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Article

Measuring Smart Sports Facility Dimensions for Smart Cities: Scale Development and Validation Using Mixed Methods, EFA and PLS-CFA

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Abstract

Smart sports facilities are increasingly positioned as key urban assets within smart-city agendas, yet there is no widely accepted, empirically validated instrument for benchmarking facility-level “smartness”. This study develops and validates a multidimensional measurement scale for smart sports facilities using a convergent mixed-methods design. In Phase 1, a targeted literature review and semi-structured interviews with domain experts (n = 30) generated an initial pool of 26 items. In Phase 2, exploratory factor analysis of 360 valid survey responses (from 406 distributed questionnaires) refined the instrument and supported a six-factor structure. In Phase 3, the measurement model was cross-validated via PLS-based confirmatory factor analysis (SmartPLS), and reliability and convergent/discriminant validity were assessed using Cronbach’s alpha, composite reliability, average variance extracted, Fornell–Larcker, and heterotrait-monotrait ratio criteria. The final instrument comprises 18 items capturing six dimensions: Technological Integration, Sustainability, User Experience, Community Engagement, Economic Impact, and Innovation and Adaptability. The scale demonstrates acceptable internal consistency and construct validity and offers a practical tool for benchmarking, prioritizing investments, and aligning sports-infrastructure planning and operations with broader smart-city objectives. The framework operationalizes smart-city concepts at the venue scale by linking digital capability, environmental performance, and service quality with community and economic outcomes. It can support municipalities, facility operators, and policymakers in monitoring progress toward sustainability and inclusivity targets, comparing facilities across districts, and designing data-informed upgrade roadmaps. Future work should replicate the scale across countries, facility types, and stakeholder groups and test measurement invariance using longitudinal and operational sensor data.

Keywords

Smart city, Smart sports facility, Scale development, Exploratory factor analysis, PLS-SEM, Sustainability

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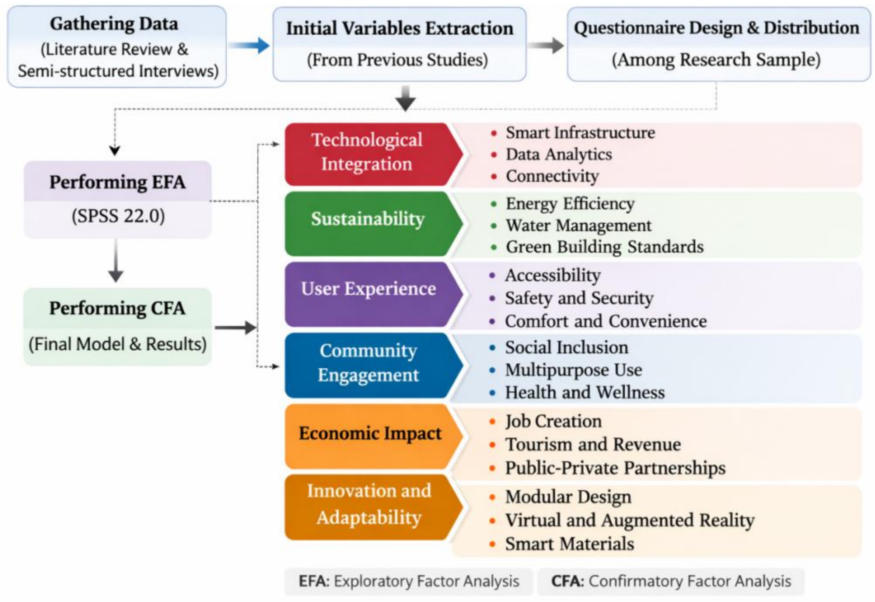
Graphical Abstract



1. Introduction

The concept of smart cities has attracted substantial attention in recent years [1], due to which governments and urban planners try to develop sustainable, efficient, and technologically advanced urban environments [2-4]. Interest also grows within this vein in regard to how sport facilities could be integrated within the fabric of smart cities toward the health and wellbeing and community involvement of citizens [5-7].

Smart cities are an innovative approach to urban living that integrates technology [8] and data to improve the quality of life for residents [9-11]. By harnessing the power of information and communication technologies, smart cities strive to enhance sustainability, efficiency, and overall well-being within urban environments [12,13]. From intelligent transportation systems and energy-efficient buildings to connected infrastructure and digital services [14], the philosophy of a smart city holds a vision for a connected and livable future for all its residents [15,16]. This high-tech, connected way of city planning now revolutionizes the way one thinks about urban development, creating opportunities for innovation and growth in communities around the world [16-18].

A smart city encompasses the most recent technologies and innovative ideas to improve all aspects of human life [19,20]. Developing state-of-the-art sport facilities forms part of upgrading health, welfare, and community participation [21,22]. These facilities are equipped with cutting-edge equipment, data analytics, and connectivity to provide a seamless and enjoyable experience for all users [23].

From indoor gyms to outdoor fields, smart cities offer a variety of sport facilities that cater to the needs and interests of diverse populations [24]. These facilities support physical fitness and recreation, social contacts, and a feeling of belonging within the community [21,25,26]. Sport facilities in smart cities have an increasingly important role in this rapidly changing urban life for healthy lifestyle and overall well-being [27,28].

Sport facilities are an essential component of urban infrastructure, providing spaces for physical activity, recreation, and social interaction [29,30]. These facilities can be envisioned and redesigned for smart cities by incorporating advanced technology, sustainability, and innovative design features that promote the overall user experience and contribute to the goals of the city in health and wellness [5,31].

