autonomously regulate illumination settings to meet the specified requirements.
2. **Switching Control:** The present system autonomously regulates the activation and deactivation of electrical illumination in accordance with prevailing requirements. The lighting units in close proximity to openings function autonomously, with a natural light intensity sensor transmitting data to a control device. This control device subsequently utilizes this data to regulate the electrical current, either by activating or deactivating it, or by adjusting the power level of the electrical current pathway.
3. **Electric Power Management System:** The system comprises a collection of monitoring and control devices that are designed to supervise the distribution of electrical power and furnish data on usage. One effective approach to mitigating energy usage is the identification and implementation of targeted systems or initiatives.
4. **Cable Management System:** The cable acts as a medium for transmitting information, audio, and visual messages in a digital manner. The process of remote message transmission relies on the electromagnetic spectrum[21].

2.3.3 Smart Envelope

The smart envelope comprises a collection of building components that are subject to external weather conditions. These components are designed to carry out various functions in reaction to environmental fluctuations, with the primary objective of ensuring the comfort of individuals within the structure while minimizing energy usage. The intelligent envelope constitutes an integral component of intelligent building systems that are interconnected with other elements within the building, such as the Enveloping Zone. This comprises a network of sensors and actuators, all of which are regulated by a

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[21] *Mayssa Moffeq Alobeidi, Abdula Abdulrhman Alsarraf, (2018), "The impact of the use of smart materials the facades of contemporary building", Published paper, International Journal of Engineering and Technology, Vol 7, No 4, P 59. (Accessed 15-4-2024)*

central Building Management System (BMS). This technology contributes to the reduction of energy consumption and enhancement of indoor conditions through its mechanical and automated response to environmental stimuli. The interaction between smart facades and external changes can occur through the utilization of physical features, such as louvers, or through the implementation of smart materials that possess the ability to alter their properties in response to external conditions.

It features a range of functions in addition to traditional ones, including:

- A thermal valve that resists heat and regulates its flow to and from the building.
- Radiation filtering allows specific spectral wavelengths to enter based on predefined indoor environmental conditions.
- The air barrier to control intentional air intake based on indoor building environment and external conditions, also acting as a barrier for pollutants.
- Energy collector and distributor where systems collect solar thermal energy to enhance the building's thermal performance.
- Dynamic change where the facade's shape changes according to external environment[22].

2.3.3.1 Classification of Intelligent Interfaces

The smart facades are divided into five main sections as follows.

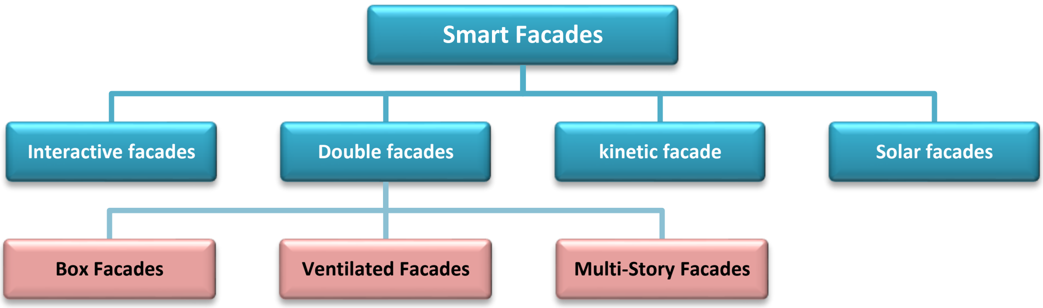

Figure 12 illustrating the types of smart facades.
Source: The researcher

1- Interactive facades

Interactive interfaces are designed to adapt to various environmental circumstances by employing robust design techniques, including the utilization of high-performance glass and the optimization of control systems to achieve optimal building performance. The external screens are automatically adjusted by opening and shutting in response to the intensity of sunlight, thereby optimizing the utilization of readily accessible natural energy for the purposes of lighting and ventilation. Figure 13 depicts the dynamic interaction between the façade and the exterior environment within the Kiefer Technic showroom. This connection is characterized by a predetermined and controlled dynamic process, which incorporates an electrical system for the automated opening and closing of the facade[23].

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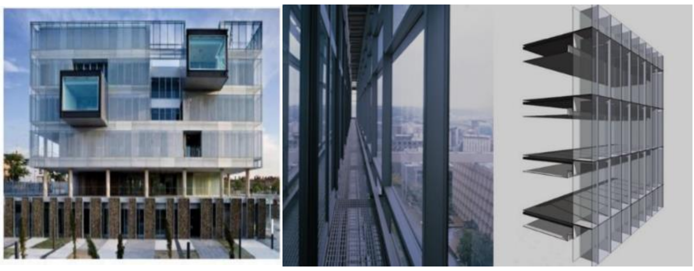
[22] *Dewidar, K., Mahmoud, A., Magdy, N.& Ahmed, S. (2010). The role of intelligent facades in energy. First international conference on sustainable buildings and the future International Conference on Sustainability and the Future: Future Intermediate Sustainable Cities (FISC), Cairo, Egypt, p 15.*

[23] *Abdeljalil, Wijdan Diaa, (2016). "The Role of Smart Materials in Adaptive Facades," Research Paper, Journal of the Arab Universities Union for Engineering Studies and Research, Issue 2, Volume 22, p. 106.*

A figure13 showing the change in the facade shape of units in response to climatic conditions.
Source: www.Lumenhaus.com/desings/index.htm. Accessed19/5/2024

2- Double facades:

Double facades are a notable advancement in architectural design due to their ability to effectively isolate the internal functions located behind the exterior surface. This objective is accomplished through the incorporation of an exterior glass layer onto the building's facade, which serves to enhance both ventilation and sound insulation. The primary distinct categories of double facades encompass box facades, corridor facades, and multi-story facades.



