

Smart Governance as a Catalyst for Sustainable Urban Development: A Comparative Analysis of Digital Transformation and Citizen Engagement in Smart Cities

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Abstract: This paper conducted a comparative policy analysis and quantitative cross-sectional study to examine the relationship between smart governance and sustainable urban development across 20 smart cities. Data were collected from 1,168 valid respondents, including urban residents, municipal officials, urban planners, and policymakers, supplemented by municipal reports and environmental performance records. The study employed structured questionnaires, key informant interviews, and stakeholder consultations. Statistical analyses included multiple linear regression, structural equation modeling, and principal component analysis. The results demonstrated that smart governance implementation significantly predicted sustainable urban development, with a standardized beta coefficient of 0.44 ($p < 0.001$). Citizen participation ($\beta = 0.36$), digital public services ($\beta = 0.31$), and environmental monitoring systems ($\beta = 0.27$) were also significant predictors. The model explained 73.1% of the variance in sustainable urban development outcomes. Pearson correlation revealed a strong positive association between smart governance and urban sustainability ($r = 0.81$, $p < 0.001$). Structural equation modeling confirmed good model fit (CFI = 0.97, RMSEA = 0.044). Performance improvements included a 29.6% increase in public service efficiency, a 25.4% rise in citizen participation, and a 24.8% enhancement in urban sustainability performance. The novelty of this research lies in its integrative framework linking digital governance indicators with tangible sustainability outcomes across multiple urban domains. Our findings indicate that smart governance, when implemented through digital public services and participatory mechanisms, serves as a critical catalyst for resilient and inclusive urban development. This study contributes evidence-based policy insights for cities pursuing digital transformation strategies to achieve sustainability goals.

Keywords: Smart Governance, Sustainable Urban Development, Digital Transformation, Citizen Engagement, Smart Cities

Introduction

Global trends of rapid urbanisation come with unprecedented opportunities and a range of issues that pose challenges for cities. The importance of efficient public services and resilient infrastructure and sustainable environmental management increases with the increasing urbanization rate of 26 percent. The notion of “smart city” has now emerged as a prevailing paradigm of urban development, envisioning the city as a sort of ecosystem that inhabits and capitalizes on the potentials of a digital environment, where information and communication technologies become tools for enhancing cities' performance, livability and sustainability (Varzeshi et al., 2025). But there is an important distinction between the deployment of technology and realisation of urban transformation. Recent studies consider good governance practices, emphasizing citizens' participation, the ability to make data-driven decisions and policy coherence, as essential to successful smart city initiatives (Tomor et al., 2019).

The study takes place at the cross section of two mutually interconnected and interpenetrated areas that have so far been relatively isolated from each other and studied separately - the concept of smart governance and the concept of sustainable urban development. Smart governance is a concept that involves leveraging digital tools and participatory methods to enhance the effectiveness of governance and the creation of policies and programs in the public sector, as well as citizen engagement in these processes (Almulhim & Yigitcanlar, 2025). Sustainable Urban Development, however, is a wide range of goals that promote economic growth, social justice and environmentalized practices (Lopez & Castro, 2020). Much has been invested in smart technologies in many cities but empirical evidence of the investments impact upon measurable sustainability outcomes is also quite fragmented. Past research has focused either on technological innovation or on the policy-making process, and only few studies have systematically considered the nature of the governance process that will lead to improvements in waste management, air quality, public transport efficiency etc., for example (Hatuka et al., 2018).

The purpose stored in this context is to close this gap and conduct a comparative quantitative study on the linkage between smart governance and sustainable urban development outcomes in a series of different smart cities all over the world. We posited that cities that had a higher level of digital governance implementation (strong digital public services, citizen participation mechanisms, and integrated environmental monitoring systems would show better performance in terms of key indicators in the spheres of urban sustainability, public service delivery, and quality of life. Smart governance is a mechanism that we believe has the potential to stimulate the efficiency and effectiveness of the urban system, enhance civic engagement and accountability.

The organization below is used in this paper. Literature gaps are addressed in Section 2 by reviewing the state of the art on the notions of smart governance, urban sustainability and their intersection. In Section 3 the methodological framework (research design, data collection and analytical methodologies) is presented. The empirical analyzes results of the statistical tests are presented in section 4. Drawing on current research and theoretical models, Section 5 explores these findings in relation to current theory and practice; the summary in Section 6 outlines key findings, limitations and possibilities for further research.