From the integration of digital technologies for monitoring and tracking in physical activity to powering renewable energy via the introduction of green open spaces, natural elements at the service of users' experience, all the way to inclusive use and accessibility to every member within the community, this presentation of smart city sports facilities will explain it. Therefore, the present study attempts to explore and classify the main features of sports facilities in the context of a smart city through the opinions of experts in a mixed-method approach. Despite the growing interest in smart cities, a comprehensive, empirically-derived framework specifying the characteristics of smart sports facilities is absent. This study aims to fill this gap by using a mixed method approach.

In this study, sustainability is discussed at two complementary levels. At the facility level, it refers to the environmental performance of sports venues (e.g., energy, water, materials, and waste management) and the adoption of green building and operational practices. At the urban level, sustainable development encompasses the broader smart-city agenda, including social inclusion, public health, governance, and economic resilience. This distinction is made explicit to avoid using sustainability as a purely local construct.

2. Literature Review

The literature on exploring the features of sport facilities in smart cities highlights the importance of recreation spaces in urban communities [32]. These spaces, including playgrounds and sports facilities, play a crucial role in promoting social sustainability and contributing to the overall well-being of residents [33]. In the context of sustainable urban form, access to sports facilities is essential for enabling residents to access city services while minimizing external costs [34]. Additionally, the distinctiveness of smart cities is often reflected in variations in urban form features, such as the presence of landmarks and smart infrastructure [35]. Urban green spaces, including sports facilities, are valued for their role in promoting healthy living and providing quality amenities such as walking paths and shade [36]. Furthermore, the concept of the 15-minute city emphasizes the importance of having sports facilities and other amenities within close proximity to residential areas to encourage sustainable and health-promoting mobility habits [37]. In terms of design, sports facilities can be leveraged to serve communities by incorporating amenities such as boutique hotels and sports clinics to create a sustainable and vibrant post-event environment [38,39]. Overall, the literature suggests that sports facilities are integral components of smart cities, contributing to social sustainability, healthy living, and community well-being.

2.1 Smart Sport Facility

Smart sports facilities can be understood as instrumented and connected venues that generate high-resolution operational and user-experience data for both facility management and city-level planning. Typical data streams include crowd flow and occupancy, energy and utility consumption, indoor environmental quality (e.g., CO_2, temperature, humidity), asset condition and maintenance logs, and safety/incident records. These data are captured through IoT sensors and smart meters, building management systems (BMS), access-control and ticketing systems, mobile applications, and analytics-enabled closed-circuit television (CCTV), and are integrated via facility data platforms. Continuous monitoring and analytics support decisions such as demand-responsive heating, ventilation, and air conditioning (HVAC) and lighting control, preventive maintenance scheduling, and real-time crowd and safety management.

The integration of smart sports facilities within a smart city framework has been a topic of increasing interest and research in recent years [32]. Smart sports facilities play a crucial role in gathering data to improve the overall functioning and efficiency of a city. These facilities are often equipped with technology that allows for data collection and analysis, ultimately leading to more informed decision-making processes [40]. One key aspect of smart sports facilities is their ability to be activated and accessed through mobile applications [41]. This technology allows for seamless interaction with the facilities, such as unlocking doors or accessing specific services [42]. By leveraging mobile apps, smart sports facilities can enhance user experience and streamline operations within the city [43].

2.2 Smart Sport Facility and Urban Development

In the context of urban development, the intersection of smart cities and sports facilities has been a focal point for discussions and initiatives. The Summit 2023 on smart cities and sport highlighted the importance of city and state diplomacy in promoting smart urban development. Collaborations between different stakeholders, such as the Truman Center for National Policy, have been instrumental in advancing the integration of smart technologies in sports facilities within a city's infrastructure [44]. The question of whether sports facilities in cities should be accessible to all residents has also been a topic of debate [45]. Some argue that sports facilities should be designed with the community in mind, ensuring that they are inclusive and serve the needs of all individuals. This perspective aligns with the principles of smart cities, which aim to create sustainable and equitable urban environments [46].

Facility contributions to city-level energy efficiency typically arise through (1) demand-side management (adaptive HVAC/lighting driven by occupancy and comfort targets), (2) on-site generation and storage (e.g., rooftop photovoltaic (PV) and battery storage), and (3) energy recovery and network integration where available. For example, facilities may export surplus electricity fromPV to local loads or a microgrid, shift non-critical loads away from peak hours, or utilize heat-pump and waste-heat recovery solutions to support district heating or domestic hot water. These mechanisms allow sports venues to act as flexible prosumers rather than passive consumers, improving overall urban energy performance.

2.3 Smart Sport Facility and Sustainability

From a sustainability standpoint, smart sports facilities have the potential to contribute to the overall energy efficiency of a city [40]. By incorporating technologies that allow for the transfer of excess energy to district heating networks, these facilities can play a role in reducing energy consumption and promoting cost efficiency [47]. Sustainability and cost efficiency are key considerations in the design and operation of sports facilities within a smart city context [48].

2.4 Smart Sport Facilities and Major Events

The present study adopted a convergent mixed-method design combining qualitative item generation with quantitative scale validation. The research proceeded in three stages: (1) a literature review and semi-structured expert interviews to generate the initial item pool; (2) exploratory factor analysis (EFA) to refine items and identify the latent factor structure; and (3) PLS-based confirmatory factor analysis (PLS-CFA) to cross-validate the measurement model. This design supports a practical, evidence-based framework for facility planning and operations within smart-city contexts (Figure 1).