A figure14 showing the box double façade.
Source: www.Lumenhaus.com/desings/index.htm. Accessed16/4/2024

3- kinetic facade

These architectural facades possess the ability to autonomously alter their shape and orientation, thereby regulating the dimensions of their apertures in response to external environmental variables such as temperature, humidity, and wind, as depicted in Figure 15. The presence of these façades exerts a substantial influence on the reduction of building temperatures. It is imperative to incorporate them within the first phases of the design process in order to seamlessly integrate with all components of the building, thereby implementing the principle of automation and minimizing energy usage. The aforementioned façade can be characterized as a viable substitute for conventional building envelopes, offering enhanced comfort to occupants. A comprehensive examination of the various uses of dynamic façades allows for the identification of distinct manifestations of façade movement, including folding, sliding, shrinking, expanding, and morphing. The implementation of these systems in the construction of environmentally responsive façades dates back to the 1920s. Over time, these systems have undergone advancements to align with technological advancements in architecture. This has been achieved through their integration with contemporary building materials, including smart materials.[24].

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[24] *Abdel-Rahman, Doaa. (2019), "The Impact of Using the Digital Revolution and Smart Materials in Designing Interactive Interior Spaces." The Second International Conference of the Faculty of Applied Arts. Innovation and Sustainability in Design. Faculty of Applied Arts, Helwan University. Cairo, p. 15.*

A figure15 showing dynamic facades. In SDU University of Southern Denmark Campus Kolding Source: https://arcdog.com/portfolio/sdu-university-of-southern-denmark-campus-kolding, Accessed 20-5-2024

4-Solar facades

In order to create and harness power for the purposes of heating, cooling, and lighting, these interfaces employ solar cells. The aforementioned cells function as a protective barrier along insulated internal walls that are equipped with pneumatic tubes, so mitigating the risk of photovoltaic units experiencing excessive heat. These establishments actively advocate for the development of ecologically conscious and sustainable structures, so contributing to the reduction of thermal energy use.

Figure16 shows the solar façades in the green building and the use of solar cells.
Source: www.architravel.com/architravel/building/gsw/headquarters, Accessed 20/3/2024

Numerous studies have provided evidence to support the notion that intelligent interfaces are of paramount importance in attaining maximum energy efficiency. Multiple research findings indicate that the incorporation of intelligent interfaces within the framework of sustainable building design is imperative in order to mitigate energy consumption and facilitate the shift towards zero-energy buildings that exclusively depend on renewable energy sources. **Smart interfaces are characterized by a variety of attributes, including:**

- The capacity to alter its own physical and thermal characteristics, such as permeability and absorption.
- The capability to adjust its color and regulate transparency remotely and locally.
- The system has the capability to adjust the shade mechanically and manage the quantity of lighting remotely.
- Implement soundproofing techniques by utilizing materials that disperse and absorb sound waves to provide effective sound insulation.
- Develop an intelligent method to optimize heat insulation in both hot and cold environments[25]

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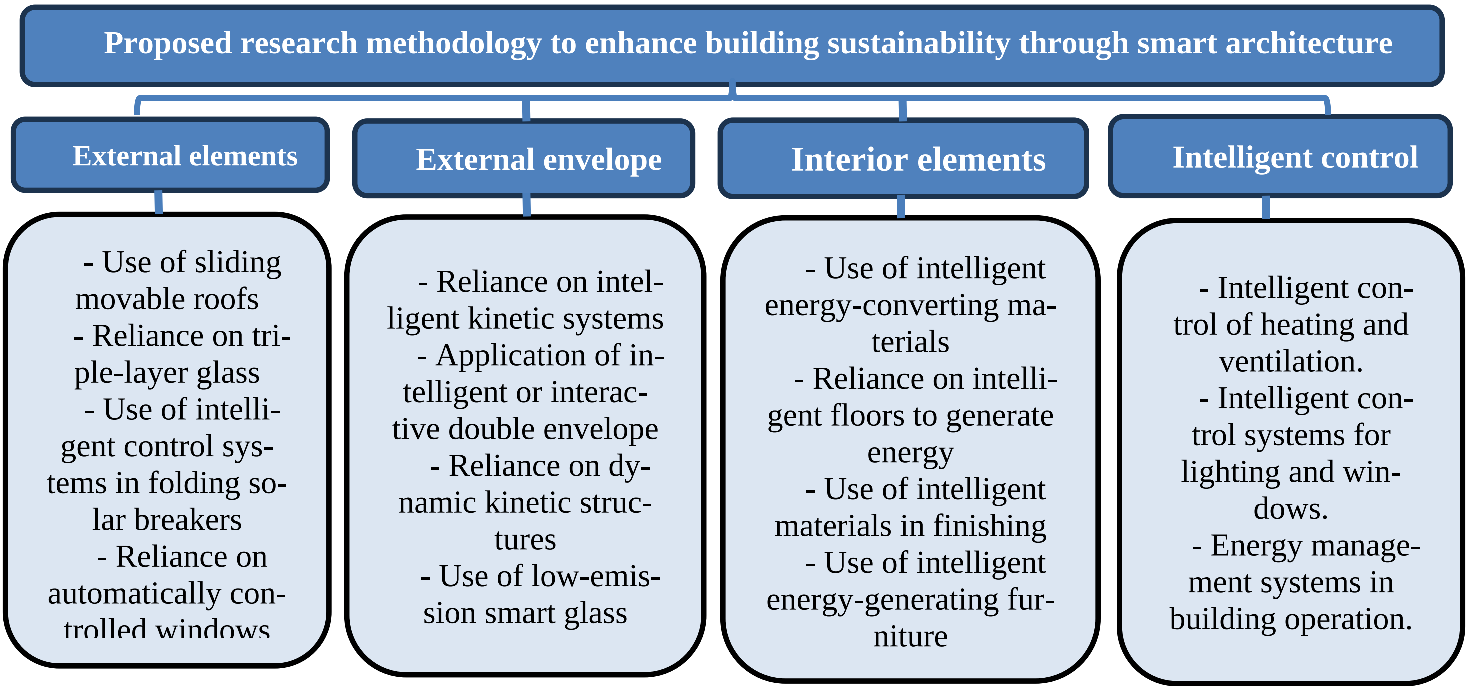
[25] *https://www.researchgate.net/publication/221078634_System_Architecture_for_a_Smart_University_Building,Accessed 20/4/2024*