Literature Review

However, smart governance has developed from its first visions as a technical concept into the wider definition of a framework that is more flexible with regard to institutions, and more participatory with respect to decision making and citizens' activation. Traditional smart city research was mainly devoted to the technologies, which are the key elements in smart cities in the city environment: sensor network, broadband connection and data platforms (Dashkevych & Portnov, 2022). Other more recent studies,

however, have pointed out the need for new governance structures to properly implement technology, nor can it be understood that, without these, sustainable results will not be achieved (Tomor et al., 2019). The use of digital platforms for participatory budgeting, real-time mechanisms of feedback between citizens and municipal authorities, and involvement of citizens in urban planning are aspects of interrelationships between citizens and municipal authorities that can be observed through research on this topic (Almulhim & Yigitcanlar, 2025). Some studies have been carried out on the link between individual smart governance meanders and urban sustainability indexes. For instance, smart city policy is more likely to be perceived as legitimate and effective when citizens are actively included in the processes of making smart city policies, such as, for example, co-creation workshop meetings or digital consultations (Przebylowski et al., 2022). It is particularly critical in the debates on solutions to sustainability problems that can only be resolved via a behavioural change and cooperation, such as waste reduction or energy conservation. Likewise, using environmental monitoring systems, like water quality dashboards and air quality sensors, has been related to better environmental performance on the grounds of transparency and accountability (Alamoudi et al., 2022).

The main goal in the current study is to providing the aforementioned void in it wherein 20 smart cities have been chosen from various economic and geographical locations as a quantitative cross-sectional study design. Unlike previous qualitative and/or small comparative scale studies, our methodology permits statistically testing hypothesized relationships and estimation of each dimension of governance effect sizes. Whilst some of the academics have forwarded the need for more longitudinal studies to be truly representative of the dynamics of smart governance (Lopez & Castro, 2020), this study is cross sectional pioneering an empirical association baseline and priority areas for more detailed and causal studies. Furthermore, our research stacking multiple data collection methods (including stakeholder surveys and information from municipal reports and environmental performance records), mitigates the single-source-of-data risk mentioned in some previous research (Hatuka et al., 2018).

The novelty of the research compared to the previous ones is to model the pathways that explicit connects the concepts of smart governance with the sustainable urban development outcomes. Finally, our analysis conceptualizes digital governance mechanisms as having a causal impact on efficiency of public services, environmental monitoring and, ultimately, better resource management and quality of life, which varies depending on the level of citizens' participation and the range of the institutional response. Such an integrative approach moves away from purely correlational analyses towards an understanding of how and why smart governance is relevant for urban sustainability and provides a more solid basis to shape smart city policies and prioritize investments in smart city projects worldwide.

Methodology

The study design, the study population, instruments of data collection, methods of data analysis and creating composite indices, which are an operationalization form of the central concepts of the study (smart governance and sustainable urban development), are presented in this section. The methodology was developed to be repeatable and able to deal with a variety of city environments to analyze presumed relationships.

Research Design and Study Area

A comparative policy analysis research design and quantitative cross-sectional approach were used to examine the smart governance initiatives vis-à-vis sustainable urban development outcomes. This design was selected as it would enable data from multiple cities to be systematically collected at a single time so that it could be compared but would overcome challenges with differences in governance and sustainability performance (Hunziker & Blankenagel, 2021). The study incorporated 20 smart cities-

three each of the six stages selected for their geographic and geographic, smart governance maturity and economics spectrum. The selection criteria were the cities' pledged smart city activities, city sustainability reports and availability of stakeholders network for collecting primary data.

Participants and Sampling

1200 questionnaires were returned from urban residents (72.3 %), municipal officials (14.6 %), urban planners (7.5 %) and policy makers (5.6 %). Also, Key Informant Interviews (KII) with Government officials responsible for guiding smart city governance were done to take their institutional perspective. Stratified purposive sampling was used to recruit participants from different city districts and socioeconomic strata and professional role pertaining to urban governance. Finally, there were 1168 valid responses after data processing and data cleaning (nonsampling error of 97.3%).

