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Interactive Architecture Design as a Respond to Local Climate Challenges

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Abstract

Modern architecture has witnessed radical transformation with emergence of the concept of a smart building, which relay on internet of Things (IOT) technologies to improve the environmental and operational Energy Performance this study aims to explore the impact of interactive architectural design using (IOT) technologies on the development of a smart building in Iraq's hot and dry climate by comparing global and local architectural models. The papers examine five principal case studies-World smart projects and local project covering heritage designs and simi- smart models focusing on green. performance indicators, energetic performance, and climate navigation. The result demonstrated the advantages of interactive smart projects in decreasing internal heat load and energy consumption by as much as 50 percent below conventional buildings. The work also revealed a potential for and local buildings (the Sunni endowment building in the International City Stadiums, towards wise and interactive through consideration of local potentials. and conditions.

Keywords: *Internet of things (IOT), hot and dry climate, environmental sustainability interactive design, environmental sustainability, architecture and hot and dry climates, and smart technology in construction.*

Introduction

The concept of "interactive architectural design" has emerged as a new approach based on the integration of smart digital systems, such as the internet of things (IOT) and environmental sensors, with design processes. This has contributed to the transition of contemporary architecture from static, inert models to interactive models that respond to the surrounding environment, particularly climatic factors. The building is projected as a dynamic object that can interact and react purposefully with the surrounding external variables while giving functional and aesthetic response to the local climate. Over time, cities in the Arab World more broadly and Iraq specifically, still remain devoid of this method of urbanization, which has now entered the lexicon of sustainable planning in light of the increasing necessity for it due to their severe environment system.

This research intends to be a contribution to architectural knowledge in Iraq by providing a comparative framework between theory and practice, oriented towards our local reality with its climatic and economic features. It also offers a reasonable scientific and academic base to sustain the development of a continuous flexible and eco-friendly smart building hence helping to upgrade the quality of the urban in Iraq. One major reason is that the Iraqi environment, its buildings, generally weakly interact with the surrounding climatic conditions, which is reflected in excessive energy consumption and poor internal thermal comfort uniformity to spaces.. The availability of successful global models and interactive design, their applications, remains limited locally. This raises and imported the question: Can interactive design serve as an effective alternative to traditional design and harsh climatic environments?

Research contributes to expanding architectural knowledge about concepts of interactive design related to climate. It demonstrates the efficiency of smart solutions compared to traditional fixed design.

It Provides designers and engineers with analytical tools to make design decisions responsive to the local climate.

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- It offers a knowledge base that can be built upon to develop suitable local models for the Iraqi environment.

Investigate the idea of interactive architectural design in response to the climate.

Comparative study of interactive architectural projects along with traditional projects

Take the influenced scope of application of this model and its local environment as an example.

Introduction of a basic applicable system of interactive design in Iraqi architecture

The section of adduction by changing the interactive architectural design instead static designs through integrating the graphical design method for these types of features to improve the environmental performance of buildings in hot and dry climate by reduce energy consumption and enhancing the thermal pleasure time:

- The research focuses on public or residential buildings within a hot dry climate (cities and central and Southern Iraq)
- It is limited to analyzing executed on known projects and doesn't include direct field applications.
- Projects executed between 2020 and 2025 to present the latest trends.

Research Methodology

This proposal investigates a comparative method by taking suitable examples of interactive and traditional architecture and extends them on environmental and functional base. The results are shown in comparative tables, noting one of the main differences on how each project reacts to dynamic climactic conditions. In this research, a comparative method is used once architectural samples are chosen among interactive and non-interactive architectural products and categorized on the basis of environmental and functional parameters. These results are subsequently displayed in comparative tables, emphasizing the major disparity in the projects' climate response.

Interactive Architecture and Global Models Design

Modern architecture has taken radically new directions in a new world dominated by digital technologies and by an urgent need to confront the climate crisis. Today, every part of a building is repositioned as dynamic systems driven by responses to the environment and occupiers of the space. It (interactive architecture) introduces smart digital systems conceptually in the design in a way that obtains flexible environmental performance depending on time, inhabitance, etc..