Research from the theoretical study concludes that sustainability can be enhanced through the application of smart architecture technologies in the design stages of the building for the outer envelope and internal elements that affect its energy consumption, The following figure shows the proposed methodology for the research.



Proposed research methodology to enhance building sustainability through smart architecture

External elements

- Use of sliding movable roofs
- Reliance on triple-layer glass
- Use of intelligent control systems in folding solar breakers
- Reliance on automatically controlled windows

External envelope

- Reliance on intelligent kinetic systems
- Application of intelligent or interactive double envelope
- Reliance on dynamic kinetic structures
- Use of low-emission smart glass

Interior elements

- Use of intelligent energy-converting materials
- Reliance on intelligent floors to generate energy
- Use of intelligent materials in finishing
- Use of intelligent energy-generating furniture

Intelligent control

- Intelligent control of heating and ventilation.
- Intelligent control systems for lighting and windows.
- Energy management systems in building operation.

A diagram showing the proposed research methodology.
Source: The researcher

The other part of the research is based on analyzing models of existing educational buildings and focusing on standards of sustainability and smart architecture strategies within the building by studying the outer envelope and efficient selection of building materials and identifying smart architecture technologies used in lighting and ventilation of the building to provide thermal comfort to users and reduce energy consumption

3 Analytical study

This part addresses a range of global projects that achieve building sustainability standards and depend on smart architecture technologies. These examples will be analyzed to understand how to enhance the building's sustainability through intelligence applications to optimize the use of the internal vacuum function and improve the building's performance and energy saving**.**

The most important criteria for selecting analytical examples are:

- The building should be certified as BREEAM, LEED. el and so to make sure the systems are employed Smart in rationalizing energy consumption.
- All selected buildings are educational buildings implemented over the past 10 years.
- All selected buildings have smart management systems and rely on technological technologies to rationalize energy.

The following table shows the samples of the analytical study.

Project name	year	location	Building Performance Rating
Cornell University	Renewed 2014	Ithaca, New York	Certificate in LEED
Research Support Facility	Established 2016	United States of America	Rated LEED Platinum

Table showing analytical examples.

Source: Researcher

3.1 Cornell University Building Analysis

There is a substantial body of research indicating that the incorporation of intelligent interfaces within the framework of sustainable building design is necessary in order to mitigate energy usage and facilitate the shift towards 100% renewable energy-based buildings.

Figure17 shows the Cornell University Building

Source: https://www.cornell.ed,Accessed 20/5/2024

3.1.1 Project Description:

The university has 2,843 faculty members and 23,890 students divided into 14 colleges. **Some of the most prominent buildings include:**

- **Olin Library**: The university's main library, housing over 14 million volumes.
- **Bailey Hall:** A large lecture hall used for various events, including lectures, concerts, and theatrical performances.
- **Sage Hall**: An academic building housing numerous classrooms and laboratories.
- **McGraw Tower:** A towering building providing panoramic views of the campus and surrounding city.
- **College of Agriculture and Life Sciences Building**: A large building housing many laboratories, study halls, and research facilities.

3.1.2 Exterior Features of the Building:

The design incorporates wood that is extracted from sustainable sources, along with locally sourced and recycled components. The new areas are equipped with radiant floor heating and cooling systems. Additionally, the single-pane glass façade of the original research tower has been replaced with a new curtain wall, resulting in enhanced insulation. The project has been awarded the LEED Gold certification.

Figure17 shows curtain wall on the existing research tower.
Source: https://www.archdaily.com/930324/cornell-university-college-of-veterinary-medicine-weiss-manfredi

Laser wall: The implementation of transmitter and receiver units positioned at a distance of 5 meters, with their repetition and exact alignment with receiver units, enables the creation of a laser wall for the purpose of displaying educational content on the walls of an educational area.

