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DESIGNING SMART BUILDINGS AND DEVELOPING INNOVATIVE SOLUTIONS

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Abstract . The article analyzes the conceptual, engineering and numerical foundations of smart building design. The issues of integrating building energy efficiency, operational safety, microclimate quality, structural stability and user comfort in a single management environment are considered. The study developed a comprehensive design algorithm for a smart building by interlinking building information models (BIM), IoT sensor networks, predictive management based on artificial intelligence, digital twin, adaptive facade, energy monitoring and cybersecurity approaches. The proposed methodology allows reducing energy losses, increasing the reliability of technical systems and making management decisions based on data from the initial design stage to the operational period.

Keywords: smart building, BIM, IoT, digital twin, energy efficiency, adaptive facade, BMS, artificial intelligence, sensor network, cybersecurity, innovative project solution.

ENTRANCE

In modern construction practice, a building is considered not only as a set of load-bearing and enclosing structures, but also as a complex technical-cybernetic system in which energy flows, information exchange, security signals and human activity are interconnected. The densification of cities, the increase in demand for electricity, the aggravation of climatic factors and the need to reduce operating costs have made the design of smart buildings a strategic direction. According to international energy analyses, buildings account for about 30% of global final energy consumption and also have a very large share in electricity consumption. Therefore, the design solutions of a building determine its economic and environmental efficiency throughout its entire life cycle.

The concept of a smart building is broader than a simple automated building. While automation involves controlling individual engineering systems in specified modes, a smart building collects real-time data, analyzes it, adapts to the external environment and user needs, and makes optimal decisions regarding energy, security, and comfort. In such a system, heating, cooling, ventilation, lighting, elevators, access control, fire alarm, video surveillance, solar panels, energy storage devices, and a digital control platform operate in a single architecture.

The issue of designing smart buildings is particularly relevant in the conditions of Uzbekistan. The long summer heat period in the republic, high cooling loads, natural lighting potential, the possibility of using solar energy, and the presence of seismic zones require an integrated approach to building projects. Therefore, the concept of a smart building should include, in addition to energy efficiency, structural safety, digital monitoring, predictive maintenance methods, and user health.

to develop a scientific and methodological approach to the formation of innovative engineering solutions in the design of smart buildings, linking them to the stages of the building's life cycle, and assessing the effectiveness of design decisions .

Scientific and practical significance of the topic

An important aspect of scientific research on smart buildings is that architecture, construction, engineering communications, energy, information technology and management theory intersect in one area. In traditional design, an architectural-planning solution, a structural scheme and engineering systems are often developed sequentially. In the smart building approach, these parts are combined in parallel and iteratively, based on a data model. As a result, the design solution not only meets construction standards, but also becomes a system that can optimize itself during operation.

From a practical point of view, smart buildings allow reducing energy consumption, predicting emergency shutdowns of technical systems, monitoring indoor air quality, quickly identifying the risk of fire and unauthorized access, as well as creating a comfortable environment for users. With the help of a building management system, temperature, humidity, CO2 content, illumination, number of people and electrical load indicators are monitored for each room, floor or zone. Based on this data, the system generates control commands in real time.

As a scientific innovation, the article considers the chain of "construction - engineering system - digital control - user behavior" as a single design object for designing a smart building. This approach allows assessing the efficiency of a building not by the sum of separate technical indicators, but by an integrated system indicator.

Analysis of literature and normative sources

In international practice, the development of smart buildings is directly linked to energy efficiency, decarbonization and digital transformation policies. According to IEA data, the buildings sector accounts for about a third of global final energy demand. This situation justifies the need to combine passive and active solutions that reduce energy consumption in building design.

The ISO 52120-1:2021 standard aims to assess the contribution of automation, control and technical management functions to the energy performance of buildings. This standard classifies control functions into areas such as heating, cooling, ventilation, lighting, hot water supply, dynamic envelope, electrical systems and monitoring. Therefore, it is important to define automation as one of the initial design requirements when designing a smart building, not as an add-on at a later stage .