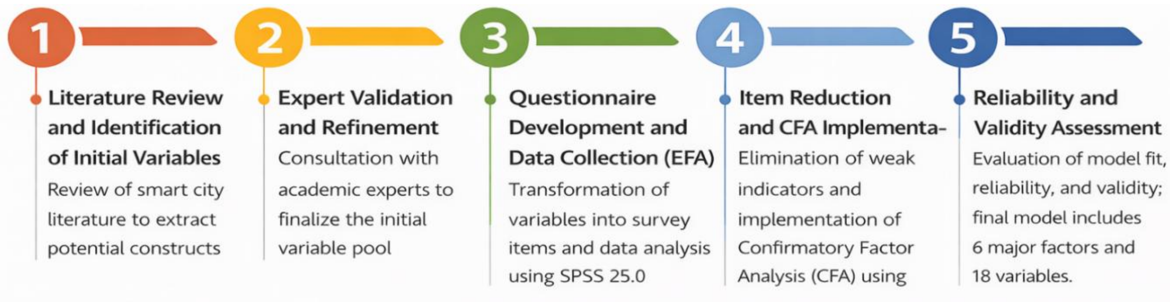


Figure 1. Graphical process of research methodology.

Overall, the role of sports facilities in smart cities is multifaceted and complex. From promoting sustainability and energy efficiency to enhancing user experience through mobile applications, smart sports facilities have the potential to transform urban environments. By considering the needs of the community and leveraging technology to improve operations, cities can create inclusive and dynamic spaces that benefit residents and visitors alike.

3. Methodology

The present study involves applied research with a specific goal that has been accomplished through the utilization of both qualitative and quantitative methods, and general methods for such research have been described elsewhere. In order to achieve the objective of this study, an overview of previous studies was initially examined using the research's main concepts and key concepts. To ultimately arrive at a variable that can be presented regarding sport facility, sport management and smart city concepts. The data collection method involved the use of a questionnaire as well as interviews with professionals and experts in this field. This article involves three main steps: (1) review the current literature and conducting semi structured interviews with experts to identifying initial variables. (2) Measuring the identified item's factor loadings and validity by EFA. (3) Evaluating the variables validity by using confirmatory factor analysis (CFA). This design of methodology helps to reach a valuable result about sport facilities' aspect in smart-city contexts. Figure 1 shows the process of research.

3.1 Recognition of Research Variables

In order to design the main questions and concepts of the research, a review of past studies was done first by examining key words and study abstracts. Key words regarding sport, sport facility, sport management and smart city were able to provide valuable information in this field. In this regard, information and opinions from 30 university professors at Tehran University (sport management and urban planning), were used. Table 1 presents the demographic characteristics of the group of research experts who collaborated in the formation of questions and initial concepts. After the final summarization of the information and taking advantage of the experts' opinions and researcher evaluations, 26 out of the 32 initial variables were approved and set as the initial variables of the research before quantitative analysis was performed on them. The information of initial variables is provided in Appendix 1.

Table 1. Demographic profile of survey participants and experts.

Demographic	**Respondents**		**Experts**	
	Survey		**Research Experts**	
	Frequency	**Percentage (%)**	**Frequency**	**Percentage (%)**
Gender	360	100	30	100
Male	219	60.8%	23	76.7%
Female	141	39.2%	7	23.3%
Age	**360**	100	30	100
Below 30	54	15%	-	-
30-35	38	10.6%	5	16.7%
36-40	167	46.4%	8	26.7%
Above 40	97	26.9%	17	56.6%
Missing	4	1.1%	-	
Level of Study	**360**	100	30	100
Bachelors	48	13.3%	-	-
Masters	79	21.9%	-	-
PhD	230	63.9%	30	100%
Missing	3	0.9%	-	-

A structured questionnaire was administered to stakeholders with relevant academic and/or professional exposure to sports facility management, smart buildings/IoT, and urban planning. To improve domain relevance, respondents were screened using inclusion criteria (e.g., demonstrated familiarity with sports facility planning/operations or smart-city/smart-building applications through coursework, projects, or professional experience). In total, 406 questionnaires were distributed and 360 complete responses were retained for analysis (response rate: 88.67%). Data were collected during October-November 2023 using a mixed-mode approach (in-person distribution at facilities and a controlled online form). To assess potential non-response bias, early and late respondents were compared on key demographic variables and construct means; no meaningful differences were observed ($p > 0.05$). Table 1 summarizes the sample characteristics.

Because the realized sample included a higher proportion of male respondents (Table 1), we examined whether this imbalance could bias the measurement results. Gender was included as a control variable in robustness checks, and construct scores were compared across gender groups; the pattern of factor loadings and main conclusions remained stable. We therefore report the imbalance transparently and interpret results with appropriate caution regarding generalizability.

3.2 Research Group

A quantitative survey was administered to respondents with relevant academic and/or professional exposure to sports facility management, smart buildings/IoT, and urban planning. In total, 406 questionnaires were distributed and 360 complete responses were retained for analysis (response rate: 88.67%). Data were collected during October-November 2023 using a mixed-mode approach (in-person distribution at facilities and a controlled online form). Table 1 presents the respondents' demographic characteristics.