Figure 18 shows laser wall to display educational content on the walls.
Source: https://www.archdaily.com/930324/cornell-university-college-of-veterinary-medicine-weiss-manfredi

3.1.3 Windows and Openings:

Low-emissivity glass is utilized in the design of spaces to mitigate heat infiltration within indoor environments, so serving as a means of thermal insulation and promoting energy conservation. The utilization of radiation-permeable glass design, with integrated sun breakers within the glass, facilitates the selective transmission of light in specific directions while impeding its transmission in other directions. The material exhibits exceptional selectivity, enabling it to effectively insulate heat and conserve energy. It has found extensive application in many environments and scientific laboratories.

Figure 19 shows Radiation-permeable glass design with integrated sun breakers
Source: https://www.archdaily.com/930324/cornell-university-college-of-veterinary-medicine-weiss-manfredi

3.1.4 Efficiency in Material Selection:

- Flat and mobile walls are utilized in the exhibition space and cooperative activity halls, whereby they are equipped with programming capabilities and connected to a personal computer. This integration transforms the walls into display screens that function as computers. Mobile walls function as interactive instructional panels, so establishing dynamic educational environments.
- The effectiveness of soundproofing panels constructed from fiberglass is contingent upon the limited duration of sound reflection resulting from the gap created between the original ceiling. The primary objective of these panels is to absorb and impede sound leakage from the interior, hence minimizing the presence of residual noise within the enclosed spaces.[26].

Figure20 Hanging panels made of fiberglass.

Source: Cornell University College of Veterinary Medicine / WEISS/MANFREDI | Archdaily

3.1.5 Roof Design:

The roof design incorporates a dual-layered glass structure with an inert gas layer positioned between it to effectively absorb external sound waves, so mitigating the presence of street noise in the vicinity of the hall. The roof has been specifically engineered with curved and narrow perforated panels in order to effectively collect surplus heat and subsequently redistribute it as required. This design objective is intended to ensure optimal thermal comfort for the students occupying the area.

3.1.6 Space Furnishings:

- A single chair is used in library spaces, attracting students as it emits sound when approached due to step sensors, stopping the sound once the student sits on it, aiming to create an engaging interaction for students.

Figure21 shows Use the only chair that has sensor

Source: https://linktr.ee/cornelluniversitycals.

- The Interactive Panel is commonly employed in various educational settings such as lecture halls, classrooms, laboratories, and workshops. It is equipped with a seamlessly responsive flat screen that is compatible with computers and data projectors. This panel offers a high-quality image that

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[26] *Abdel-Rahman, Doaa. (2019), "The Impact of Using the Digital Revolution and Smart Materials in Designing Interactive Interior Spaces." The Second International Conference of the Faculty of Applied Arts. Innovation and Sustainability in Design. Faculty of Applied Arts, Helwan University. Cairo, p. 15.*

can be conveniently resized and operated using touch or digital pen input. This technology facilitates the recording and presentation of lessons, resulting in time and effort savings, while also providing learners with a platform to express themselves and foster active engagement.[27].

Figure22 shows The Surface Interactive Desk
source: https://linktr.ee/cornelluniversitycals

- The Surface Interactive Desk is commonly employed in library and classroom environments, featuring copper wire elements and arrays of cells, each consisting of 1010 cells. The surface of the desk is adorned with many air networks. The utilization of a projector facilitates the dissemination of knowledge onto a desk, thereby enhancing the ease and efficiency of the learning process. This technology also accounts for the evolving generational dynamics, fostering connectivity among students and between students and teachers.[28].

3.1.7 Artificial Intelligence Technologies in the Building:

- Hologram technology is utilized to capture lectures in three dimensions, thereby reducing the expenses associated with telephonic classroom interactions. This technology enables students to engage with their instructors remotely, regardless of their geographical location. Additionally, it facilitates attendance at historical events, thereby enabling teachers to deliver lessons and lectures in multiple classrooms worldwide concurrently.
- The implementation of transparent display glass involves the conversion of the display wall into a screen that transmits information. This is achieved by the use of specialized curtains equipped with little black shelves. The purpose of these curtains is to regulate the distribution of light on the whiteboard, ensuring a uniform distribution of glare. Additionally.
- The glass is designed to absorb sound and prevent any leakage. The absorption of photons of a specific wavelength result in the quick emission of corresponding photons as visible light. This phenomenon is employed to highlight emergency guides on walls, which are typically utilized in reception areas. [29].

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[27] *Nouran Adel, (2015), "Smart Learning Spaces Moving Towards a Smart Campus", Paper Published at Engineering research Journal - Faculty of Eng., Shubra, Egypt, P.25.*

[28] *https://cornellsun.com/2021/04/07/as-cornell-prepares-for-in-person-classes-parts-of- zoom-era-learning-might-stay.*

[29] *https://www.researchgate.net/publication/221078634_System_Architecture_for_a_Smart_University_Building,Accessed 20/4/2024*

3.2 Analysis of the Research Support Facility

Figure23 shows Research Support Facility - United States
Source: http://www.aiatopten.org/node/Accessed 20/4/2024

The Facilities Support Center is a Saudi government facility located in Colorado, United States, designed by Haseden Construction Architects, covering an area of 222,000 square meters in a cold dry climate region.