The Smart Readiness Indicator concept, developed by the European Commission, assesses the smart readiness of a building in terms of three key functions: optimizing energy efficiency, adapting to user needs, and responding to energy grid signals. This approach demonstrates the need to assess the effectiveness of a smart building not only by the number of devices, but also by the ability of systems to communicate with each other and the management strategy.

The Republic of Uzbekistan has adopted state programs on the transition to a green economy, rational use of energy resources, widespread introduction of renewable energy sources, and development of energy-efficient buildings. The Strategy for the Transition to a “Green

Economy" until 2030 and the State Program for Environmental Protection and a Green Economy in 2025 identify energy-efficient construction, solar panels, and a green building certification system as topical areas.

Research methodology

The research methodology is based on the methods of systematic analysis, comparative assessment, parametric design, energy modeling and multi-criteria decision-making. Initially, the functional composition of a smart building is determined: architectural and design solution, structural scheme, engineering systems, digital sensors, control algorithms, energy sources and security components. Then, the connections between these elements are identified and a single design model is formed.

The criteria for assessing the efficiency of a smart building are energy consumption, indoor environmental quality, safety, operational reliability, investment cost, ease of maintenance and digital flexibility. Each criterion is assessed using a relative weighting coefficient. This allows comparing design options not only in terms of initial construction cost, but also in terms of their entire life cycle efficiency.

The proposed generalized evaluation model is expressed as follows:

$$I\_ab = w1\ E\_s + w2\ C\_m + w3\ X\_f + w4\ R\_i + w5\ K\_x + w6\ M\_t$$

where I_ab - integrated efficiency index of a smart building; E_s - energy efficiency index; C_m - comfort and microclimate quality; X_f - completeness of security functions; R_i - level of digital integration; K_x - cybersecurity and data protection; M_t - predictive maintenance capability; w1...w6 - weighting coefficients of the criteria.

This formula serves as a comprehensive assessment of a smart building project. In practical calculations, weighting factors are determined depending on the type of building. For example, in residential buildings, comfort and safety factors may be higher, in public buildings, energy monitoring and evacuation systems, and in industrial facilities, technological safety and continuity indicators may be prioritized.

Smart building architecture and key components

The architecture of a smart building consists of three main layers. The first layer is the physical layer, which includes structural elements, engineering networks, sensors, actuators and energy devices. The second layer is the information and communication layer; it collects, transmits, stores and performs initial processing of data. The third layer is the control and analysis layer; it implements artificial intelligence algorithms, digital twins, energy optimization and security protocols.

Sensors are the "sense organs" of a smart building. Sensors that detect temperature, humidity, CO2, dust particles, lighting, noise, vibration, smoke, water leakage, electrical load, and human movement reflect the real situation in the building. Actuators, on the other hand, implement system decisions through valves, fans, pumps, dimmers, motorized blinds, electromagnetic locks, and automatic doors.

A building management system (BMS) integrates these elements into a single platform. A BMS should not just be a control panel, but a management environment that analyzes data and optimizes resources. At the design stage, the BMS architecture is selected taking into account open protocols, modular expansion, cybersecurity, and integration with other systems.

Table 1. Functional composition of intelligent building systems

System unit	Basic elements	Project task	Expected result
Energy management	Smart meter, inverter, battery, solar panel	Load monitoring and optimization	Reducing electricity consumption, smoothing peak loads
Microclimate	HVAC, CO2 sensor, humidity and temperature sensor	Real-time room condition management	Increased comfort, health and productivity
Lighting	LED, dimmer, presence sensor, natural light sensor	Adjust lighting as needed	Electricity saving and visual comfort
Security	Fire alarm, ACS, CCTV, evacuation notification	Identify and manage emergencies	Risk reduction and rapid response
Digital control	BMS, IoT gateway, cloud platform, API	Data collection, analysis, and integration	Predictive management and maintenance

Design algorithm

The process of designing a smart building should begin with a target technical specification. The technical specification clearly defines the type of building, the number of users, the target indicators for energy efficiency, security requirements, the level of digital integration and the exploitation strategy. While in a conventional project, engineering systems are selected after the architectural solution, in a smart building project, engineering and digital control components are developed simultaneously with the architectural concept.