Data Collection Instruments and Variables

There were three instruments used for collecting primary data which were complementary. Initially, the structured questionnaires have been filled with the urban population and the municipal stakeholders measuring the Perception of implementation's Smart Governance, Perception regarding the use of Digital Public Services, Perception of citizen participation and Perception of the quality of life. To look at the governance structures and sustainability issues from institutional perspective, key informant interviews (KII) were also conducted with city actors, the municipal administration and urban planners. Thirdly, the preliminary results were validated and qualitative inputs were collected by conducting stakeholder consultations in every city. Secondary data from municipal reports, urban development plans and environmental performance records and the smart city policies were the most frequently cited sources of data.

The variables that were collected were: demographic variables (age, occupation, education level); digital governance implementation level, judged by a smart governance index (SI), that included a series of comprehensive indicators regarding their availability and digitization level in public services (obtaining a permit, paying bills, etc.); use of digital public services (frequency of using electronic public services); citizen participation (number of public consultations; participatory budgeting; etc); urban infrastructure quality; environmental sustainability indicators (air quality, water quality etc); lack of efficient garbage collection (frequency; percentage of recycled garbage etc); public transport accessibility; energy efficiency indicators (energy performance of public buildings, energy grid management, etc); management of water resources; urban resilience indicators (frequency of preparedness for flooding, timeliness of emergency response etc); quality of life.

Data Preprocessing

A series of processing techniques were used on the data to maintain data validity and quality. Incomplete responses – more than 15% of their items are missing – were not included in the data set. The missing values were imputed using the $\square$ imputation $\square$ method, a common method, which does not change the data distribution (continuous data were imputed with median, categorical data were imputed with mode, see Newman 2014 for further details). Data Coding was done to ensure that the response forms are uniform particularly the likert scale items. Outlier data points were identified using the Interquartile Range (IQR) method and then analyzed and winsorized based on real world context as needed, leaving elements that were below 1.5 times the IQR of the first quartile and greater than 1.5 times the IQR of a third quartile outlier data points. The data for all variables were min-max normalized to have values between 0 and 1 to make them comparable with other indicators with varying measurement units of the

original data (Abdelkader et al., 2025). All composite scales had Cronbach's Alpha internal consistency scores above 0.80 indicating high internal consistency.

Composite Index Construction

Seven composite scores were developed for theory-based constructs by conducting a Principal Component Analysis (PCA). The principal component extraction method was used for each set of indicators to produce the first principal component as a proxy for the composite indicator as indicated in Table 1.

Table 1. Composite indices and constituent indicators

Index Name	Constituent Indicators	Cronbach's Alpha
Smart Governance Index	Digital platform availability, service digitization score, open data portal usage, online feedback mechanisms	0.87
Urban Sustainability Index	Waste management efficiency, air quality index, energy consumption per capita, green space ratio, water resource management	0.84
Environmental Performance Index	Air quality monitoring coverage, water quality compliance rate, noise pollution levels, carbon emission reduction rate	0.82
Citizen Satisfaction Index	Perceived service quality, trust in local government, ease of accessing information, satisfaction with urban amenities	0.88
Public Service Efficiency Index	Service delivery time, application processing speed, user satisfaction with digital services, cost per transaction	0.85
Urban Resilience Score	Flood preparedness score, emergency response time, infrastructure redundancy, disaster recovery capacity	0.79
Digital Governance Adoption Index	Share of population using digital services, frequency of digital engagement, broadband penetration rate, mobile app download rate	0.86

Analytical Framework

The statistical analysis was carried out in a number of steps. Initial descriptive statistics (means, standard deviations, frequencies) were calculated for all variables to describe and to examine the properties of all variables in terms of their distributions. Secondly, correlation approximation was provided for the bi-varied relations between the smart governance parameters and sustainability results, using Pearson correlation analysis. Thirdly, significant factors (urban sustainable development variables) in the case of Urban Sustainability Index, the Smart Governance Index, the citizen participation score, the Digital public service utilization score, and the environmental monitoring system index) were determined using multiple linear regression. The assumptions of linearity, normality of residuals and homoscedasticity were confirmed by diagnostic plots and statistical tests. Next, an another data analysis technique was employed to compare the mean sustainability index score among cities that were grouped based on the level of enacting smart governance implementations, which was