3.2.1 Project Description:

The structure has been constructed in an H-shaped configuration, including two expansive wings, each comprising four levels, as depicted in the accompanying diagram. The architectural design of the building incorporates an east-west axis in order to mitigate heat loads during the summer season and introduce suitable amounts during the winter season. The building spans a distance of 780 feet from east to west and 60 feet from north to south.

Figure24 shows General Site of the Building:
Source: https://www.archdaily.com/148060/the-research-support-facility-rnl-design

Passive design solutions are employed in the building's cooling and heating systems, wherein thermal mass, represented by the thick exterior walls, is utilized to retain energy. A concrete maze is utilized at the basement level beneath the entirety of the building's wings for the purpose of storing heat produced by the complex and passively heating the air during winter seasons. This function serves to mitigate the heat generated by the data center and thus decrease the necessary cooling loads[30].

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[30] *U.S Department of Energy, "Research Support Facility: Leadership in Building Performance", 2010, available online: eere.energy.gov, Accessed 2016*

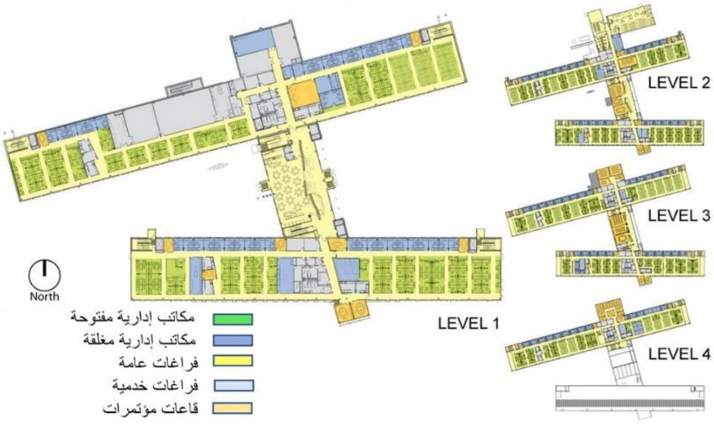

Figure 25 illustrating the horizontal sections of the administrative building to clarify the offices and common spaces.

. Source: http://www.aiatopten.org/node, Accessed 20/3/2024

3.2.2 Exterior Building Envelope:

- The building's exterior is composed of modular units of Insulated Precast Wall Panels.
- The selection and sizing of glass openings are deliberate, employing high-efficiency triple-pane glass windows to minimize heat loads on the building and maintain natural lighting for office areas.
- The eastern and western sides of the building are intentionally intended to limit heat gain during the summer season. The structure's massing is strategically arranged to facilitate air movement and promote the ingress of natural light and ventilation from the exterior.
- Solar ventilation preheating is employed on the southern facades of the three buildings within the project. These facades are equipped with Transpired Solar Collectors for the purpose of pre-heating air, as depicted in the accompanying image.

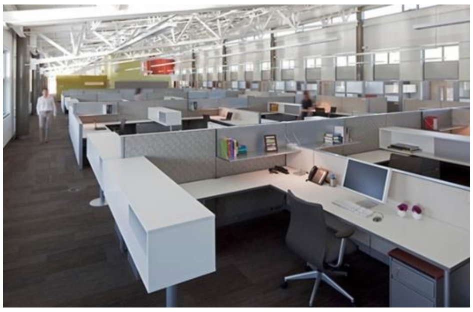

Figure26 shows Natural Lighting for Interior Spaces

Source: http://rnldesign.com/projects/national-renewable-energy-laboratory-nrel-research-support-facility,Accessed 20/4/2024/

Figure27 shows Window Design on Southern Facades with Sun Breakers and Photovoltaic Cells

Source: http://rnldesign.com/projects/national-renewable-energy-laboratory-nrel-research-support-facility, Accessed20/4/2024/

3.2.3 Windows and Openings

- The building has a shallow depth to allow natural light and ventilation to penetrate into the interior spaces.
- In order to facilitate the ingress of sunshine into the interior spaces, sun breakers composed of reflecting material are strategically positioned around the windows on the southern facades. Additionally, the windows dedicated to illumination are constructed with two layers of high-efficiency glass.
- The architectural design of the northern façade incorporates expansive glass windows to optimize the utilization of natural lighting. These windows are equipped with reflective surfaces that effectively transport sunlight further into the interior spaces. The architectural design exhibits a window-to-wall ratio of 28% on the southern face and 24% on the northern facade.

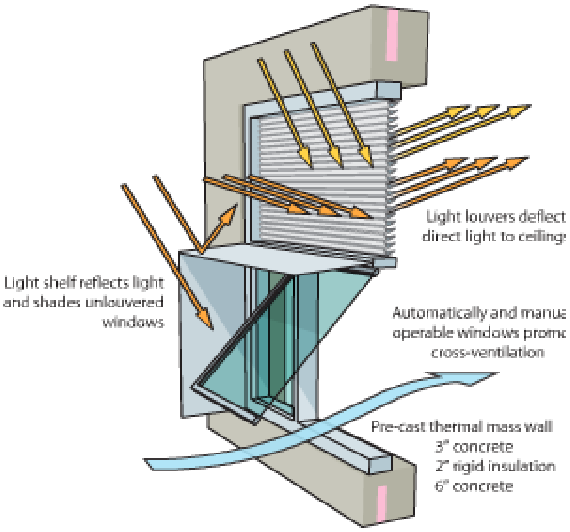

Figure28 shows Window and Sun Breaker Design with Solar Reflective Materials on the Facades
Source: http://www.aiatopten.org/node/103/2016.

