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A multi-criteria decision-support framework for optimising intelligence in high-performance buildings

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Abstract:
This study proposes an exploratory decision-support approach aimed at optimising the performance, spatial quality, and intelligence of high-performance architectural spaces. The methodology combines a structured literature review with numerical modelling based on the Analytic Hierarchy Process (AHP). The analytical framework addresses diverse uses of architectural space and their conceptual foundations, enabling the development of a multidimensional model of building intelligence integrating technological, environmental, and human-centred criteria. Four groups of themes and associated indices were identified and validated through a questionnaire survey conducted with a panel of experts. The results reveal strong interdependencies between the evaluated criteria and confirm the coherence and robustness of the proposed framework. This is further supported by a satisfactory consistency ratio within the AHP model (CR = 7.2%), indicating the reliability of the decision-making structure. The findings highlight the importance of moving beyond automation toward adaptive, data-driven, and user-centred intelligent systems. The proposed approach addresses the lack of reliable decision-support tools in the early stages of high-performance building design and provides practical implications for cost estimation, spatial quality management, environmental strategies, communication systems, and the integration of smart and passive technologies.

Keywords:
high-performance buildings; smart architecture; exploratory approach; Analytic Hierarchy Process (AHP); decision-support framework

1. Introduction

The notion of new technologies is inherently plural and transdisciplinary, permeating all spheres of contemporary life. Architecture is no exception: it explores this intersection as a powerful lever for modernisation and a catalyst for innovation, with significant repercussions for the design, construction, and use of buildings. As demonstrated in previous studies [1–3] and as confirmed by more recent research on the digital transformation of the built environment [4,5], digital technologies are reshaping the way architecture is conceived and produced, liberating creativity from traditional material and physical constraints while enabling substantial gains in time, efficiency, and resource management. Recent advances in artificial intelligence (AI) and Building Information Modelling (BIM) further reinforce this transformation by enabling real-time simulation, predictive analysis, and data-driven decision-making throughout the building life cycle [6,7].

Designing and operating architectural spaces effectively requires integrating diverse characteristics and expressions that account for technological, environmental, economic, and social considerations [8]. This trajectory is reflected in the work of renowned architects such as Kas Oosterhuis, Frank Gehry, Zaha Hadid, and Jean Nouvel, whose projects emphasise proactive, interactive architecture that employs digital devices to foster novel spatial and functional experiences. Beyond these iconic examples, recent studies demonstrate that digital environments enhance user interaction, adaptability, and the spatial performance of contemporary buildings [9].

The successive evolution of digital technologies, combined with functional and environmental imperatives, has generated new forms of architectural expression, producing hybrid or cyber-physical spaces in which physical and digital realities converge. These environments are increasingly supported by sensor networks, IoT systems, and digital twins, enabling continuous interaction between users and the built environment [4,5,10]. This hybridisation requires renewed attention to the notion of use in architecture, encompassing function, appropriation, social practices, and user perceptions. According to Zepf [11], use refers to the social practices associated with a given space, while earlier studies demonstrated that the perception of space results from the interaction between spatial form and the activities it accommodates [12]. More recent research extends this perspective by showing that user experience in smart environments is shaped by real-time feedback, environmental conditions, and adaptive systems [9,13].

A new dimension has thus emerged in architectural design, redefining how space is used and perceived [8,9]. Contemporary architectural space can be described as:

- Anthropocentric: designed by and for users, integrating human-centred design principles and personalisation.
- Healthy and comfortable: providing optimal environmental conditions that support well-being, productivity, and indoor environmental quality.
- Communicative and interactive: enabled by intelligent systems capable of responding to users’ physical and cognitive needs through automation and adaptive control.

- Safe and monitored: connected to integrated infrastructures that ensure safety, monitoring, and environmental regulation through sensors and intelligent systems.

The integration of digital technologies into architecture is currently studied at multiple spatio-temporal scales, although many contributions remain fragmented. Existing research often addresses isolated issues such as the dematerialisation of space, intelligent buildings, comfort and ambience, or conceptual ambiguities in contemporary urban environments [14–18]. However, recent literature also highlights the emergence of data-driven and AI-enhanced approaches aimed at integrating these different dimensions, particularly through digital twins and integrated models of building intelligence [4–7].

Despite these advances, there remains a need for integrated frameworks capable of linking technological innovation with spatial quality and user practices. This gap is widely recognised in recent studies, which emphasise the lack of reliable decision-support tools capable of addressing the complexity of intelligent architectural systems [19].

The objective of this study is to address this gap by proposing a conceptual and methodological framework, hereafter referred to as the Approach, aimed at optimising the efficiency of architectural design and use while clarifying the key concepts of contemporary architectural expression. This framework is intended to function as a decision-support tool capable of providing reliable and structured information for project development processes. It integrates both the physical and digital dimensions of architecture, including structural characteristics, system intelligence, and facility-management strategies, while responding to contemporary challenges of sustainability, spatial performance, and technological integration.

The Approach aims to evaluate the innovation potential of digital technologies in the use of architectural spaces and to identify current limitations in their implementation. To achieve this, the study combines a structured and up-to-date literature review with analytical modelling and expert input. It first establishes the current state of knowledge regarding new uses and perspectives of digital integration in architecture, before proposing a hierarchical framework designed to optimise performance, spatial quality, and building intelligence.

The final part of the paper defines the theoretical foundations of the framework, its themes, indices, and sub-indices, and validates them empirically using the Analytic Hierarchy Process (AHP). This method, which combines quantitative modelling and expert judgment, is applied through structured questionnaires designed to evaluate and weight the identified criteria. The resulting consistency ratio confirms the reliability and robustness of the proposed model.

In summary, this research is positioned at the intersection of digital technologies and architectural space, contributing both to theoretical advancement and practical innovation. By proposing and validating an exploratory decision-support framework, it seeks to help architects, engineers, and policymakers integrate intelligence into high-performance buildings in a structured, coherent, and effective way.

2. Literature review

2.1. High-performance buildings

High-performance buildings are generally defined as facilities that achieve high standards of energy efficiency, environmental sustainability, and indoor comfort. International certification systems, such as LEED (U.S. Green Building Council, 2022), BREEAM (BRE, 2021), and HQE (Alliance HQE – GBC France, 2020), provide benchmarks to evaluate performance in terms of energy consumption, material efficiency, water management, and indoor environmental quality [20–22]. While these frameworks highlight measurable dimensions of performance, they remain limited in capturing emerging notions of building intelligence, particularly the dynamic interaction between space, users, and digital technologies [23]. Recent studies emphasise that high-performance buildings must evolve beyond static metrics to integrate adaptive, responsive, and user-centred strategies for enhanced operational and experiential performance [19].