3.3 Exploratory Factor Analysis

Statistical basis. EFA was conducted on the correlation matrix R of the observed items. Eigenvalues (lambda_i) were obtained from the spectral decomposition R v_i = lambda_i v_i. Factor retention was guided by multiple criteria: (1) Kaiser criterion (lambda_i > 1) [49], (2) scree-plot inspection for the elbow point [50], and (3) interpretability and simple structure of the rotated solution. Sampling adequacy was assessed by the Kaiser-Meyer-Olkin (KMO) statistic: KMO = sum(r_ij^2) / (sum(r_ij^2) + sum(p_ij^2)), where r_ij is the correlation and p_ij is the partial correlation between items i and j. Bartlett's test of sphericity evaluates H0: R = I using chi-square = -(n - 1 - (2p + 5)/6) * ln|R|, with df = p(p-1)/2. After extraction, varimax rotation was used [51] to enhance interpretability by maximizing the variance of squared loadings within each factor. Variance explained by factor k is computed as the sum of squared loadings across items.

4. Findings

4.1 Item Refinement

Items were retained when their primary loading was at least 0.50 and cross-loadings were below commonly used thresholds (e.g., <0.30), and when removal did not reduce construct coverage. From the initial 26 items, four items were removed due to low loadings and/or cross-loadings, yielding 22 items for the final EFA solution. The six-factor solution (Technological Integration, Sustainability, User Experience, Community Engagement, Economic Impact, and Innovation and Adaptability) explained 86.26% of the total variance. For example, the Water Management item loaded strongly on Sustainability (0.842) while its secondary loadings were small, indicating no problematic cross-loading in the final rotated matrix.

At this stage, in order to measure the content validity of the research questionnaire, the opinions of professors and experts were used. A factor analysis was carried out through the varimax rotation method, using SPSS version 22, to increase the credibility of the research work by identifying inappropriate factor loadings and removing them from the research process [52]. Next, the results of the previous step were analyzed using CFA [53]. The analysis of this step was performed using statistical software PLS version 3.

4.2 Exploratory Factor Analysis

The basic framework constructed during this research was investigated and assessed using EFA. The 26 items which made up the targeted scale for this study were created with the concept of smart city and sport facilities in consideration. The main factor analysis was carried out on the scores derived from the responses provided by the 360 respondents, and varimax rotation was used [54] to determine the actual structure of the scale and reduce the number of relevant subscales. In the current stage of the study, 360 completed questionnaires out of 406 distributed ones were considered to be valid, representing an 88.66% response rate. The variables were measured through a Likert scale with seven points (1 being strongly disagree and 7 being strongly agree). Notably, α Cronbach's of = 0.874 was used to determine the reliability of the questionnaire, which is confirmed.

In order to evaluate the factorability of the data and ensure adequate sampling, Bartlett's test of sphericity and the measure of sampling adequacy were employed. For a factor analysis to be considered appropriate, the minimum recommended KMO index [54] (which varies from 0 to 1) is 0.6, and the Bartlett's test of sphericity [55] is required to be significant at $p < 0.05$. The data in this study are very well suited for EFA as indicated by the significant results of Bartlett's test of sphericity ($p = 0.00$) and the measured KMO index of 0.877. The rotated factor-loading matrix is reported in Table 2.

Table 2. EFA analysis for the survey using SPSS software.

Factor	Item	Factors*						α
		1	2	3	4	5	6	
Technological Integration	Smart Infrastructure by using IoT devices for real-time monitoring and management in smart sport facilities	**0.885**	0.013	-0.054	0.078	0.223	0.025	0.912
	Data Analytics and Use of big data to optimize smart sport facility operations	**0. 876**	0.019	0.023	0.192	0.023	0.014	
	Connectivity by using high speed internet inside smart facilities	**0.851**	0.110	0.068	0.121	0.011	0.068	
	Integrating new technologies in smart sport facilities to enhance operational efficiency and service quality	**0.832**	0.182	0.093	0.045	0.024	0.021	
Sustainability	Implementing renewable energy systems like solar panels and enhancing Energy Efficiency in smart sport facilities	0.102	**0.864**	0.025	0.341	0.012	0.087	0.894
	Designing an efficient Water Management system in smart facilities	0.087	**0.842**	-0.029	0.114	0.009	0.098	
	Using LEED or other green building certifications to minimize environmental impact and comply with green building standards	0.141	**0.812**	0.175	0.216	0.031	0.047	
User Experience	Accessibility of sport facilities to all user	0.097	0.054	**0.784**	0.084	0.022	0.078	0.881
	Safety and Security of facilities to users	0.074	0.0354	**0.754**	0.028	0.003	0.069	
	Using Smart ticketing, navigation apps, and personalized services to enhance user satisfaction and Comfort and Convenience experience	0.295	0.097	**0.697**	0.134	0.124	0.067	
	Designing aesthetic atmosphere for sport facilities	0.168	0.119	**0.680**	0.028	0.017	0.124	
Community Engagement	Maximize using of smart facilities by multi-purpose approach	0.223	0.113	0.102	**0.734**	0.098	0.021	0.868
	Programs and initiatives to encourage participation from diverse community groups (social inclusion)	0.247	0.124	0.136	**0.719**	0.014	0.009	
	Promoting using sport facilities as a healthy place for all people	0.144	0.114	0.0314	**0.684**	0.074	0.004	
	Holding big events like concerts and famous speeches	0.142	-0.144	0.027	**0.653**	0.006	0.024	
Economic Impact	Opportunity for creating job in smart sport facilities	0.024	-0.021	0.142	0.358	**0.691**	0.047	0.824
	Attracting tourism during events and boosting revenue	0.003	0.008	-0.009	0.024	**0.676**	0.124	
	Collaborations between government and private sector to fund and manage smart sport facilities	0.014	0.012	0.024	0.012	**0.652**	0.235	
	Smart sport facilities generate local economic value (e.g., jobs, spending, and services)	0.102	0.098	0.098	0.009	**0.632**	0.004	
Innovation and Adaptability	Modular Design of smart sport Facilities that can be easily adapted or expanded based on future needs	0.287	-0.170	0.098	0.004	0.095	**0.634**	0.810
	Trying to Enhancing training and spectator experiences through immersive technologies	0.235	0.152	0.062	0.025	0.001	**0.621**	
	Using smart materials to increase durability and performance	0.325	-0.124	0.092	0.072	0.024	**0.598**	
Eigen Value		6.48	6.21	5.31	4.92	2.92	1.67	-
Percent of Variance		21.78	9.65	8.23	6.98	4.52	-	-
Cumulative Percent		26.75	50.24	67.85	73.24	86.26	-	-
KMO		0.877						
Bartlet		<0.001						