- In order to minimize the usage of artificial lighting in the presence of natural lighting, electronic control systems are implemented, alongside the utilization of high-efficiency LED lighting technology.
- Natural ventilation reaches up to 100% of the interior spaces thanks to the use of operable windows and an Underfloor Air Distribution System (UFAD).
- The integration of the UFAD ventilation system with the solar preheating ventilation system on the southern facades of the three buildings in the project is depicted in the accompanying figure. These facades are equipped with transparent solar collectors for the purpose of preheating ventilation.

3.2.4 Efficiency in Material Selection:

- Utilization of local materials such as stones found on-site, which form the external walls.
- The building is well insulated using continuous foam panels with an R-14 coefficient.

3.2.5 Roof Design

- The open horizontal layout design allows for natural light and ventilation to penetrate all spaces through operable windows based on the "Cross-Ventilation" principle.
- Most of the surfaces of the three buildings in the project are covered with solar cells to generate electricity at a 10-degree angle from the horizon and facing the southern façade.

- Equipment and mechanical devices are removed from the building roofs for this purpose, as the generated energy offsets the consumed and wasted energy by the buildings, amounting to approximately 3.4 million kilowatt-hours per year[31].

The following figure illustrates the energy-saving techniques used in the building:

1. Insulated concrete wall panels.
2. Solar arrays on the southern walls.
3. Sun breakers around windows.
4. A concrete maze for energy storage in the basement.
5. Photovoltaic cells installed on the exterior surface for power generation.

Figure29 shows Horizontal Sections of the Administrative Building Showing Offices and Public Spaces
Source: http://www.aiatopten.org/node

3.2.6 Interior Furnishings:

- Motion sensors are used to automatically activate lighting when someone enters a room and turn it off when they leave.
- Smart thermostats can regulate room temperature automatically based on the time of day and the number of people in the room.
- Integrated audio and video systems are used for remote meetings and conferences.
- Digital display screens are used to show real-time information and data[32].

3.2.7 Intelligent Building Technologies:

- The implementation of a complete Energy Management System (EMS) is employed to oversee the energy consumption required for lighting, ventilation, cooling, and heating appliances, as well as the energy produced by solar cells. This system enables ongoing monitoring and evaluation in order to attain optimal building energy efficiency. The implementation of a control system has the potential to mitigate the necessity for industrial lighting through the utilization of occupancy rates to activate or deactivate lighting units. Additionally, it has the capability to diminish light intensity in the presence of incoming natural light.
- Indoor quality sensors can monitor air quality in rooms and adjust ventilation systems accordingly.
- Sensor systems are used to collect data on energy and water usage in buildings and identify areas for improvement.
- Data analytics tools are used to understand building usage patterns and identify opportunities for cost reduction and efficiency improvement.

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[31] *U.S Department of Energy, "Research Support Facility: Leadership in Building Performance", 2010, available online: eere.energy.gov, Accessed 2016*

[32] *Nouran Adel, (2015), "Smart Learning Spaces Moving Towards a Smart Campus", Paper Published at Engineering research Journal - Faculty of Eng., Shubra, Egypt, P. 10.*

Analysis of Sustainability and Smart Systems in the Building:

Criteria		Analysis of Cornell University Building	Research Support Facility (RSF)
Sustainability Building Criteria	**Site Considerations**	Integral relationship between the exterior envelope and the site's natural conditions; Ithaca has a moderate climate with four seasons	The design relies on passive design strategies for heating and cooling suitable for the location
	Form and Orientation	The building's exterior form suits the concept of low-energy construction	The open floor plan design allows for natural lighting and ventilation in all spaces through operable windows with "Cross-Ventilation" principle
	Windows and Openings	- Spaces designed with low emissivity glass. - roof design with narrow, staggered holes.	- North-facing facades with wide glass windows use of sun breakers around Smart Building Standards windows on the southern facades
	Water Efficiency	Storage of hot and cold water in insulated wells for heating and cooling	
	Energy Efficiency	- Use of photovoltaic cells in the library and lecture rooms. - the building acts as an environmental barrier to reduce energy consumption	Most of the three-building surfaces are covered with photovoltaic cells to generate electricity
	Material Efficiency	Designed with fiberglass hanging panels with sound insulation properties; flat and movable walls in lecture rooms	Use of local materials like stones found on-site for the external fence
	Waste Management	Implementation of an external glass envelope	