2.2. Smart and intelligent buildings

The concepts of smart and intelligent buildings extend beyond the traditional high-performance paradigm. Smart buildings integrate digital systems such as IoT devices, automated controls, and Building Management Systems (BMS) to monitor and optimise performance in real time [9]. Intelligent buildings, however, add another layer: adaptability, learning capacity, and responsiveness to changing user needs and environmental conditions [8]. According to Wong [24], they can proactively adjust lighting, thermal conditions, and ventilation based on occupant behaviour and environmental inputs, bridging technological integration with spatial and human-centred design. Recent studies highlight the growing role of AI-driven analytics and digital twins in enabling proactive, context-aware decision-making in building operations [25,26].

2.3. Dimensions of building intelligence

Several key dimensions of building intelligence have been identified in the literature [27,28,19]:

- Technological systems: integration of IoT, AI, and automation to support efficient operation.
- Energy and environmental performance: optimising resource use, reducing emissions, and enhancing resilience.
- User comfort and well-being: ensuring thermal, acoustic, and visual comfort, as well as supporting health and productivity.
- Communication and interoperability: enabling seamless interaction between systems, users, and external networks.

Although these dimensions are widely acknowledged, there is no consensus on how they should be structured, measured, or prioritised. This ambiguity has limited the operationalisation of the concept of building intelligence in both research and practice.

2.4. Identified research gap

Despite growing interest in smart and intelligent buildings, existing literature reveals three persistent gaps:

- Conceptual clarity: the term “intelligent building” is often used inconsistently, with no unified framework for.
- Integration of architecture and technology: most studies emphasise technical systems or sustainability metrics while neglecting spatial quality and human practices.
- Decision-support tools: there is a lack of validated methodological instruments to guide designers and managers in integrating intelligence into buildings.

2.5. Towards an exploratory framework

To address these gaps, recent research has called for new approaches that combine quantitative modelling with qualitative insights [8,19,29]. The Analytic Hierarchy Process (AHP) has been highlighted as a robust multi-criteria decision-making tool, particularly for evaluating complex architectural systems where multiple dimensions: technical, environmental, and human interact. Building upon this line of inquiry, the present study proposes an exploratory framework that integrates:

- Theoretical foundations from contemporary architecture and smart building research,
- Empirical validation through expert surveys,
- AHP-based analysis for prioritising and weighting the identified dimensions of building intelligence.

This framework aims to provide a decision-support tool that guides designers and managers in operationalising intelligence in high-performance buildings, bridging the gap between conceptual clarity, technological integration, and user-centred spatial quality.

3. Methods

The methodological approach adopted in this research aims to conceptualise and empirically test a framework for optimising the intelligence of high-performance buildings. It is designed not only to analyse how digital technologies influence the use of architectural space but also to translate these insights into a structured operational model for practical application. The overall process (Fig. 1) is structured in two main phases:

- A comprehensive literature review and conceptual analysis, to establish theoretical foundations and identify emerging trends in intelligent architecture.
- The construction of an exploratory framework, including themes, indices, sub-indices, and their hierarchical structuring for decision support.

3.1. Phase 1: literature review and theoretical foundations

This phase aimed to establish a robust theoretical base by examining published studies, architectural practices, and conceptual debates on intelligent and digitally augmented spaces [8,19].

3.1.1. Analysis of new uses of architectural space

The review focused on how digital technologies (e.g., IoT sensors, automation, immersive devices, computational tools) transform architectural space. Modern buildings are no longer static; they are dynamic, interactive, and responsive environments accommodating multiple simultaneous uses.

Empirical examples from educational, cultural, healthcare, administrative, and industrial sectors show that users now engage with spaces that are immersive, reconfigurable, and adaptive [30]. These transformations introduce new emotional and sensory dimensions, making space an experiential interface rather than a mere functional container.

3.1.2. Identification of notions and concepts of intelligent space

A taxonomy of architectural concepts was developed, identifying recurring characteristics such as flexibility, adaptability, interactivity, multifunctionality, openness, sustainability, and automation [31–40]. These were organised into nine interrelated concepts, representing the core properties of intelligent spaces:

- Flexibility and fluidity: ability to rearrange layouts and furnishings to meet evolving needs.
- Adaptability and transformation: enabling structural or design modifications over time.
- Interactivity: ensuring real-time dialogue between space, users, and environment via digital interfaces.
- Multifunctionality: supporting reconfiguration of activities within spaces.
- Openness: promoting collaboration, spatial continuity, and perceived spaciousness.
- Sustainability: aligning with energy efficiency and environmental objectives.
- Automation: integrating technical systems for security, energy monitoring, and facility management.

These concepts are interdependent, creating synergies (e.g., transformation closely linked to interactivity and automation), forming the conceptual foundation for the next phase.

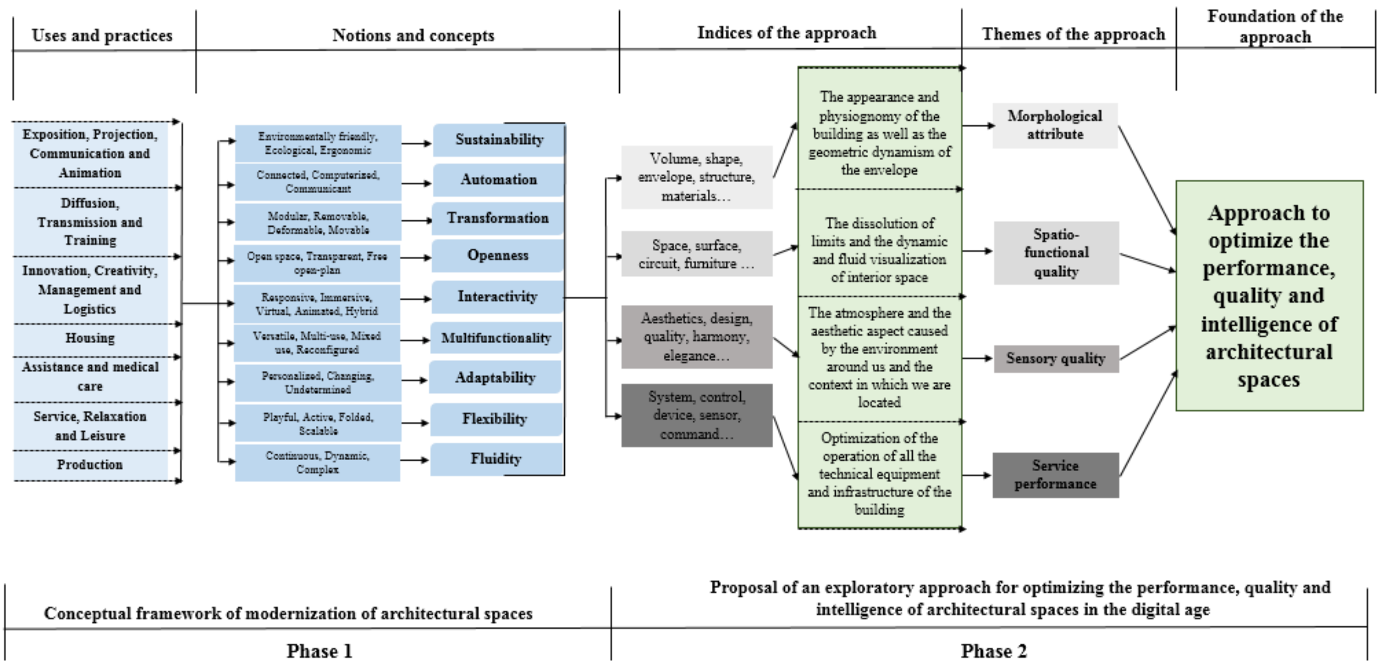

Fig. 1. Synoptic diagram summarising the process of the adopted methodology. Source: Authors