*Factor loading value after varimax rotation that categorizes the challenges into groups.

4.3 Cross-Validating the Factor Structure with PLS-Based CFA

To cross-validate the EFA structure, we employed a PLS-based confirmatory approach (PLS-CFA) using SmartPLS 3. PLS-CFA is appropriate for prediction-oriented measurement validation and is robust under mild non-normality and complex measurement models. The model was estimated using the PLS algorithm, and the significance of outer loadings was evaluated via nonparametric bootstrapping (5,000 resamples). Items were retained when their standardized outer loadings were preferably >=0.50, were statistically significant, and supported content validity.

Composite reliability (CR) and average variance extracted (AVE) were used to assess internal consistency and convergent validity. CR = ((sum lambda_i)^2)/((sum lambda_i)^2 + sum theta_i), and AVE = (sum lambda_i^2) / (sum lambda_i^2 + sum theta_i), where lambda_i denotes the standardized loading and theta_i the error variance of item i.

Discriminant validity was assessed using the Fornell-Larcker criterion and the heterotrait-monotrait ratio (HTMT). Fornell-Larcker requires the square root of AVE for each construct to exceed its correlations with other constructs; HTMT values below 0.85-0.90 indicate adequate discriminant validity [54]. (The corresponding matrices are reported in the revised manuscript as an additional validation check.)

4.4 Reliability and Validity Statisti

Cronbach's alpha was computed to evaluate internal consistency: alpha = (k/(k-1)) * (1 - (sum sigma_i^2)/sigma_T^2), where k is the number of items, sigma_i^2 is the variance of item i, and sigma_T^2 is the variance of the total score. For newly developed scales, alpha values around 0.70 are commonly considered acceptable when supported by CR and AVE and when item removal would reduce content coverage.

To compare nested CFA models, the chi-square difference test was used: Delta chi-square = chi-square_1 - chi-square_2 with degrees of freedom Delta df = df_1 - df_2. A statistically significant decrease indicates improved model fit.

4.5 Verifying the Initial Factor Structure with Confirmatory Factor Analysis

The created scale's factorial structure was confirmed by CFA, performed using SmartPLS, and was initially conducted to ascertain the fit of the proposed model using the data and 22 variables (from the previous section and EFA test). Different fit indices were used to assess the suitability of the CFA model in accordance with the researchers' standards, which are listed in Table 3. Following the removal of one variable (promoting energy-efficient practices and investing in renewable energy sources in developing policies factor) in initial CFA, a revised CFA was conducted using 18 variables to determine which model best described the scale that was obtained (see Table 3). Table 4 confirms the model of measurement demonstrates a reasonable fit, as overall path coefficients are determined to be important at p < 0.001, denoting a reasonable contribution of each variable to the pertinent factor. Overall, the six dimensions were found to be conceptually distinct yet moderately correlated, consistent with the proposed framework.

Table 3. CFA analysis performing by smart PLS software.

Factor	Item (Abbreviated)	β	SE	CR	AVE	α
	Smart Infrastructure	0.735^{**}	0.012			
Technological Integration	Data Analytics	0.722^{*}	0.018	0.877	0.714	0.852
	Connectivity	0.813^{**}	0.014			
	Energy Efficiency	0.808^{**}	0.016			
Sustainability	Water Management	0.875^{**}	0.025	0.825	0.687	0.887
	Green Building Standards	0.586^{*}	0.011			
	Accessibility	0.580^{*}	0.024			
User Experience	Safety and Security	0.903^{**}	0.026	0. 865	0.669	0.897
	Comfort and Convenience	0.882^{**}	0.021			
	Multipurpose Use	0.803^{**}	0.034			
Community Engagement	Social Inclusion	0.863^{**}	0.022	0.822	0.647	0.765
	Health and Wellness	0.859^{**}	0.015			
	Job Creation	0.894^{**}	0.018			
Economic Impact	Tourism and Revenue	0.492^{*}	0.029	0.832	0.665	0.771
	Public-Private Partnerships	0.596^{*}	0.027			
	Modular Design	0.783^{**}	0.019			
Innovation and Adaptability	Virtual and Augmented Reality	0.852^{**}	0.021	0.814	0.629	0.709
	Smart Materials	0.671^{*}	0.017			

The symbols * and ** indicate the statistical significance levels of the factor loadings obtained through bootstrapping in SmartPLS. Specifically, *represents p < 0.05 and ** represents p < 0.01.