The first stage involves a climatic and functional analysis. The area's solar radiation, wind direction, temperature amplitude, dust level, noise sources and traffic flows are studied. This information is taken into account when designing the building orientation, facade design, natural ventilation, sun protection elements and placement of renewable energy sources.

In the second stage, a BIM model is created. A BIM model is not only a 3D geometry, but also a database of information enriched with materials, element properties, engineering systems, equipment passports, maintenance periods and energy calculations. Based on this model, collision checks, energy analysis, lighting simulation, evacuation routes and operating costs are estimated.

In the third stage, the BMS and IoT architecture is selected. The location of the sensors is developed according to the building zones. The function of each sensor, its measurement range, accuracy, communication protocol and data transmission frequency are specified. In the fourth stage, control algorithms are developed: schedule control, availability-based control, control based on the external weather forecast and self-learning control strategies are selected.

In the fifth stage, a digital twin is created. A digital twin is a continuous exchange of information between a real building and its virtual model. Through this approach, the calculation parameters adopted at the design stage are compared with real indicators during the operation period. As a result, the system detects malfunctions early, indicates areas where energy consumption exceeds the norm, and plans maintenance work.

Innovative design and engineering solutions

In a smart building, structural solutions should be integrated with digital monitoring capabilities. For example, in a multi-storey residential or public building, structural health monitoring is carried out by installing vibration, bending, temperature and deformation sensors on key structural elements. This approach is especially important in seismic areas, helping to make rapid post-earthquake diagnostics and safe operational decisions.

Adaptive facade is one of the most important innovative directions of smart buildings. Adaptive facade changes its state depending on solar radiation, external temperature, wind and internal microclimate. Heat ingress is controlled through motorized blinds, electro-chromic windows, ventilated facade gaps, photovoltaic panels and sun protection panels. As a result, cooling loads are reduced in summer and heating losses in winter.

Innovative solutions in HVAC systems include zonal control, heat recovery, variable air flow, CO2 ventilation, geothermal heat pumps, and weather-based pre-control. Such a system saves energy during periods of low occupancy and automatically increases air exchange when the number of people increases.

The lighting system uses LED technology, daylight-dependent dimming, motion sensors and individual control systems. Smart lighting encompasses not only energy efficiency, but also the concept of lighting that is compatible with biological rhythms. For example, changing the color temperature in day and night modes can have a positive effect on human health and productivity.

Fire safety, access control and video analytics systems are integrated into a single emergency control loop. When smoke is detected, the ventilation system switches to smoke extraction mode, elevators are redirected to a safe floor, lighting in evacuation corridors is increased, and mobile notifications are sent to users.

Table 2. Impact of innovative solutions on project effectiveness

Solution	**Scope of application**	**Evaluation indicator**	**Advantage**	**Project requirement**
Digital twin	Operation and monitoring	The difference between real and estimated spending	Early detection of malfunctions	BIM-BMS integration

Adaptive facade	Shell and energy balance	Cooling/heating load	Heat flow control	Facade actuators and sensors
AI predictive management	HVAC and Energy	Peak load, comfort index	Adaptive optimization	Database and algorithm
Constructive monitoring	Load-bearing elements	Deformation, vibration	Security diagnostics	Sensor placement and calibration
Energy storage	Solar energy	Self-sufficiency rate	Reduce network dependency	Battery and inverter selection

Results and discussion

The analysis shows that the effectiveness of a smart building is determined not by the multiplication of separate technologies, but by their proper integration into a single management concept. A building with a large number of sensors, but without data analysis, cannot be a truly smart building. On the contrary, fewer but strategically placed sensors, a quality algorithm and clear management objectives can yield high results.

The most effective areas of smart solutions in residential buildings are energy monitoring, zone control of heating and cooling, lighting automation, water leak detection, secure access and user app control. In public buildings, due to the high flow of people, CO2 monitoring, evacuation systems, video analytics, presence-based lighting and HVAC systems are important.