The Concept of Interactive Architecture

Responsive architecture isan architectural design technique in which a building or portions of a building changes over time in response to its environment or to the actions of the people using it made possible through smart control and sensing systems By totally disregarding any existing dogma of design - it not using static solutions but dynamic - opening the facades when the temperatures rise, shading when the sun is moving over the sky-. **[1]**.

Supporting Technology for Interactive Design

- Interactive design relies on a number of tools on the systems that allow the building to sense its surrounding environment and react **[2]**:
- Among other things, environmental sensors assess temperature, humidity, illumination, and wind movement.
- Smart control systems rely on the programming on feedback to execute specific responses.
- Internet of Things (IOT): connects all parts of the design system, allowing for automatic data management and decision-making. Kinetic facades are moving elements that change and respond to climatic factors.
- These elements together form an integrated design system that transforms the building from a static entity into an intelligent, evolving, and interactive entity

Architecture and Climate: The Necessary Relationship

Climate is one of the fundamental factors guiding architectural design. Especially in harsh environments like hot, arid regions. Studies show that integrating smart solutions into architectural design can reduce energy consumption by between (30%) and (50%) in some cases **[3]**.

The climatic interaction is not limited to environmental aspects alone but extends to economic and social aspects such as reducing operational cost and improving the quality of life within the building. Therefore, interactive design represents a natural evolution in the course of climatic-responsive architecture **[4]**.

Global Models of Interactive Design

In the last decade, prominent architectural projects have emerged that applied concepts of smart interaction, among the most notable are **[5]**:

- Al Bahr Towers – Abu Dhabi: The project used shaded facades responsive to the movement of the sun, reducing thermal load by up to (50%).
- Media-TIC Building – Barcelona: A smart facade that relies on an air membrane responsive to humidity and temperature.
- The Edge – Amsterdam: One of the smartest buildings in the world, fully reliant on a central intelligent management system connected to motion, lighting, and ventilation sensors.
- The models demonstrate how technology can be integrated to achieve flexible and adaptive architectural performance in different climatic contexts, enhancing the idea of applicability in areas like Baghdad.

Interactive Architecture in the Iraqi Environment

Thermal comfort in Baghdad and other regions in Iraq is a significant issue due to the extreme climate of the region, however, most buildings are not designed to take this into consideration leading to higher energy demand and less comfort. A niche for interactive architecture is evident that adjust itself to the local climate whilst catering to the community demands. This study identifies the main concept and technical elements for such designs in order to build a framework to assess future works in the rapidly changing environmental context of Iraq. [6].

Comparative analysis of local and global cases

This transition from traditional cities to eco-friendly cities is dependent upon smart buildings, which reduce resource consumption and increase operational efficiency with the aid of intelligent control technologies, responsive facades, and renewable energy systems. It is within this local Iraqi backdrop that the immediate need to implement such solutions arises. Especially given the call of the times on environmental issues and economic disparities. Here we discuss a smart and traditional architectural project addressing a number of selected local significant case studies that represent the architectural towards intelligent on the sustainable in the Iraqi environment. **[7]**.

AL Bahr Towers- AbuDhabi (P1)

AL Bahr Towers consists of an innovative prototype for responsive architecture in high-rise buildings with a unique facade system called a masharabiya. The system comprises thousands of moving shutters, which react automatically to the intensity of solar radiation in order to reduce the penetration of heat into the building and improve the quality of natural light. By integrating Internet of Things technologies for real-time monitoring and control of building performance, energy consumption is reduced through an appropriate and cheaper indoor environment. This design serves as a perfect case study for smart architecture functions within hot desert climates **[8]**. (See figure 1)

Figure 1: (: Al Bahr Towers – Abu Dhabi- Project 1) The interactive facade of the Al Bahr Towers building in Abu Dhabi, showing the dynamic facade system for controlling solar radiation. Image adapted from. Attia et al. (2019) and used under a Creative Commons Attribution-Non Commercial 4.0 International (CC BY-NC 4.0) license.