3.2. Phase 2: Development of the exploratory approach

This phase translates the theoretical insights into a structured approach, comprising indices, sub-indices, and thematic groups, intended as a decision-support tool.

3.2.1. State of the art on evaluation criteria

A targeted review of evaluation frameworks for intelligent buildings and spaces was undertaken. The majority of existing studies focus on isolated aspects such as energy performance, comfort, or automation [14,15]. However, few provide a holistic view that simultaneously integrates environmental, technological, economic, and socio-cultural dimensions [8,19] (Table 1). This study seeks to address this gap by consolidating dispersed knowledge into a multi-dimensional framework that reflects both global advancements and local contextual needs. Keywords such as intelligent space, performance optimisation, digital architecture, and user-centred design guided the literature survey.

Table 1. Analysis of articles relating to the criteria necessary to improve the intelligence of architectural spaces. Source: Authors

Source	Object of Study	Methodology	Main Content / Results
Fathian & Peyman [41]	Identification of key factors of intelligent buildings and development of an evaluation framework	Literature review, conceptual modelling, and expert surveys in Iran	Development of an evaluation model structured into eight domains. Weighting of factors through expert surveys and validation using mathematical equations.
Zhen et al. [42]	Development of IBAssessor: a multi-criteria decision-making tool for lifetime energy efficiency assessment of smart buildings	MCDM approach using quantitative energy-time consumption indicators (ETI)	Creation of IBAssessor based on 10 groups of KPIs. Demonstrative application for smart building performance assessment.
Zhen et al. [43]	Comparative review of intelligent building assessment methods to establish a more beneficial construction approach	Critical review of six rating systems; application of Analytic Network Process (ANP)	Proposal of an alternative evaluation framework integrating ANP to better weigh criteria and enhance decision-making reliability.
Wong & Li [24]	Selection and prioritisation of evaluation criteria for intelligent buildings	Expert and practitioner surveys combined with the Analytic Hierarchy Process (AHP)	Identification of relevant evaluation criteria through surveys. Prioritisation and weighting of criteria using AHP.
Reda Abdin & Badr Ahmed [44]	Evaluation of intelligent building performance and use of advanced technologies for environmental goals	Comparative study of the IBI method vs. proposed Intelligent Building Features approach; surveys in Egypt and internationally	Proposal of an approach based on automation, sustainability, and responsiveness. Comparative analysis of 10 indices with 378 elements.
Alwaer & Clements-Croome [45]	Development of a multi-attribute tool to assess sustainable smart buildings	AHP-based SuBETool model applied to case studies	Identification of main issues in sustainable smart buildings. Creation of SuBETool for measuring sustainability.
Kaklauskas et al. [46]	Development of a multi-criteria integrated model of intelligent built environment (MCAIBE)	MCDM framework integrating multiple stakeholders and objectives	Proposal of MCAIBE addressing economic, comfort, aesthetic, environmental, legal, and social objectives simultaneously.
Kaya & Kahraman [47]	Comparative evaluation of smart buildings using AHP and TOPSIS	Application of two MCDM methods on case studies	Identification of five groups of criteria: Engineering, Environmental, Economic, Socio-cultural, and Technological. Both methods yielded consistent results for best alternative selection.
Brad & Murar [48]	Introduction of IoT technologies for advancing smart buildings	Literature review and experimental IoT applications	Development of IoT-based technologies and demonstration of their role in improving smart building performance.
Andrey & Eugeny [49]	Proposal of a Building Intelligence Quotient simulation process	Development of a computational tool integrating hardware, software, and communication networks	Simulation process to calculate and compare building intelligence levels for decision-making.
Arditi et al. [14]	Taxonomy of smart building characteristics based on professionals' perspectives	Questionnaire survey and Kruskal-Wallis statistical analysis	Identification of domains and variables associated with smart buildings. Classification of perspectives in a structured taxonomy.
Banani et al. [50]	Framework for sustainable non-residential building assessment criteria in Saudi Arabia	Comparative review of five methods: surveys with Saudi experts, AHP application	Definition of 9 criteria and 36 sub-criteria. Use of AHP to prioritise relative importance.
Bonyad et al. [51]	Proposal of regenerative architecture indicators for research-education buildings	Framework development tailored to the Tehran context; expert surveys with AHP weighting	Creation of a four-dimensional indicator system. Estimation of the importance of indicators using AHP.
Osama [52]	Conceptual clarification of smart buildings	Development of a multi-criteria framework with 68 sub-factors	Classification of smart buildings into 10 environmental quality modules, with added facilities. Proposal of a two-level evaluation framework.
Benjamin & Dylan Del Rio [53]	Critical examination of smart home technologies, promises, and risks	Semi-structured expert interviews and literature review	Identification of 13 categories of smart technologies (267 options). Analysis of 13 benefits and 17 risks/barriers of smart homes.

Source	Object of Study	Methodology	Main Content / Results
Malagnino et al. [54]	Integration of BIM and IoT for sustainable smart environments	Comprehensive literature review and modular architecture proposal	Establishment of a knowledge base on smart/sustainable environments. Proposition of modular BIM-IoT architecture inspired by best practices.
Azouz & Elariane [55]	Retrofitting existing office buildings using smart technologies to improve energy efficiency.	Applied study and descriptive survey on office buildings, analysis of potential energy savings through smart technologies	Case studies and surveys on office buildings showing significant energy savings after integrating smart technologies (automation, lighting, HVAC control). Identified barriers such as cost, complexity, and retrofit feasibility.

The reviewed studies reveal a clear evolution in smart building evaluation methods over time. Early research primarily focused on identifying critical factors and proposing basic scoring models, thereby laying the conceptual groundwork for subsequent frameworks [41–43].

During the period 2010–2016, increasing attention was given to the application of multi-criteria decision-making (MCDM) methods such as the Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), and TOPSIS [45,47,50]. These approaches highlighted the complexity of interdependent architectural, technological, and environmental dimensions, with particular emphasis on sustainability and context-sensitive evaluation.