4.6 Reliability and Validity

The Cronbach's alpha internal consistency coefficient was computed in this study to determine the degree of consistency between the variables. Based on the findings of the CFA, using SPSS, reliability analysis was conducted using Cronbach's alpha for each factor, providing results of 0.852, 0.887, 0.897, 0.765, 0.771, and 0.709 (Table 3). Additionally, the variables' general reliability was assessed by a Cronbach's alpha of 0.858.

The CR values, which measure how well a detected instrument shows an underlying factor, were also used to assess the constructs' reliability. All constructs that surpassed the suggested minimum value of 0.6 of factor loadings for overall dimensions were approved (Table 3). Moving to a confirmatory perspective is the most straightforward way to validate the results. To do this, a factor of principal component and varimax rotation was employed, and the results were analyzed using CFA, as was done in earlier steps. To determine whether there was an important variation between the original and revised CFA models, the chi-square statistical variance test was used.

The difference in chi-square ($\Delta\chi2$) between the initial and revised CFA models was significant ($p < 0.05$), and the reduction in $\chi2$ indicated improved model fit. Moreover, standard goodness-of-fit statistics and approximate fit indices indicated an acceptable model (Table 4). Furthermore, a particular category of construct validity known as convergent validity evaluates the degree of correlation between dimensional measures of the same idea. Convergent validity is evaluated using the AVE, and each construct should have convergent validity above the suggested threshold of 0.5. The factors' respective AVEs were determined to be 0.714, 0.687, 0.669, 0.647, 0.665 and 0.629, as indicated in Table Additionally, inter-construct correlations were significant ($p < 0.001$), supporting the overall reliability and construct validity of the measurement model.

Table 4. Goodness of fit indices for models.

Fit index	Value	Criteria
Ratio of chi-square* per its degree of freedom (CMIN/DF)	258.47/202 = 1.27	<3
P (Probability level)	0.118	>0.05
Goodness of fit index (AGFI)	0.902	>0.8
Comparative fit index (CFI)	0.927	>0.9
Incremental fit index (IFI)	0.941	>0.9
Non-normed fit index (NNFI)	0.919	>0.9
Approximation for root mean square error (RMSEA)	0.048	<0.08
P-Close	0.729	>0.05

*p < 0.05.

4.7 Describing the Dimensions of Smart Sport Facilities in Smart City Concept

After evaluating the CFA and identifying and confirming the six main factors in this field, we examine in this section the sub-factors and the identified main factors. The overall conceptual framework is summarized in Figure 2.

Figure 2. Summary of the research's developed concept about smart sport facility.

The first factor including three variables (smart infrastructure, data analytics, and connectivity) focuses on the technologies required for use in sports venues that can provide a pleasant experience for audiences by improving the level of communication and facilitating user experience. Therefore, the factor with mean of 3.68 and standard deviation (SD) = 0.84 was named “Technological Integration”.

The second factor including three variables (energy efficiency, water management, green building standards) focuses on practical actions in the domain of sustainability. Given the high energy and water consumption during major sporting events, it should always be kept in mind that necessary measures in this regard must always be taken. Therefore, the factor with mean of 3.49 and SD = 0.65 was named “Sustainability”.

The third factor including three variables (accessibility, safety and security and comfort and convenience) the main focus in this section is on the users' experience of being in a smart sport facility that can provide them with a pleasant and appropriate experience, which is defined in the form of smart cities. Therefore, the factor with mean of 3.78 and SD = 0.79 was named “User Experience”.

The fourth factor including three variables (multipurpose use, social inclusion and health and wellness) focuses on transforming the smart sports facility into a multi-user location for various uses so that the costs incurred for holding competitions, concerts, conferences, and educational and public sports purposes can be met in one place for citizens. Therefore, the factor with mean of 3.23 and SD = 0.94 was named “Community Engagement”.

The fifth factor including three variables (job creation, tourism and revenue, and public-private partnerships). Focuses on the economic aspects of building a smart sports facility. The creation and development of a smart sports stadium in the concept of a smart city, in addition to providing numerous tourist attractions for the city, can also help create jobs and develop the income of the city's residents, and in this way, the costs incurred for construction can be largely covered. Therefore, the factor with mean of 3.93 and SD = 0.62 was named “Economic Impact”.

Theoretically, the six validated dimensions map onto core smart-city pillars (technology, environment, people/community, governance and service quality, and economy). Technological Integration and Innovation/Adaptability represent the digital infrastructure and dynamic capabilities required for continuous improvement. Sustainability reflects resource efficiency and environmental stewardship at the venue level, aligning facility operations with city-wide decarbonization goals. User Experience and Community Engagement connect smart-city objectives to sport facility management theory by emphasizing service quality, accessibility, safety, and stakeholder co-creation. Economic Impact captures the role of venues as urban assets that can catalyze local value creation through events, employment, and ancillary services. Overall, the framework operationalizes smart-city concepts at the facility scale, enabling benchmarking and targeted investment decisions.

The sixth factor including three variables (modular design, virtual and augmented reality, and smart materials). Focusing on creativity and innovation in creating smart sports facilities is a very important aspect in this field. Utilizing current knowledge in the field of design, implementation, and use of smart materials can be of great importance. Therefore, the factor with mean of 3.62 and SD = 0.73 was named “Innovation and Adaptability”.