Media-TIC Project – Barcelona (P2)

Media-Tic in Barcelona uses multi-layered smooth facades made of (ETFE) (Ethylene Tetrafluoroethylene), which allow for intelligent control of light and temperature transmission based on ambient environmental data **[9]**. Advanced sensors are used to measure temperature, humidity, and solar radiation intensity, and transmittance is adjusted to achieve a balance between natural lighting and reducing heat load. By Increasing energy efficiency and reducing carbon emissions. This project is an advanced example of integrating the internet of things into architectural design **[10]**. (See Figure 2).

Figure 2: (Project 2) Media-TIC – Barcelona The Media-TIC building in Barcelona's multi-layer smart facade, where the envelope regulates heat and light permeability based on environmental factors.By Fred Romero - flickr.com, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=76782699,By Matt Clark - Flickr: Media-TIC, CC BY 2.0, https://commons.wikimedia.org/w/index.php?curid=17153696

Sunni Endowment Building – Baghdad (P3):

The Sunni Endowment Building is one of the local examples that seeks to improve environmental performance through the use of enhanced building materials and technologies. The building employs double-glazed glass and insulated facades to reduce heat loss and limit the rise in indoor temperatures, in addition to shading systems that minimize direct exposure to sunlight, which is vital in Baghdad's hot and dry climate. Despite the limited use of digital smart systems, the design reflects a gradual trend towards sustainability and energy consumption savings within the local technical and economic capabilities **[11]**. (See figure 3).

Figure 3: (Project 3) Sunni Endowment Building – Baghdad (P3): By the Media Office of the Prime Minister of Iraq - YouTube channel of the Media Office of the Prime Minister of Iraq, [1]. And https://ar.wikipedia.org/w/index.php?curid=9375661

International City Stadium – Baghdad (P4)

The International City Stadium represents one of the modern projects that has begun to adopt renewable energy technologies within the infrastructure of buildings in Iraq. The design includes installation of solar panels on the roofs to generate the electrical energy used to operate the facility, thereby reducing reliance on the traditional electrical grid. Despite the limited use of smart control systems on the internet of things, the project demonstrates a clear trend towards energy sustainability and mitigating environmental impact. This sodium serves as particular example of local potential of adopting smart building technologies in the future **[12]**. (See figure 4).

Figure 4: (Project 4): An exterior view of the International City Stadium – Baghdad, showcasing the architectural facade and crowd capacity, with a focus on integrating solar energy into the design.Source: StadiumDB.com via AroundUs, taken from Wikimedia Commons, licensed under CC BY SA.

An old university building in Baghdad as example The Collage of Science Building- University of Baghdad (P5)

The Collage of Science Building is one of the old university models that represent the "static" design style, as it was constructed in the 1950s and relies on a traditional approach of lighting and ventilation. The bulging currently faces challenges related to high energy consumption and difficulties in maintenance due to the absence of smart sensing systems.

This building represents an ideal model for analyzing "the transition from static to dynamic" by comparing its current performance with a hypothetical scenario for its modernization using internet of things technologies, such as smart environmental monitoring systems, protective maintenance, and the integration of flexible architectural solutions like dynamic facades on green roofs. **[13]** The building shows challenges in maintenance or environmental performance, and its current state can be compared with possible smart applications. It is preferable for the building to be in Baghdad or within the Iraqi environment to reflect the local dimensions of the research.

Proposal for a realistic and analytical university building [14]

College of Science – University of Baghdad (Al-Khwarizmi Building).

Year of construction: 1950s.

Character: Static design relying on natural ventilation systems and flat roofs.

Current issues:

Deterioration of ventilation and insulation systems.

High energy consumption.

Lack of smart monitoring or control systems.

Potential:

Ability to integrate smart systems such as motion and humidity sensors.

Possibility of using artificial intelligence to monitor faults and prioritize maintenance.

Introduction of a dynamic facade system or vertical farming to improve thermal performance.

Methodology for Selecting Case Studies (P1)-(P2)-(P3)-(P4)-(P5)

Comparative analysis is adopted to compare selected projects based on the following criteria **[15]**:

Degree of integration between smart design and environmental response.

Use of sustainable technologies or smart materials.

Compatibility of the design with local climatic conditions.

Applicability to future projects in Iraq.

Reasons for Choosing the Two Local Cases:

(Sunnah Endowment Building – Baghdad (P3))

The administrative building is one of the first projects in Iraq to integrate sustainability elements into its design through:

The double glazing and shading techniques.