In more recent years, the focus has progressively shifted toward the integration of advanced digital technologies, including the Internet of Things (IoT), Building Information Modelling (BIM), and automation systems [14,48,52]. This transition marks a move from purely conceptual models toward applied and experimental frameworks, where socio-cultural, economic, and regulatory dimensions are increasingly considered alongside technical performance.

More recently, research has expanded to incorporate data-driven and user-centred approaches, reflecting the growing importance of adaptability and user experience in intelligent environments. Studies such as Benjamin and Del Rio and Malagnino et al. [53,54] examine intelligent spaces in terms of risks, opportunities, and interoperability, while more recent contributions emphasise the role of artificial intelligence, digital twins, and real-time data analytics in enhancing building intelligence and performance [6,7]. These developments underline the increasing importance of real-time adaptability, user feedback, and experiential quality in contemporary smart architecture.

Building upon this trajectory, our proposed exploratory framework employs the Analytic Hierarchy Process (AHP) to integrate both technological and experiential dimensions. Through hierarchical structuring and expert-based comparisons, the model assigns relative importance to spatial, morphological, service-related, and sensory qualities. Unlike prior approaches that often privilege technical or sustainability criteria, this framework highlights the creative and imaginative dimensions of digital architecture. In doing so, it bridges quantitative assessment with qualitative user perception, offering a decision-support tool for both design optimisation and long-term performance in intelligent buildings.

3.2.2. Selection of indices

From this corpus, indices were identified and selected according to rigorous criteria [56]: relevance, objectivity, precision and sensitivity, availability and representativeness, and simplicity. The analysis also examined correlations between indices to avoid redundancy and to ensure a coherent taxonomy (Fig. 2).

3.2.3. Taxonomy of indices and thematic groups

The retained indices were classified into four thematic categories (Fig. 2):

- Environmental indices: addressing sustainability, energy efficiency, and ecological integration.
- Social and cultural indices: focusing on user comfort, adaptability, inclusiveness, and cultural appropriateness.
- Economic indices: relating to resource optimisation, cost-effectiveness, and life-cycle performance.
- Technological indices: covering automation, interoperability, digital connectivity, and smart management systems.

Beyond this initial classification, a complementary grouping was established to better capture the qualitative dimensions of intelligent space. These were defined as four perspectives:

- Morphological attributes: dealing with spatial form, flexibility, and transformation.
- Spatio-functional quality: focusing on adaptability of functions, interactivity, and multifunctionality.
- Sensory quality: addressing immersion, comfort, and experiential dimensions of space.
- Service performance: ensuring sustainability, security, monitoring, and optimisation of building operations.

3.3. Towards the construction of the approach

By integrating both phases, the study proposes a methodological framework bridging theory and operational tools. The framework:

- Serves as a decision-support tool for architects, planners, and facility managers.
- Is refined through expert consultations, surveys, and AHP-based analysis, which assign weights to indices and validate the hierarchical structure.
- Ensures the framework reflects both technological and human-centred dimensions, bridging quantitative assessment and qualitative perception [57].

4. Investigative tools

To validate the proposed framework, it was necessary to establish a systematic method for aggregating and weighting the selected themes and indices. Three families of aggregation methods are distinguished in the literature: complete, partial, and local aggregation [58,59]. Among these, the complete aggregation method, also known as the unique synthesis criterion, was retained, as it eliminates incomparability and ensures a consistent evaluation process.

Several techniques belong to this category, including SMART, TOPSIS, SAW, and AHP. Among them, the Analytic Hierarchy Process (AHP) was selected due to its robustness and widespread application in complex decision-making problems across disciplines such as engineering, architecture, and sustainability assessment [60]. AHP is particularly suitable for this research as it allows the decomposition of a complex problem into a hierarchical structure, facilitates pairwise comparisons between criteria, and enables the quantification of qualitative judgments while ensuring consistency through the calculation of a consistency ratio (CR) [61].

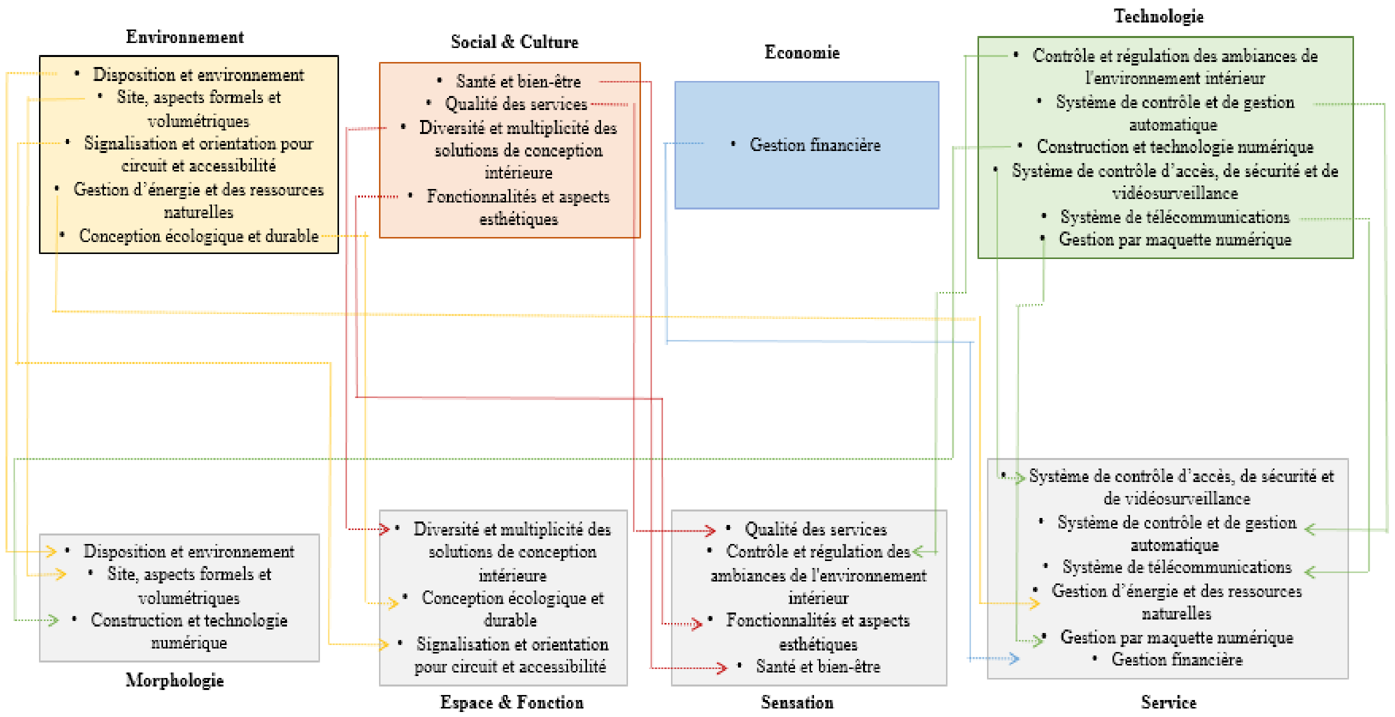

Fig. 2. Interaction between the different indices. Source: Authors

Furthermore, recent studies emphasise the relevance of AHP in evaluating intelligent and high-performance buildings, especially when integrating multiple dimensions such as technological performance, environmental efficiency, and user experience [8]. Its ability to combine quantitative modelling with expert judgment makes it particularly appropriate for assessing the multidimensional nature of building intelligence.