one-way ANOVA. Fifth, structural equation modeling (SEM) analysis was performed to analyze the pathways between smart governance and sustainability outcomes through citizens' participation, improvement of public services and others (Han et al., 2025). We modeled the SEM as mentioned above, using the latent variable of smart governance (organized by the variables of digital platforms, service digitization, citizen participation), the latent variable of sustainability outcomes (organized by the variables of environmental performance, infrastructural quality, and resource efficiency); and the latent variable of quality of life (organized by citizen satisfaction and urban resilience). Chi-square per degree of freedom ratio, Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), and Root Mean Square Error of Approximation (RMSEA) were used to assess the model fit. The program SPSS 29 was used for descriptive and regression statistical analysis of all the data, while the program AMOS was used to create the SEM and R (Version 4.3) was used to perform the PCA and other diagnostics. The information was then subsequently mapped, and spatial analysis conducted for representation at city scale, showing spatial variation across governance and sustainability indices.

Results

The results from the statistical analysis of the cleaned data of 1,168 valid responses are provided in subsequent subsections. The results are presented as follows: firstly, the participant characteristics are described, followed by the results of the smart governance initiatives and then the findings of sustainable urban development, achieved under the actions of smart governance, and lastly, the results of the inferential analyses testing the expected relationships among categories of smart governance and indicators of sustainable urban development.

Participant Characteristics

Following data cleaning (which also involved removing incomplete responses, and imputing some of the missing responses using median imputation), there were 1,168 valid responses and the initial sample remained at 1200 participants. This is very good data quality with a high retention rate of 97.3% showing that there was very little attrition which should aid the reliability of the data quality in subsequent statistical inferences (Newman, 2014).

Urban planners constituted 7.5% of the participants, who contributed to the knowledge of urban planners on spatial and infrastructure elements of urban planning concerning land-use and the distribution of green space and transport. Especially their attitude towards how, by implementing smart governance policies, resources are managed and urban infrastructure is improved (Lopez & Castro, 2020). A sample of policy actors (5.6%) has been added due to the strategic inputs and perceptions influencing the smart city pathways. They have shared their insights about the political and institutional frameworks in which digital governance projects are successful or unsuccessful in supporting sustainability (Q. Hu & Zheng, 2021).

Of note is that a high proportion of the sample (84.2%) identified as 'digital public service users'. This contribution is remarkable as many of the cities selected are already full-fledged smart cities and there is a relatively high adoption of digital platforms to obtain feedback from citizens, issue permits and other municipal services, and pay taxes. This is demographically advantageous as it covers individuals who have actually interacted with digital governance that is being measured – this increases the validity of variables measured in this study such as citizen participation in digital public services and citizens in digital governance (Leow, 2026). There were no significant disparities between professional groups in using digital services, indicating there is no unequal adoption of digital services in the different professional groups in urban regions.

The multi-faceted nature of smart governance construct and its relation to sustainable urban development outcomes is explored underpinned by a rich mix of technology users and institutional actors, who provide a strong basis of research. This heterogeneity of the various types of stakeholders enables the transfer of conclusions to other smart city contexts having a similar mix of various stakeholders (Meijer & Bolívar, 2016).

Table 2. The distribution of characteristics of the final analytical sample (N = 1168).

Characteristic	Percentage
Urban residents	72.3%
Municipal officials	14.6%
Urban planners	7.5%
Policymakers	5.6%
Digital public service users	84.2%

Smart Governance Performance

Public service efficiency was the biggest area of improvement, with a 29.6% increase over baseline. This aligns with the theoretical perspective that digitization of municipal processes, including applications, bill payments and permits being issued, eliminates friction from administration that can slow the delivery of services within the municipalities (Varzesi et al., 2025). The efficiency improvements may be due to the implementation of an integrated digital platform that can automate repetitive tasks, freeing time up for staff on more intricate problem-solving endeavors, and also track service requests in real-time by the citizens. At the same time, adopters of digital tools for consultation and participatory budgeting also showed this growth by expanding civic engagement beyond the traditional face-to-face style of the public meeting by 25.4% (Almulhim & Yigitcanlar, 2025). The extent of the growth demonstrates how digital can overcome the hesitation to participate and enable a broader swath of urbanites to be involved in urban planning and policy making.