The adoption of facades with high thermal performance.

Reducing reliance on artificial air conditioning during certain seasons reflects a smart design approach that relies on materials rather than technology, serving as a practical link between traditional and intelligent architecture in the local context.

(International City Stadium – Baghdad (P4))

The sodium is also fitted with solar panels spanning the roof surface to generate electric power for its own electrical system, so this project displays a welcome rise in the renewable energy domain. It is important because it is also the first real demonstration of solar heating on the scale of a modern government facility that can be used to help sustain the future deployment of smart technologies in administrative or educational buildings throughout Iraq. **[16]**.

Analysis of the Case Studies Subject of the Study (P1)-(P2)-(P3)-(P4)-(P5)

Technical details for each project of the selected case studies (P1)-(P2)-(P3)-(P5)-(P4), the main technical features; materials; smart systems/technologies descriptions of each material or technology As shown in table (1).

Table (1): Main technical characteristics, materials, smart systems, and technologies used, with a description of each element

Item	Al Bahr Towers (P1)	Media-TIC (P2)	Sunnah Endowment Building (P3)	International City Stadium (P4)	(An old university building in Baghdad as a comparison example (P5)
Location	Abu Dhabi - UAE	Barcelona - Spain	Baghdad - Iraq	Baghdad - Iraq	Baghdad - Iraq
Design Type	Interactive smart architectural design	Smart Environmental Facade Design	Sustainable local design with thermal improvements	Sustainable energy design with the integration of renewable energy	A fixed design based on natural ventilation systems and flat roofs
Facade Materials	Dynamic facades with movable mashrabiyas	Multi-layer ETFE Cover	Double glazing, insulated facades	Solar panels, enhanced traditional materials	Traditional materials, lack of insulation
Smart Control Systems	Automatic control system using Internet of Things technology	Integrated Smart Management System with Environmental Sensors	Manual shading system, no digital smart systems	Limited solar power generation system, no comprehensive smart control	Absence of smart monitoring systems or smart control systems
Tempera ture Control	Moving facades reduce solar radiation by 50%	Dynamic Light and Heat Permeability Adjustment	Good thermal insulation and shading to reduce heat ingress	Improved thermal insulation with the use of solar energy	Deterioration in insulation systems
Ventilatio n	Enhanced natural ventilation	Mechanical Ventilation with Smart Control	Limited natural ventilation	Industrial ventilation	Deterioration in ventilation systems
Energy Systems	High efficiency with energy consumption monitoring	Integration with Smart Air Conditioning and Ventilation Systems	Traditional cooling and air conditioning system	Renewable energy generation through solar panels	Traditional cooling and air conditioning system
Monitorin g and Control	Internet-connected sensors for performance monitoring	Environmental Sensors for Monitoring Temperature and Humidity	Manual monitoring without advanced sensors	Basic monitoring excluding IoT systems	Manual monitoring without advanced sensors

Implementation Cost	Elevated due to advanced technology and materials	Relatively High Due to Smart Technologies and Materials	Low to medium, dependent on local materials	Medium with additional costs for solar panel installation	Low to medium reliance on local materials
Maintenance	Periodic technical maintenance with specialized teams	Periodic Maintenance of Sensors and Electronic Systems	Simple traditional maintenance	Maintenance of solar panels and electrical equipment	Simple traditional maintenance
Environmental Sustainability	Very high, reduction in energy and material consumption	High, Smart Control of Energy Consumption	Medium, reliant on material and technology improvements	Medium to high with support for clean energy	Low
Climate Adaptation	Ideal for hot and dry climates	Good with Adaptability to Changing Conditions	Suitable for local conditions with limited technology	Good with partial support for sustainable energy	Low, non-adaptive

Details and Specs of the Case Studies (P1)-(P2)-(P3)-(P4)-(P5)

Sustainability must become a topic where innovations and cooperation across fields are essential to the solution of managing environmental problems. In this, we shall illustrate the case studies details and specifications by setting the purpose of the study and the components of intelligence and sustainability related to case studies [17] such as in table one. (2).