Applying AHP in this study enables a structured prioritisation of the selected indices and supports the evaluation of the impact of digital technologies on architectural design, spatial use, and building performance (Fig. 3).

4.1. Expert selection and data collection

To ensure the reliability and validity of the results, the study involved a panel of experts selected according to the following criteria:

- Proven expertise in architecture, building technologies, or digital systems.
- Professional or academic experience in design, research, or building management.
- Familiarity with smart building concepts and digital integration.

The selection aimed to ensure diversity of perspectives while maintaining a high level of expertise.

4.2. Preliminary validation

A first stage involved eight experts, consulted between December 2020 and January 2021. Due to COVID-19 restrictions, this phase was conducted online. The objective was to validate the conceptual structure of the framework, including its themes, indices, and sub-indices. The experts confirmed:

- The coherence and clarity of the proposed framework.
- Its alignment with the current state of knowledge in intelligent and digital architecture.
- The relevance and completeness of the selected themes.
- The scalability and adaptability of the indices.

They also emphasised the importance of reconsidering architectural design approaches in light of rapidly evolving digital technologies.

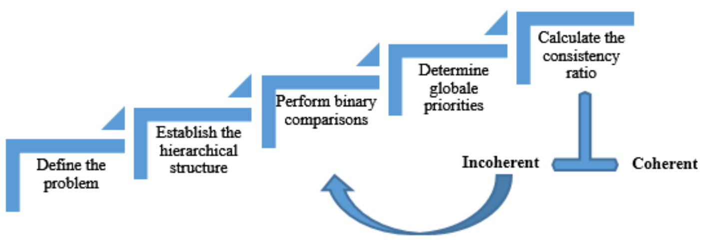

Fig. 3. Steps for applying AHP- analytic hierarchy process. Source: [60], adapted by authors

4.3. Empirical investigation and AHP application

The second stage consisted of an empirical investigation involving twenty experts, including the initial eight participants. This phase was conducted in February 2021 through a combination of online and in-person sessions. Participants were asked to perform pairwise comparisons of the identified indices using Saaty's nine-point scale [62]. This process allowed the transformation of qualitative expert judgments into quantitative values representing the relative importance (weights) of each index.

The AHP procedure involved:

- Construction of pairwise comparison matrices.
- Calculation of priority vectors (weights).
- Verification of consistency using the Consistency Ratio (CR).
- Aggregation of individual judgments into a collective decision model.

The resulting weights provide quantitative evidence of the relative influence of digital technologies on architectural design, spatial practices, and building performance (Table 2).

4.4. Methodological contribution

This methodological approach contributes to the field by:

- Providing a structured and replicable framework for evaluating building intelligence.
- Integrating expert knowledge with quantitative modelling.
- Bridging the gap between technical performance metrics and spatial/experiential qualities.
- Supporting decision-making processes in the design and management of intelligent buildings.

Table 2. Average responds to AHP questionnaires. Source: Authors

Please circle the most important perspective/indices per pairwise comparison by marking X in the appropriate scale	A scale of nine degrees (1-Equal importance, 3-Moderate importance, 5- Strong importance, 7- Very strong importance, 9- Extreme importance, 2,4,6,8- intermediate values) [45].								
P1- Morphological attributes P2- Spatio-functional qualities P3- Sensory qualities P4- Service performance	Degree of importance								
	1	2	3	4	5	6	7	8	9
P1 Vs P2	X								
P1 Vs P3		X							
P1 Vs P4		X							
P2 Vs P3				X					
P2 Vs P4	X								
P3 Vs P4	X								
P1.1- Disposition and environment P1.2-Site, formal and volumetric aspects P1.3-Construction and digital technology	Degree of importance								
	1	2	3	4	5	6	7	8	9
P1.1 Vs P1.2					X				
P1.1 Vs P1.3				X					
P1.2 Vs P1.3				X					
P2.1- Diversity and multiplicity of interior design solutions P2.2- Ecological and sustainable design P2.3- Signaling and orientation for circuit and accessibility	Degree of importance								
	1	2	3	4	5	6	7	8	9
P2.1 Vs P2.2				X					
P2.1 Vs P2.3				X					
P2.2 Vs P2.3				X					
P3.1-Quality of services P3.2-Control and regulation of indoor environment atmospheres P3.3-Functionality and aesthetic aspects P3.4-Health and well-being	Degree of importance								
	1	2	3	4	5	6	7	8	9
P3.1 Vs P3.2				X					
P3.1 Vs P3.3			X						
P3.1 Vs P3.4					X				
P3.2 Vs P3.3				X					
P3.2 Vs P3.4						X			
P3.3 Vs P3.4				X					
P4.1-Access control and security system P4.2-Video surveillance system P4.3-Automatic control and management system									

Please circle the most important perspective/indices per pairwise comparison by marking X in the appropriate scale	A scale of nine degrees (1-Equal importance, 3-Moderate importance, 5- Strong importance, 7- Very strong importance, 9- Extreme importance, 2,4,6,8- intermediate values) [45].								
P4.4-Telecommunications and data system P4.5-Management of energy and natural resources P4.6-Management by digital model P4.7-Financial management	Degree of importance								
	1	2	3	4	5	6	7	8	9
P4.1 Vs P4.2						X			
P4.1 Vs P4.3				X					
P4.1 Vs P4.4			X						
P4.1 Vs P4.5				X					
P4.1 Vs P4.6					X				
P4.1 Vs P4.7		X							
P4.2 Vs P4.3				X					
P4.2 Vs P4.4				X					
P4.2 Vs P4.5			X						
P4.2 Vs P4.6			X						
P4.2 Vs P4.7			X						
P4.3 Vs P4.4			X						
P4.3 Vs P4.5			X						
P4.3 Vs P4.6				X					
P4.3 Vs P4.7						X			
P4.4 Vs P4.5						X			
P4.4 Vs P4.6					X				
P4.4 Vs P4.7					X				
P4.5 Vs P4.6				X					
P4.5 Vs P4.7			X						
P4.6 Vs P4.7			X						

5. Results

5.1 Application of the AHP method

After collecting expert judgments, the data were processed using the online AHP Priority Calculator, which applies Saaty's mathematical framework [62]. The problem was decomposed into a hierarchical structure consisting of four themes (P1–P4) and seventeen indices. Experts, lecturers, and researchers in architecture and digital technologies performed pairwise comparisons to assess the relative importance of indices. Judgments were transformed into numerical values using Saaty's nine-point scale. A sample of the comparison matrices is shown in Table 3.