The economic efficiency of a smart building project is assessed by balancing the initial investment and operating costs. The initial cost may be higher than that of a traditional building, but the life cycle costs are reduced due to energy efficiency, reduced failures, maintenance planning and user convenience. Therefore, it is advisable to use the LCC - life cycle cost approach in investment assessment, rather than being limited to a simple construction estimate.

Three problems are evident in the implementation of smart buildings in local conditions: first, digital systems are often introduced late as a separate department at the design stage; second, there are not enough specialists in operating organizations to analyze BMS data; third, closed protocols from different manufacturers complicate inter-system integration. To solve these problems, it is necessary to specify open protocols, data standards, cybersecurity requirements, and maintenance regulations in advance in the technical specifications.

In addition to energy efficiency, data security is also an important indicator when evaluating a smart building. Because sensors inside the building collect information about user movements, room occupancy and consumption profiles. Such data must be encrypted, managed by permission levels and backed up. If cybersecurity is neglected, a smart building can become a vulnerable object from an operational security perspective.

Table 3. Proposed step-by-step algorithm for designing a smart building

Stage	**Work to be done**	**Result document**	**Control criterion**

1	Climatic, functional and energy analysis	Project concept	Energy and comfort target accuracy
2	Harmonizing BIM models and engineering systems	Coordinated model	No conflicts, complete information
3	Sensors and BMS architecture development	IoT/BMS scheme	Open protocol, expandability
4	Energy modeling and comparison of options	Energy report	Savings compared to the basic option
5	Cybersecurity and exploitation regulations	Security concept	Permission levels, backup, monitoring
6	Launching a digital twin	Exploitation model	Monitoring of real and calculated indicators

Scientific innovation

The study proposed an evaluation model based on an integrated performance index for smart building design. The model evaluates energy efficiency, microclimate quality, safety, digital integration, cybersecurity, and maintenance capabilities in a single system.

The need to organize the exchange of information between BIM, BMS and digital twin from the design stage was justified. This approach reduces the gap between design and operation and allows for the optimization of management decisions based on real-time data.

A classification of innovative solutions for a smart building was developed: energy management, microclimate, lighting, security, structural monitoring, adaptive facade and user interface. Project requirements, performance indicators and practical effects were defined for each area.

Practical recommendations

1. In a smart building project, BMS and IoT systems should be developed simultaneously with the architecture and engineering departments. Adding them as an add-on at the end of the project will cause technical conflicts, excessive costs, and integration problems.

2. The location of sensors should be determined based on room function, human flow, energy load, and safety risks. If each sensor does not have a design function, it will cause excessive data flow and increase maintenance costs in operation.

3. In smart buildings, it is necessary to prioritize open protocols and modular architecture. This will facilitate future equipment replacement, system expansion, and integration of devices from different manufacturers.

4. When assessing energy efficiency, it is recommended to create a comparative model with a baseline conventional building, and compare real consumption indicators with this model during the operational period.

5. Cybersecurity requirements should be included as a separate section of the project documentation, specifying data encryption, user roles, backup, and a disaster recovery plan.

Conclusion

Smart building design is a priority area of modern construction where the requirements for energy efficiency, safety, comfort and digital control intersect. In this case, the building should be considered not as a separate structural object, but as a complex integrated system controlled based on real-time data.

The results of the study showed that to ensure the efficiency of a smart building, BIM, IoT, BMS, digital twin, artificial intelligence algorithms, adaptive facade, energy monitoring and cybersecurity must be designed in an inextricable manner. If these components are not interconnected, even if the building is technologically equipped, it will not be able to achieve a fully intelligent level of management.

The proposed integrated performance index allows for a comprehensive assessment of design options. This index combines the criteria of energy efficiency, microclimate, safety, digital integration, cybersecurity, and maintenance. This serves as a methodological basis for scientifically based, cost-effective, and operationally safe design of smart buildings in the conditions of Uzbekistan.

In the future, it is important to develop smart building certification criteria taking into account local climatic conditions, building types, and operating culture, create national practical recommendations on digital twins, and research energy-efficient facade systems integrated with local building materials.

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