Table (2): Information and Specifications of Case Studies

The symbol	The project	Location	Type of design	Elements of intelligence and sustainability	Objective of the study
P1	Al Bahr Towers	Abu Dhabi	Smart interactive design	Dynamic facades, smart solar control, natural ventilation	Advanced global model for smart design
P2	Media-TIC	Barcelona	Smart environmental design	ETFE facades, environmental sensors, climate response	Integrated smart environmental design
P3	Sunnah Endowment Building	Baghdad	Smart physical design	Double glazing, insulated facades, thermal shading	Semi-smart local model with improved materials
P4	International City Stadium	Baghdad	Smart energy design	Solar panels, renewable energy generation	Smart local model in the field of energy
P5	Old University Building	Baghdad	Traditional design	Traditional materials, full industrial air conditioning	Traditional local model for comparison

Performance Comparison Criteria Between Case Studies (P1)-(P2)-(P3)-(P4)-(P5): Shown in table (3).

Table (3): Performance Comparison Criteria between Case Studies

The standard	P1(The Sea)	P2(Media-TIC)	P3(Sunnah Endowment)	P4(City Stadium)	P5(Traditional Building)
Reduction of thermal load (%)	50%	48%	25%	30%	0%
Energy consumption (%)	45%	42%	28%	35%	100% (Reference)
Type of smart systems	Integrated	Integrated	Limited	High Capacity	None
Local applicability	Low	Low	Medium	Average	High (Traditional)
Adaptation to climate	High	High	Average	P4 (City Stadium)	Low

Comparative analysis of case studies (P1)-(P2)-(P3)-(P4)-(P5): Shown in table (4)

Table (4): Comparative analysis of the case studies subject of the study.

The symbol	The project	Location	Design Type	Elements of Intelligence and Sustainability
P1	Al Bahr Tower	Abu Dhabi	Smart Interactive Design	Responsive facades, solar control system, smart ventilation
P2	Media-TIC	Barcelona	Eco-smart	ETFE facades, climate-responsive, environmental sensor systems
P3	Sunnah Endowment Building	Baghdad	Smart Physical Design	Insulated facades, double glazing, passive climate response
P4	International City Stadium	Baghdad	Smart Energy Design	Solar power generation system, reduction of national grid consumption
P5	Old University Building - Local Example	Baghdad	Traditional Design	Traditional materials, lack of insulation, complete reliance on industrial cooling

Accordingly, we can indicate the following:

- Global projects (P1, P2) show integration between digital technologies and smart materials with high environmental performance.
- The local project (P3) represents a gradual shift in design towards smart environmental performance using locally available capabilities.
- The project (P4) demonstrates the potential for adopting solar energy in modern projects, indicating the feasibility of developing government buildings towards energy independence.
- The traditional project (P5) represents the main challenge in the Iraqi environment and illustrates the gap between reality and aspirations.

Through this study, we can know that the Iraqi environment has realistic examples that can be developed towards full intelligence in buildings, especially if digital technologies are invested in and cadres capable of managing smart systems are developed **[18].**

Results and Discussion

Comparative Analysis Results

Environmental performance and climate response

Global interactive models, such as the AL Bahr Towers (Media-Tic), demonstrated clear superiority and reduced internal temperature on heat load thanks to integrated smart systems, such as moveable facades and solar radiation control systems. The heat load reduction rate reached approximately (45-50%) compared to traditional structures. The Sunni endowment building on the Medina International Stadium showed enhanced performance and thermal insulation and reduced energy consumption by adopting relatively intelligent technologies such as double facades. The appilcation of glass and solar power systems, despite the use of partially digital systems. These results show the potential for raising the employment of smart designs as per local capacities [19].

Energy efficiency

For homes using smart technologies and improved insulation techniques, we see amazing energy savings, often in the range of 30%-50%. These results validate the architectural design measures to enhance energy efficiency, redece running costs, an important issue within the context of Iraq with the lack in energy supply and the raising prices..[20].