Normalization was carried out by dividing each element by the sum of its column, followed by the calculation of row sums (SL). Global priorities (GP) were then obtained by averaging the normalized values for each line. Table 4 presents the results of normalization and the global priorities for themes and indices.

Table 3. Pairwise comparison matrices of themes and indices. Source: Authors

(a) Main themes (P1–P4)

	P1	P2	P3	P4
P1	1	1	2	2
P2	1	1	4	1
P3	1/2	¼	1	1
P4	1/2	1	1	1
Sums of columns (SC)	3	3.25	8	5

(b) Indices under P1 – Morphological attributes

	P1.1	P1.2	P1.3
P1.1	1	5	4
P1.2	1/5	1	4
P1.3	¼	¼	1
Sums of columns (SC)	1.45	6.25	9

(c) Indices under P2 – Spatio-functional qualities

	P2.1	P2.2	P2.3
P2.1	1	4	4
P2.2	¼	1	4
P2.3	¼	¼	1
Sums of columns (SC)	1.5	5.25	9

(d) Indices under P3 – Sensory qualities

	P3.1	P3.2	P3.3	P3.4
P3.1	1	4	3	5
P3.2	1/4	1	4	6
P3.3	1/3	¼	1	4
P3.4	1/5	1/6	1/4	1
Sums of columns (SC)	1.783	5.416	8.25	16

(e) Indices under P4 – Service performance

	P4.1	P4.2	P4.3	P4.4	P4.5	P4.6	P4.7
P4.1	1	6	4	3	4	5	2
P4.2	1/6	1	4	4	3	3	3
P4.3	1/4	1/4	1	3	3	4	6
P4.4	1/3	1/4	1/3	1	6	5	5
P4.5	1/4	1/3	1/3	1/6	1	4	4
P4.6	1/5	1/3	¼	1/5	1/4	1	3
P4.7	1/2	1/3	1/6	1/5	1/3	1/3	1
Sums of columns (SC)	2.699	8.499	10.082	11.566	17.583	22.333	24

Table 4. Themes and indices global priorities. Source: Authors

(a) Main themes (P1–P4)

	P1	P2	P3	P4	SL	GP = SL/4
P1	0.333 (1/3)	0.308 (1/3.25)	0.25 (2/8)	0.40 (2/5)	1.291	0.3227
P2	0.333 (1/3)	0.308 (1/3.25)	0.50 (4/8)	0.20 (1/5)	1.341	0.3352
P3	0.167 (0.5/3)	0.077 (0.25/3.25)	0.125 (1/8)	0.20 (1/5)	0.569	0.1422
P4	0.167 (0.5/3)	0.308 (1/3.25)	0.125 (1/8)	0.20 (1/5)	0.800	0.2000

(b) P1 — Morphological attributes (3 indices)

	P1.1	P1.2	P1.3	SL	GP = SL/3
P1.1	0.690 (1/1.45)	0.800 (5/6.25)	0.444 (4/9)	1.934	0.6446
P1.2	0.138 (0.2/1.45)	0.160 (1/6.25)	0.444 (4/9)	0.742	0.2473
P1.3	0.172 (0.25/1.45)	0.040 (0.25/6.25)	0.111 (1/9)	0.323	0.1076

(c) P2 — Spatio-functional qualities (3 indices)

	P2.1	P2.2	P2.3	SL	GP (SL/3)
P2.1	0.667 (1/1.5)	0.762 (4/5.25)	0.444 (4/9)	1.873	0.6243
P2.2	0.167 (0.25/1.5)	0.190 (1/5.25)	0.444 (4/9)	0.801	0.2670
P2.3	0.167 (0.25/1.5)	0.048 (0.25/5.25)	0.111 (1/9)	0.326	0.1086

(d) P3 — Sensory qualities (4 indices)

	P3.1	P3.2	P3.3	P3.4	SL	GP (SL/4)
P3.1	0.561 (1/1.783)	0.739 (4/5.416)	0.364 (3/8.25)	0.313 (5/16)	1.977	0.4942
P3.2	0.140 (0.25/1.783)	0.185 (1/5.416)	0.485 (4/8.25)	0.375 (6/16)	1.185	0.2962
P3.3	0.187 (0.333/1.783)	0.046 (0.25/5.416)	0.121 (1/8.25)	0.250 (4/16)	0.604	0.1510
P3.4	0.112 (0.2/1.783)	0.031 (0.1666/5.416)	0.030 (0.25/8.25)	0.063 (1/16)	0.236	0.0590

(e) P4 — Service performance (7 indices)

	P4.1	P4.2	P4.3	P4.4	P4.5	P4.6	P4.7	SL	GP (SL/7)
P4.1	0.371 (1/2.699)	0.706 (6/8.499)	0.397 (4/10.082)	0.259 (3/11.566)	0.227 (4/17.583)	0.224 (5/22.333)	0.083 (2/24)	2.267	0.3238
P4.2	0.062 (1/2.699)	0.118 (1/8.499)	0.397 (4/10.082)	0.346 (4/11.566)	0.171 (3/17.583)	0.134 (3/22.333)	0.125 (3/24)	1.353	0.1932
P4.3	0.093 (1/2.699)	0.029 (0.25/8.499)	0.099 (1/10.082)	0.259 (3/11.566)	0.171 (3/17.583)	0.179 (4/22.333)	0.25 (6/24)	1.080	0.1542
P4.4	0.123 (1/2.699)	0.029 (0.25/8.499)	0.033 (0.333/10.082)	0.086 (1/11.566)	0.341 (6/17.583)	0.224 (5/22.333)	0.208 (5/24)	1.044	0.1491
P4.5	0.093 (1/2.699)	0.039 (0.333/8.499)	0.033 (0.333/10.082)	0.014 (0.1666/11.566)	0.057 (1/17.583)	0.179 (4/22.333)	0.167 (4/24)	0.582	0.0831
P4.6	0.074 (1/2.699)	0.039 (0.333/8.499)	0.025 (0.25/10.082)	0.017 (0.2/11.566)	0.014 (0.25/17.583)	0.045 (1/22.333)	0.125 (3/24)	0.339	0.0484
P4.7	0.185 (0.5/2.699)	0.039 (0.333/8.499)	0.016 (0.166/10.082)	0.017 (0.2/11.566)	0.019 (0.333/17.583)	0.015 (0.333/22.333)	0.042 (1/24)	0.333	0.0475

5.2. Aggregated priorities

The aggregation and weighting of themes and indices revealed the following order of importance (Table 5):

Spatio-functional qualities (33.52%) emerged as the most influential theme, reflecting the importance of new spatial and functional solutions.