Smart Building Criteria	**Indoor Environmental Quality**		Roof designed with narrow, staggered holes to provide thermal comfort	Employment of a comprehensive Energy Management System (EMS) to monitor energy consumption
	Thermal Treatments for Exterior Envelope			Use of sun breakers around the windows
	Insulating Materials for Exterior Envelope		Roof designed with double-layered glass as a noise insulator	The building is well insulated using continuous foam boards with an R-14 rating
	Smart Materials	**Smart facades**	Radiation-permeable glass with integrated sun breakers helps reduce energy consumption	
		Sensors	Provision of sensors to control between natural and artificial lighting	Use of sensors to collect data on energy and water usage in buildings
	Smart Systems	**Environmental Control**	Natural ventilation and lighting	
		Security and Safety Systems	Building monitoring system	Building monitoring system
		Electric Grid Management	Comprehensive building management system	Comprehensive building management system
	Smart Envelopes	**Energy collection and distribution**	Generating energy from human movement through sensors	Generating energy from sensors
		Dynamic Change	Integrated smart environmental control system through sensors	Integrated smart environmental control system through sensors
	Smart Building Technologies	**Smart Lighting**	ABB technology in lighting system and remote control between natural and artificial light	Smart control system to reduce the need for artificial lighting, as sensors detect occupancy of spaces
		Smart HVAC System	Use of applications to adjust heating and lighting through smartphones	Use of internal quality sensors to monitor air quality in rooms
		Cleaning Robots	Robot moves to clean spaces and has dust detection sensors	

		Smart Building Services	- Hologram technology for recording lectures - transparent display glass turns display wall into an information screen	transparent display glass turns display wall into an information screen
		Smart Audio-Visual Systems	Emergency lighting on walls by absorbing light photons. use of interactive surface table for easy communication	- Use of analysis tools to reduce costs - integrated audio and video systems for remote meetings and conferences

A schedule showing the comparison between the building of the Cornell University building analysis and the building of the Facility Support Research Center

Source: Researcher

To understand and update sustainable design standards and smart architecture techniques affecting the energy consumption of the building, we review the following tables to analyze selected examples by Licert scale to highlight key aspects affecting the enhancement of the building's sustainability The following table shows the analysis of intelligence techniques in building management for analytical examples

Criteria for evaluating intelligent technologies in building management																
Comparison	**Safety & Security systems**		**Intelligent Building Management Systems**						**Intelligent energy management system**				**Entertainment & Integration System**			**Realized intelligence techniques**	**Percentage**
	Fire Extinguishing Systems	**Smart Camera Network**	**Climate Control Systems**	**Smart Ventilation and A.C Control Systems**	**Smart Lighting Control Systems**	**External Opening Control Systems**	**Smart Sound Systems**	**Smart Water Systems**	**Energy Management and Conservation**	**Using Renewable Energy Resources**	**Environmental Dimension of Energy**	**Self-Sufficiency in Energy Resources**	**Smart Building Monitoring Systems**	**Smart Building Intercom Systems**	**Smart Wi-Fi and Central Dish Systems**		
Cornell University	●	●	◯	●	◯	●	●	●	—	●	○	◯	●	●	●	75/68	**90%**
Research Support	●	●	●	●	●	●	●	●	◯	●	◯	○	●	○	◯	75/67	**89%**

● Good use 5 ◯ Average usage 3.75-2.5 ○ Poor usage 2.5-1.25 — Unused 1.25-1

Table showing a comparison between analytical examples and the application of intelligence techniques in building management.

4 Results of the Analysis

The following table shows the analysis of the criteria for achieving sustainable design and its impact on improving energy efficiency based on analytical examples.

Sustainable design standards and their impact on improving energy efficiency in buildings																				
Comparison	Layout	Building shell						internal environmental quality						Consumption Measurements	Energy Measurement		Power Generation		Designed Criteria Achieved	Percentage
		Roofs		walls		Windows		Thermal comfort				Acoustic comfort	Light comfort							
	Orientation Efficiency	Formation Efficiency	Building Materials	Building Materials	Roof Formation	Insulation Materials	Opening ratio	Glass Material	Humidity & Temperature	Air Movement	Insulation Materials	Solar Radiation Ratio	HVAC equipment	Consumption Measurements	Artificial Lighting	Refrigeration Equipment	Solar Cells	Solar Collectors		
Cornell University	●	●	●	●	◯	●	◯	●	●	●	◯	●	●	○	●	○	◯	●	**90/80**	**88%**
Research Support	●	●	●	●	●	●	◯	●	●	◯	●	●	●	◯	●	●	●	●	**90/87**	**96%**

● **Good use 5** ◯ **Average usage 3.75-2.5** ○ **Poor usage 2.5-1.25** — **Unused 1.25-1**

Table showing a comparison of analytical examples of sustainable design standards.

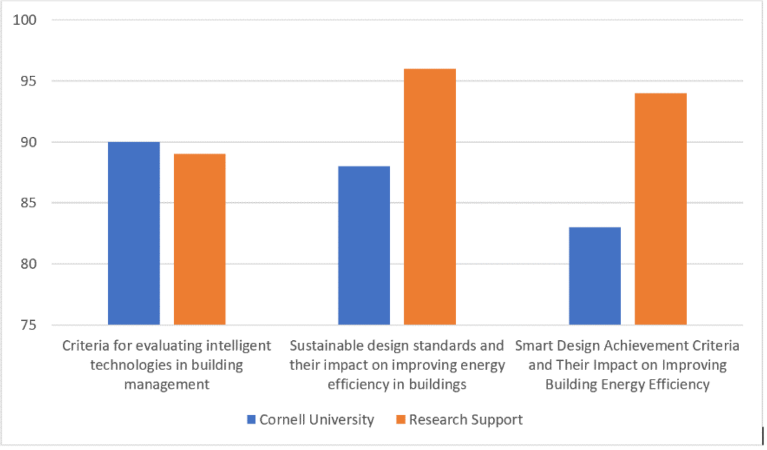
The following table shows the analysis of the criteria for achieving smart design and its impact on improving the building's energy efficiency.