Applicability in Iraq

The study explains that applying sustainable and smart design principles into local architecture projects such as Sunni Endowment Building and International City Stadium represents a step towards practical implementation of sustainable design within the local context. This could later be extended to types of advanced digital systemsm such as environmental sensors and IOT applications. But this progress relies upon creation of robust technical infrastructure, trained human resources and adequate legal and institutional assistance 21. As shown in table (5) and (6)

Table (5): Summary of the main results of the comparative analysis.

The side	Main Results	Interpretation and Impact
Environmental performance	Clear superiority of smart models in reducing internal heat by (45-50%)	Improving thermal comfort and reducing the need for artificial cooling
Energy efficiency	Reduction in energy consumption by (30-50%) in smart buildings compared to traditional ones	Reducing operating costs and environmental impact
Local applicability	Existence of a foundation for developing smart buildings locally with technical and institutional challenges	The need for training, awareness, and updating legislation to support development
Challenges	Lack of infrastructure, high costs, weak institutional awareness, impact of climatic conditions	Barriers to the rapid adoption of smart building technologies

Table (6): Recommendations of the study based on the results

Relevant parties	**Objective**	**Recommendations**
Governments, construction companies	**Facilitate the application of smart systems in buildings**	**Enhancing technical infrastructure**
Universities, training centers	**Enhance the skills of engineers and designers**	**Developing human competencies**
Legislative bodies, specialized authorities	**Encourage the adoption of smart design and sustainability**	**Supporting policies and legislation**
Media, government entities, society	**Promote the culture of smart and sustainable buildings**	**Increasing institutional and community awareness**

Discussion of the results in light of the research hypothesis

The study results confirm the validity of the hypothesis stating that "interactive architectural design contributes to improving the environmental performance of buildings in hot, dry areas, reduces energy consumption, and enhances thermal comfort." The research highlights that the shift towards interactive design is not just a technical option but an environmental and economic necessity, especially with the rise of climate change phenomena and the increasing demand for sustainably performing buildings in Iraq.

Challenges and limitations

- Technical limitations: Iraq faces a lack of infrastructure supporting smart system and high cost of advanced devices and software.
- Institutional limitations: week awareness and technical knowledge among engineers and the planners, in addition to slow supporting legislation.
- Environmental constraints: the impact of local climatic conditions such as dust and humidity on the efficiency of smart devices, which requires adaptive design solution

Conclusion and Recommendations

Conclusion

This illustrates how current literature related to architecture shows that intelligent layers integration in smart environment is a design imperative rather than an option bringing this design element to the forefront of the interactive-building design paradigm. It is necessary to have a proper enhancement in efficiency and indoor comfort to face either climate challenges or increasing energy demand, especially in hot and dry climates such as Iraq. According to the researcher with its interactive architectural design in Iraq creates an ideal opportunity to accelerate environmental on economic sustainability and enhance users qualité of life. And support a training program on supportive legislation and something of the most important next phases to ensure the success of this work in infrastructure development.

Recommendations

Enhancing the technical infrastructure by equipping government and educational building with the Smart control system

Developing human capabilities specialized training program in a smart design on the internet of things

Develop a legal and regulatory framework that encourages the adoption of interactive design and sustainability in architecture

Support applied research that focuses on adopting smart assistants to local climatic environmental conditions.

Disseminating sustainable architecture culture and raising awareness among government and private entities about the importance of smart buildings

Develop specialized the training program for engineering and Architects and the field of smart design on the internet of things

Governmental and institutional technologies on renewable energy and urban projects

Updating flows and regulations to encourage the adoption of responsive designs on sustainability in the real estate sector

Contacting ongoing field research to monitor the actual performance of local smart buildings and their development

Carry out continuous field the research to track and improve the real-world performance of nearby smart buildings

Suggestions for Future Studies

Thorough field research to assess local smart buildings' performance following real- world deployment.

Detailed investigation into how renewable energy sources and internet of things systems can be integrated in Iraqi structures.

Creation of sophisticated computer simulation models that account for Iraq's social and environmental features

List of Abbreviations

P1	**Project 1**
P2	**Project 2**
P3	**Project 3**
P4	**Project 4**
P5	**Project 5**

Declarations

Availability of data and materials

Not applicable.

Competing interests

The author declares that there are no competing interests.

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Authors' contributions

The author solely contributed to the conception, design, analysis, and writing of this manuscript.

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