Morphological attributes (32.27%) ranked second, emphasizing the role of form and environment in new projects.

Service performance (20%) was placed third, underlining the integration of automated systems.

Sensory qualities (14.22%) ranked fourth, highlighting the long-term significance of comfort and well-being.

Table 5. Aggregation and weighting of themes and indices. Source: Authors

Indices	Rating= GP*100
Morphological attributes 32.27%	
Disposition and environment	64.46%
Site, formal and volumetric aspects	24.73%
Construction and digital technology	10.76%
Spatio-functional qualities 33.52%	
Diversity and multiplicity of interior design solutions	62.43%
Ecological and sustainable design	26.7%
Signaling and orientation for circuit and accessibility	10.86%
Sensory qualities 14.22%	
Quality of services	49.42%
Control and regulation of indoor environmental atmospheres	29.62%
Functionality and aesthetic aspects	15.1%
Health and well-being	5.9%
Service performance 20%	
Access control and security system	32.38%
Video surveillance system	19.32%
Automatic control and management system	15.42%
Telecommunications and data system	14.91%
Management of energy and natural resources	8.31%
Management by digital model	4.84%
Financial management	4.75%

5.3. Interpretation of results

The results indicate that spatio-functional qualities constitute the most influential theme, with a weight of 33.52%. This finding is consistent with the current architectural context, where there is a strong demand for new functional and spatial solutions to ensure adaptability and resilience. Morphological attributes follow closely with 32.27%, confirming the continuing importance of external form, site integration, and volumetric composition in the development of new projects. Service performance ranks third with 20%, reflecting the growing necessity of incorporating automated systems into buildings. Finally, sensory qualities occupy the fourth position with 14.22%, underlining the need to enhance user comfort and well-being for long-term productivity.

As shown in Table 5, spatio-functional qualities play a central role in contemporary architectural discourse. They are often associated with the dissolution of spatial boundaries, where interior and exterior spaces interconnect in fluid and continuous ways, generating openness and freedom [63]. Within this theme, the diversity and multiplicity of interior design solutions emerge as the most critical index, emphasising flexible, convertible, and communicative environments that foster dialogue and visual continuity. Ecological and sustainable design comes next, highlighting the integration of ecological devices and climate-control systems. Finally, signage and orientation provide essential functional and organisational support, ensuring clear circulation and accessibility.

Morphological attributes form a solid foundation for project development and optimisation, offering a framework for both architectural action and vision. Here, disposition and environment rank highest, reflecting a sustainable perspective that aligns architectural form with its surrounding context. Site, formal, and volumetric aspects come second, ensuring homogeneity and spatial quality. The construction and digital technology index ranks third, pointing to the role of advanced materials and smart technologies in transforming architectural production.

Within service performance, the most significant contribution comes from access control and security systems, which enable both physical and logical access through digital identifiers such as badges, biometric systems, or passwords. Video surveillance and automatic control and management systems follow, representing vital requirements for enhancing building intelligence, safety, and comfort. Telecommunications and data systems are equally important, ensuring real-time communication, information sharing, and operational control. Although less weighted, energy and resource management highlights strategies for optimising electricity, heating, and water consumption [64]. Finally, digital model management and financial management provide supportive roles in cost optimisation, resource tracking, and collaborative planning.

The sensory qualities theme, although ranking fourth, remains essential for user-centred architecture. The leading index, quality of services, significantly outweighs the others, demonstrating its capacity to enhance efficiency, performance, and user satisfaction. Control and regulation of indoor atmospheres come next, ensuring thermal, acoustic, visual, and olfactory comfort, which are crucial for well-being. Functionality and aesthetic aspects are ranked third, addressing refinement, harmony, and visual coherence. Finally, health and well-being complete this group, reflecting the perceptual dimension of lived environments, where hygiene, satisfaction, freedom, and environmental quality contribute to overall happiness and long-term comfort [65].

Overall, the findings suggest that the conceptualisation of intelligence in architecture lies at the intersection of four key domains: spatial flexibility, morphological integration, technological performance, and sensory experience. The hierarchy obtained through AHP demonstrates that architecture is no longer conceived as a static product, but rather as a dynamic system, simultaneously responsive, sustainable, secure, and perceptually engaging. By bridging quantitative prioritisation with theoretical frameworks [63,65], this study confirms that the optimisation of architectural intelligence requires a holistic approach – one that balances functional adaptability, environmental responsibility, technological innovation, and human-centred design.

5.4. Consistency check

To ensure the reliability of expert judgments, the maximum eigenvalue (λ), the consistency index (CI), and the consistency ratio (CR) were calculated (Eq. 1–3). According to Saaty [45], CR values below 10% confirm acceptable consistency. The results (Table 7) showed a CR of 7.2%, validating the coherence of the comparison matrices.

$$\lambda = \sum_{i=1}^{n} GP \times SC \tag{1}$$

$$CI = \frac{\lambda - n}{n-1} \tag{2}$$

$$CR = \frac{CI}{RI} \tag{3}$$

with RI: Random index defined by Saaty [62] (see Table 6).

Table 6. Saaty's random index. Source: [62]

N= Number of criteria	1	2	3	4	5	6	7	8	9	10	11
RI= Random index	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51

Table 7. Testing the consistency and coherence of the approach. Source: Authors

	SC	GP	GP*SC	Maximum eigenvalue λ	Consistency index CI	Consistency Ratio CR
P1	3	0.3227	0.9681	λ=0.9681+1.0894+1.1376+ 1 λ= 4.1951	CI=(4.1951-4)/ (4-1) CI= 0.065	CR= 0.065/0.9 CR=0.072= 7.2%
P2	3.25	0.3352	1.0894			
P3	8	0.1422	1.1376			
P4	5	0.2	1			

5.5 Exploratory dashboard

To broaden the scope of application, each index was further subdivided into sub-indices, as summarised in Table 8. This dashboard provides a comprehensive tool for optimising performance, intelligence, and quality of architectural spaces. It serves a triple purpose:

Supporting architectural design by guiding decisions toward sustainability, flexibility, and user well-being.

Providing a framework for continuous adaptation of spatial uses.

Acting as a decision-making instrument that integrates economic, environmental, and social concerns with digital innovation.