Smart Design Achievement Criteria and Their Impact on Improving Building Energy Efficiency																		
Comparison	**Smart Technology Elements**								**Smart Design Elements**									**Design criteria achieved**	**Percentage**
	Smart Materials	**Dynamic Responsive**	**Automation**	**Sensors**	**Dynamic shading**	**Dynamic covers**	**Double covers**	**Moving solar breakers**	**Self-sensing and adjustment**	**Network connectivity**	**Operation efficiency**	**Self-operating and maintenance**	**Self-managed**	**Reliance on passive technologies**	**Security and safety**	**Protection and durability**		
Cornell University	●	●	◯	◯	○	●	●	◯	◯	●	●	●	●	◯	●	○	**80/6**	**83%**
Research Support	●	●	●	●	●	●	●	◯	●	◯	●	●	◯	●	●	◯	**80/7**	**94%**

● **Good use 5** ◯ **Average usage 3.75-2.5** ○ **Poor usage 2.5-1.25** — **Unused 1.25-1**

Table showing comparison between analytical examples of achieving smart design standards.

The following chart shows the percentages and ways to achieve each example of smart design standards and sustainable design principles while applying technological intelligence technologies to educational buildings.



5 Research Findings

In light of the objectives of the research study, a number of relevant conclusions can be drawn regarding improving sustainability in educational facilities by implementing smart technologies in the design of university space. These results are determined as follows:

1. Applying the proposed methodology to the building achieves high efficiency in rationalizing energy consumption in all building elements.
2. The logic of the relationship between sustainability and smart system technologies lies in the integration and compatibility between them, and the technological revolution represented by intelligence technologies represents a new challenge in finding a design language that reflects

the response of the educational space design to the system technologies.

3. Smart technologies have contributed to the outer envelope to raise its efficiency to include dynamic envelopes, moving and fixed breakers, and the use of smart, movable, openable roofs to contribute to controlling ventilation and natural lighting inside the space, which affects the rationalization of energy consumption.
4. The use of smart control systems for cooling, heating and ventilation in buildings based on sustainable design standards is a key factor in rationalizing energy consumption in the building.
5. The response of smart fixed materials and dynamic moving envelopes significantly reduces the building's energy consumption, by enabling the envelope components to adapt. Energy can also be collected, which contributes to energy-free buildings.
6. Integrating communication technologies and environmental technologies helped improve the efficiency of university spaces and rationalize energy consumption, and applying smart technologies contributed to providing thermal comfort when placed at the surface of the openings of the spaces and addressing the determinants of the climate surrounding the space.
7. The development of intelligence technologies affects university spaces in general and contributes effectively to the development of the educational process.
8. Benefiting from the use of intelligent technology in lighting to maximize the benefit from the use of natural lighting and save the energy used in artificial lighting.
9. Dispensing with many traditional tools and applying intelligence technologies within spaces made it possible to use one space in several activities due to the ease of dividing it into several spaces using different wall technologies.
10. Using virtual intelligence technologies helped students within space to increase and improve the student's imaginative ability, as he now has the ability to interact and communicate with information in a three-dimensional image.

The implementation of intelligent technology in diverse areas of the university significantly enhances design effectiveness across many levels.

- **Space Design**: Utilizing technology on space walls facilitated the development of interactive environments and enabled the simulation of concepts within space.
- **Space Quality**: Selective transmittance walls for sunlight direction achieved thermal comfort within the space, improving space quality and consequently enhancing the occupants' experience as students in absorbing information and as teachers in delivering it in a suitable climate for the spaces.
- **The modification of space furniture**, coupled with the incorporation of interactive boards and tables, resulted in enhanced flexibility inside the area.
- **Lighting:** The utilization of optical lighting and electronic glass facilitated the illumination of the areas through complementary methods, in addition to natural lighting, by harnessing sunlight and transforming it into visible light.
- **Acoustic Comfort**: The implementation of suspended panel technology and soundproof glass, particularly in assembly spaces, has proven effective in mitigating sound leakage and noise disruption inside educational environments, including lecture halls and classrooms.

6 Recommendations

1. - The research recommends that project owners encourage the work team to introduce smart technology into the design process, which affects the same design efficiency and the return on

all construction stages.

2. - The need to educate engineers and users through awareness and guidance campaigns about the importance of relying on smart architecture in building design, which enhances the quality of space and works to reduce the building's energy consumption.
3. - Work on more research and development and support future studies and research to understand the role of smart architecture and its impact on sustainable building design.
4. - The need to apply the proposed methodology in the early design stages of the building, which saves consumption in all construction stages.
5. - Conduct studies by researchers on how to make modern modifications to existing buildings without disrupting the workflow inside the building and in the shortest possible time.
6. - Reducing the overall cost of applying smart architecture technologies, including the cost of training programs, devices, operating systems, etc.
7. - Adherence to the requirements of codes and building evaluation systems, whether local or international, to raise the efficiency of construction and building at the local level and reduce energy consumption.
8. - Strengthening the role of the state in urging the people to deal in an environmentally friendly manner through programs and training courses to encourage the importance of preserving the environment.