5. Results and Discussion

In order to identify and introduce the characteristics of smart sports venues, this study was carried out with a mixed approach including qualitative and quantitative methods. In order to fully understand the concept of smart cities and the sports venues present in them, a review of the work done in the past was conducted and by conducting interviews with experts, the initial research variables were extracted and confirmed in the next stage through quantitative statistical methods.

As previously stated, the 32 components that made up the research's initial variables were determined by collecting primary data through the examination and analysis of prior research on the topic, then adding the opinions of academic experts. After reexamination, 26 initial variables ultimately progressed to the factor analysis stage, enabling us to classify and identify them using quantitative analysis and questionnaire conversion. In the first part, a revised scale, less cohesive subscales, and an assessment of the validity and reliability of measurement scales were all created using factor analysis. The created factors and appropriate factor loadings among the items were also analyzed in a study that included 360 individuals who had finished the whole research questionnaire. The validity and reliability of the created tool were also investigated and validated.

This study developed and validated a multidimensional measurement framework for smart sports facilities, providing an empirical basis for assessing facility-level smartness and its alignment with smart-city objectives.

Each path coefficient was statistically significant at $p < 0.001$, according to the CFA, meaning that each variable significantly contributed to the associated scale. The suggested model had a sufficient fit after the CFA test was run and its results evaluated. The significance level was confirmed for each of the six main factors that were identified (CMIN/DF = 1.27, $p = 0.118$, AGFI = 0.902, CFI = 0.927, IFI = 0.941, NNFI = 0.919, RMSEA = 0.048, and P-close = 0.729). The constructive validity of the characteristics of smart sport facilities which developed in this study was shown by the CFA. AVE was used to assess convergent validity in addition to content and construct validity. AVE values over the 0.5 criterion varied from 0.629 to 0.714. Cronbach's alpha reliability coefficients (α) and CR were also examined for the six-factor structure, and the results demonstrate that all of the constructs are reasonably consistent.

The exploration of the characteristics of sport facilities in smart cities using a mixed method approach has provided us with valuable insights into key aspects that shape the design and functionality of these facilities. The six main characteristics identified in our study, Technological Integration, Sustainability, User Experience, Community Engagement, Economic Impact, and Innovation and Adaptability offer a comprehensive framework for understanding how sport facilities in smart cities can be optimized to meet the diverse needs of their users and contribute to the overall well-being of their communities.

Technological Integration emerged as a prominent characteristic in our study, highlighting the importance of incorporating cutting-edge technologies such as data analytics, smart infrastructure (virtual reality, and biometric sensors …) into the design and management of sport facilities. By leveraging these technologies, cities can enhance the efficiency, effectiveness, and overall experience of users, while also enabling data-driven decision-making and performance monitoring.

6. Limitations

This study has limitations. First, the survey is cross-sectional and self-reported, which constrains causal inference and may be affected by common method bias. Second, although screening criteria were applied, the sample reflects the accessible respondent pool and may not represent all stakeholder groups (e.g., municipality operators, technology vendors, professional facility engineers). Third, results are based on one national context; replication across countries and facility types is needed. Future research should combine survey-based measures with behavioral and operational data (e.g., facility sensor logs) and test measurement invariance across demographic groups.

Sustainability was revealed as another key characteristic, emphasizing the need for sport facilities to be environmentally friendly, resource-efficient, and socially responsible. By adopting sustainable practices such as energy conservation, waste minimization, and green building design, cities can reduce their environmental footprint, lower operating costs, and promote a healthier and more resilient built environment for all stakeholders.

User Experience emerged as a crucial characteristic in our study, underscoring the significance of designing sport facilities that cater to the diverse needs, preferences, and abilities of users. By prioritizing inclusivity, accessibility, and comfort, cities can create spaces that are welcoming, engaging, and enjoyable for people of all ages, backgrounds, and interests, thereby fostering greater participation and satisfaction among the community.

Community Engagement was identified as a key characteristic, highlighting the importance of involving residents, stakeholders, and organizations in the planning, development, and facility planning and operational programming. By fostering collaboration, dialogue, and partnerships, cities can ensure that their facilities are responsive to local needs, values, and aspirations, and serve as vibrant hubs for social interaction, cultural exchange, and community building.

Economic Impact emerged as a significant characteristic, emphasizing the potential of sport facilities to generate economic value, stimulate business growth, and create employment opportunities in smart cities. By attracting visitors, hosting events, and supporting local businesses, sport facilities can contribute to the sustainability and prosperity of urban economies, while also enhancing the overall quality of life for residents and visitors alike.

Innovation and Adaptability were revealed as critical characteristics, highlighting the need for sport facilities to be flexible, resilient, and future-proof in the face of rapid technological advancements, demographic shifts, and evolving user preferences. By fostering a culture of innovation, experimentation, and continuous improvement, cities can ensure that their facilities remain relevant, competitive, and responsive to changing needs and trends, while also inspiring creativity, entrepreneurship, and excellence among their stakeholders.

7. Conclusion

This study successfully developed and validated a comprehensive framework defining the characteristics of smart sports facilities within the context of a smart city. Through a rigorous mixed-method approach, six core characteristics were identified and confirmed: Technological Integration, Sustainability, User Experience, Community Engagement, Economic Impact, and Innovation and Adaptability.

The findings demonstrate that a smart sports facility transcends its traditional role as a mere venue for physical activity. Instead, it emerges as a multifunctional urban hub that leverages technology to optimize operations, prioritizes environmental stewardship through sustainable design, and places a high value on user-centric experiences. Furthermore, its success is deeply tied to its ability to foster community cohesion, generate tangible economic benefits, and maintain long-term relevance through adaptable and innovative design.