Table 8. Dashboard of the exploratory approach. Source: Authors

Perspectives	Indices	Sub-indices
Spatio-functional qualities	Diversity and multiplicity of interior design solutions	Malleable and elastic furniture and furnishings
		Communicative and expansive space
		Fluid and flexible space
		Convertible space
		Multifunctional space
		Adaptable space
	Ecological and sustainable design	Ecological devices
		Control and regulation elements for thermal environments and space amenities
	Signage and orientation for the circuit and accessibility	Signage and orientation for vertical and horizontal traffic
		Access and movement for people with reduced mobility
		Emergency exits
Morphological attributes	Disposition and environment	Density
		Composition
		Rapprochement / Distance
	Site, formal and volumetric aspects	Situation
		Orientation
		Form
		Volume
	Construction and digital technology	Smart Envelope
		Smart materials
		Interactive building elements
		Specific structure processes
		Technological devices in the layout
Service performance	System of Access Control and Security	Physical access control
		Logical access control
	Video surveillance system	IP video surveillance Cameras
		Wireless video surveillance Cameras
	Automatic control and management system	Heating
		Ventilation and air conditioning
		Lighting
		Sanitary hot water and plumbing
		Fire detection
		Detection of pollutants
	Telecommunications and data system	Digital signage
		Ease of access to internet networks
		Indoor location
		Fax and telecommunications
		Cable management
	Management of energy and natural resources	Use of renewable energy sources
		Energy-saving strategies and conservation techniques
		Consumption counting and measurement system
		Wastewater and stormwater management
		Waste management
		Tracking the amount of greenhouse gases
	Management by digital model	Management of organisation and space reservation
		Management and planning of the maintenance and operation of the technical equipment of the building
		Material inventory management
		Management of documentation associated with equipment, visit, evaluation, inspection and enhancement of heritage
	Financial management	Resource management and control of budgets and expenses
		Consideration of cost and time-saving strategies

Perspectives	Indices	Sub-indices
Sensory quality	Quality of services	Reception and support
		Listening and guidance
		Accessibility to information
		Speed and Responsiveness
		Security
		Service efficiency
	Control and regulation of the atmosphere of the interior environment	Acoustic comfort
		Visual comfort
		Olfactory comfort
		Hygrothermal comfort
		Thermal comfort
	Functionalities and aesthetic aspects	Harmony and refinement of colours, lines, shapes and volumes
		Elegance and sobriety
		Structural eurythmy
		Solidity and usefulness
		Decoration, technical ornamentation
		Objective Animation
		Advertising and digital signs
	Health and well-being	Perceived hygiene and health
		Feeling of freedom
		Satisfaction and happiness
		Environmental quality

5.6. Synthesis

The analysis highlights the interdependence of the four perspectives – spatio-functional qualities, morphological attributes, service performance, and sensory qualities. The results demonstrate that digital technologies not only transform architectural performance and efficiency but also reshape spatial perception, comfort, and adaptability. This comprehensive framework therefore provides a coherent basis for optimising intelligent, sustainable, and human-centred architecture in the digital age.

6. Discussion

The results of this research provide important insights into the conceptualisation and optimisation of building intelligence. This section discusses the findings in relation to recent literature, identifies their theoretical and practical implications, and highlights emerging challenges.

The prioritisation of environmental and passive technologies as a leading dimension confirms current global trends in architecture and construction, where sustainability and climate responsibility have become central concerns. This finding is consistent with recent studies emphasising low-carbon design strategies, energy efficiency, and climate-responsive architecture [28,40,64,66]. It also aligns with broader perspectives on smart buildings and cities, which underline that technological innovation must be embedded within ecological frameworks to be truly effective [8,19,67].

At the same time, the interdependence of indicators revealed by the AHP analysis demonstrates that building intelligence cannot be reduced to technological performance alone. Instead, it requires an integrated vision that combines spatial quality, user well-being, communication infrastructure, and environmental strategies. This supports recent research highlighting the convergence between technological systems and human-centred design in intelligent environments [26].

From a practical perspective, the validated framework serves as a decision-support tool for architects, engineers, and policymakers. It allows them to:

- Prioritise investments in building projects, focusing on sustainable technologies without neglecting spatial adaptability and user comfort.
- Integrate digital technologies such as sensors, IoT, and AI-based management systems in a way that complements ecological strategies.
- Anticipate long-term performance by using forecasting models that incorporate both economic and environmental scenarios.

This integrative approach contributes to bridging the gap between theoretical research and professional practice, offering a structured methodology for addressing the complexity of intelligent building design.

However, the results also reveal certain tensions. While environmental and functional dimensions are strongly prioritised, sensory and experiential aspects remain less emphasised, despite their growing importance in contemporary research on well-being and indoor environmental quality.

Moreover, the findings stress the necessity of adapting intelligent building strategies to local socio-cultural contexts. In emerging regions such as North Africa and the Middle East, the implementation of advanced digital systems must be aligned with economic constraints, climate conditions, and local practices to avoid reinforcing spatial and social inequalities.

Overall, this exploratory approach contributes to the ongoing debate on building intelligence by demonstrating the feasibility of a multi-criteria framework that integrates both quantitative and qualitative dimensions. Its flexibility and scalability make it applicable to diverse architectural and urban contexts.

7. Conclusion and perspectives

This research advances the understanding of building intelligence by proposing a structured and operational framework capable of translating complex architectural concepts into measurable and actionable criteria. Rather than focusing solely on technological sophistication, the study highlights intelligence as an emergent property resulting from the interaction between spatial, environmental, digital, and human dimensions.

The proposed approach introduces a hierarchical and multi-criteria model that supports informed decision-making in the design and management of high-performance buildings. By combining conceptual analysis with AHP-based validation, the study demonstrates how architectural intelligence can be assessed, compared, and optimised in a systematic way.

Beyond its methodological contribution, the research points toward a broader transformation in architectural practice, where buildings are increasingly conceived as adaptive and responsive systems rather than static objects. This perspective opens new possibilities for integrating innovation, sustainability, and user-centred design within a unified framework.

7.1. Contributions

The main contributions of this research can be summarised as follows:

- The development of a multi-dimensional conceptual framework for defining and evaluating building intelligence.
- The operationalisation of this concept through a hierarchical and quantitative decision-support model (AHP).
- The identification of interdependencies between spatial, technological, environmental, and human factors.
- The provision of a flexible and transferable tool applicable to architectural design and decision-making processes.

7.2. Perspectives for future research

Future research could extend this work in several directions:

- Applying the framework to real-world case studies to test its robustness across different building typologies;
- Expanding the empirical base through larger and more diverse expert samples;
- Integrating the model into BIM and digital twin environments for real-time performance evaluation;
- Exploring the role of artificial intelligence and data-driven systems in enhancing predictive and adaptive capacities;
- Investigating the ethical and governance dimensions of intelligent buildings, including data privacy, transparency, and inclusivity;
- Extending the approach to the urban scale, contributing to the development of smart and resilient cities.

Declaration of competing interest

The author declares that there are no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability statement

The data supporting the findings of this study are available from the author upon reasonable request.

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