This research provides a validated model and a practical tool for urban planners, sport facility managers, and policymakers. The identified framework serves as a strategic guideline for the planning, development, and management of future sports infrastructure. By integrating these six characteristics, cities can ensure their sports facilities are not only technologically advanced but also sustainable, economically viable, and inclusive, thereby maximizing their contribution to public health, social well-being, and the overall resilience of the smart city ecosystem.

Conflict of Interest

The authors declare they have no conflicts of interest.

Generative AI Statement

The authors declare that no Generative AI was used in the creation of this manuscript.

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Appendix

Appendix 1. Initial variables of research (which created by literature review and expert's opinion).

No	Variable
1	Integrating new technologies in smart sport facilities to enhance operational efficiency and service quality
2	Data Analytics and Use of big data to optimize smart sport facility operations
3	Connectivity by using high speed internet inside smart facilities
4	Designing a sustainable sport facility is very important in the concept of smart cities
5	Implementing renewable energy systems like solar panels and enhancing Energy Efficiency in smart sport facilities
6	Designing an efficient Water Management system in smart facilities
7	Using LEED or other green building certifications to minimize environmental impact and comply with green building standards
8	Using AI technology to control of energy management systems in sport facilities
9	Safety and Security of facilities to users
10	Integrating to new technologies to smart sport facilities should enhance the performance and efficiency
11	Holding big events like concerts and famous speeches
12	Maximize using of smart facilities by multi-purpose approach
13	Programs and initiatives to encourage participation from diverse community groups (social inclusion)
14	Smart Infrastructure by using IoT devices for real-time monitoring and management in smart sport facilities
15	Smart sport facilities should help to economy growth in the city
16	Opportunity for creating job in smart sport facilities
17	Accessibility of sport facilities to all user
18	Collaborations between government and private sector to fund and manage smart sport facilities
19	Smart sport facilities generate local economic value (e.g., jobs, spending, and services)
20	Designing aesthetic atmosphere for sport facilities
21	Trying to Enhancing training and spectator experiences through immersive technologies
22	Using smart materials to increase durability and performance
23	Attracting tourism during events and boosting revenue
24	Promoting using sport facilities as a healthy place for all people
25	Modular Design of smart sport Facilities that can be easily adapted or expanded based on future needs
26	Using Smart ticketing, navigation apps, and personalized services to enhance user satisfaction and Comfort and Convenience experience

Appendix 2.

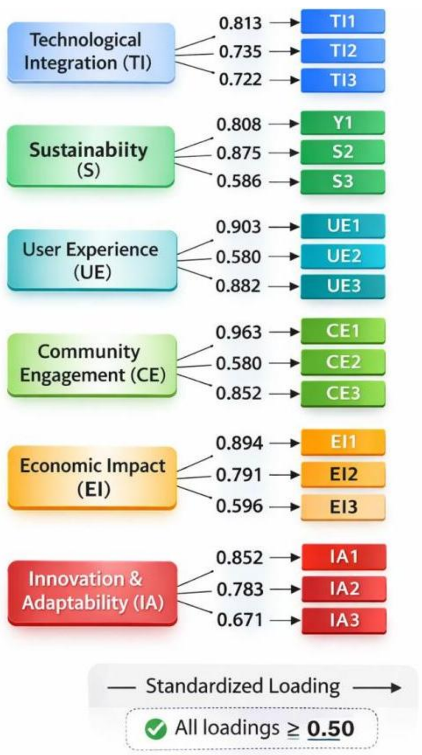

Figure A1. Smart-PLS out-put in standard-solution. TI= Technological Integration, S= Sustainability, UE= User Experience, CE= Community Engagement, EI= Economic Impact, IA= Innovation and Adaptability.

Appendix 3. Definition of sub-factors created at the research.

Technological Integration	Smart Infrastructure: Incorporation of IoT devices for real-time monitoring and management of facilities. Data Analytics: Use of big data to optimize facility operations, enhances user experience, and improves maintenance schedules. Connectivity: High-speed internet and seamless connectivity for both operational efficiency and user convenience.
Sustainability	Energy Efficiency: Implementation of renewable energy sources like solar panels and energy-efficient lighting systems. Water Management: Advanced systems for water recycling and efficient usage. Green Building Standards: Adherence to LEED or other green building certifications to minimize environmental impact.
User Experience	Accessibility: Ensuring facilities are accessible to all, including people with disabilities. Safety and Security: Advanced surveillance systems and emergency response protocols. Comfort and Convenience: Smart ticketing, navigation apps, and personalized services to enhance user satisfaction.
Community Engagement	Multi-purpose Use: Facilities designed for various sports and community events to maximize usage. Social Inclusion: Programs and initiatives to encourage participation from diverse community groups. Health and Wellness: Promoting physical activity and well-being through well-designed sports facilities.
Economic Impact	Job Creation: Opportunities for employment in the construction, maintenance, and operation of smart sport facilities. Tourism and Revenue: Attracting events and visitors, boosting local economy. Public-Private Partnerships: Collaborations between government and private sector to fund and manage facilities.
Innovation and Adaptability	Modular Design: Facilities that can be easily adapted or expanded based on future needs. Virtual and Augmented Reality: Enhancing training and spectator experiences through immersive technologies. Smart Materials: Use of advanced materials that improve durability and performance.