Urban infrastructure management saw improvements of 23.8% as digital monitoring and asset management systems have helped improve maintenance and optimisation of the physical infrastructure of roads, bridges, water systems and other public utilities. This research corroborates other work that seeks to reduce downtime and extend the useful life of critical infrastructure (CI) by using sensor networks in condition monitoring systems (Hatuka et al., 2018). There was an increase in inefficiency in waste management of 27.1%, possibly because of smart sensors in bins, waste collection route optimisation and digital waste flows tracking. These technologies provide the opportunity for cities to far improve collection schedules, based on current contents of cans or bins as opposed to set schedules, which not only saves fuel but also cuts back on service costs and better ensures reliability of services (Lopez & Castro, 2020).

There was a 21.7% gain in energy management efficiency, which is indicative of the use of smart grid features, building energy management systems, and demand-response systems, which enable more precise control of energy consumption patterns. Remarkably, this enhancement is occurring at a time where climate change mitigation is being increasingly emphasised and where urban energy systems contribute to the national emissions reduction targets (Tomor et al., 2019). Enhanced results have been achieved for environmental monitoring (+26.9%) and expanding networks to monitor air quality, water quality and noise pollution contribute to this increase. Publicly accessible systems using dashboards

enhance transparency and municipal authorities' accountability regarding the environment (Leow, 2026).

The positive change in all 06 indicators consistently (the range from 21.7% appeared in Hilo City to 29.6% in Kiama City), creates overwhelming evidence that the smart governance measures undertaken in all 20 cities have been successful in improving the performance of each city. It also needs to be noted that the degree of improvement served by digitalization can be different as some parts of 'smart governance' (such as the improvement of the efficiency of public service provision) can be more easily achieved starting with digitalization, other parts (such as energy management) may also require digitalization efforts but may have a longer time horizon or may be harder to attain in institutional change. These findings form a solid empirical underpinning for the subsequent analyses of the relationship of these governance performance gains with sustainable urban development outcomes.

Sustainable Urban Development Outcomes

This subsection will summarize the open question item responses to the measurements listed above with regard to the state of smart governance in 20 cities, in terms of sustainable urban developments. Five outcome indicators are analysed, including (1) urban sustainability performance, (2) time spent getting service from the municipality, (3) efficiency of air quality monitoring, (4) use of public transport and (5) water resources management efficiency. The indicators were selected as they can represent the complexity of sustainable urban development, the environmental quality, the efficiency of the use of resources and the accessibility to services (Lopez & Castro, 2020).

The average municipal service delivery time was seen to be reduced by 22.5% in the study cities. Some of the regular transactions that are currently automated, and which have caused the cut-back, include serving requests and permitting and tax processing via digital means. Especially in terms of improving citizens' satisfaction and trust in local governments, the efficiency in service provisioning is a concrete and direct impact of smart governance that is directly felt by citizens in their daily lives (Almulhim & Yigitcanlar, 2025). This is larger than previous estimates based on single city studies and seems to reflect that the cross-city comparative approach uses a wider spectrum of benefits, which may be multiplied by cities learning from one another and creating synergies by sharing good practices.

Monitoring of air quality efficiency increased by 19.8% (as a result of the upscale of monitoring network and real time data dashboards which allows to view the results of monitoring pollutants concentration with more details and high frequency). This enhancement helps the city authorities to identify pollution hot spots and disabilities to take proper action, in time, and even to issue the necessary health warnings, such as controlling the movements of vehicles and stopping industrial pollutants. Monitoring capability is important as it is a key enabling tool for developing evidence-based environmental policies, and is a key enabler in shifting air quality management from being a 'reactive', complaints-driven approach into a 'proactive' data-driven approach (Hatuka et al., 2018). The increase in monitoring efficiency by 19.8% is especially impressive as the air quality is one of the most difficult environmental areas in which to govern, and places a responsibility on a number of sectors and levels of government.

With public transportation use increasing by 20.7% as a result of the findings, smart mobility solutions have proven effective at encouraging a mode shift from using road transport and onto public transit such as through real-time transit information applications, ticketing integration and responsive routing. This increase can have a cascading effect on the sustainability of cities, including relieving traffic congestion, reducing the emission of GHGs and improving air quality. The same kind of utilisation growth was also observed in previous studies where it was proved that the use of public transport due to the provision of digital public information decreases uncertainty and inconvenience and so increases the potential of

citizens to use public transport over the private car (Lopez & Castro, 2020). In such a big transformation change, it suggests a possibility that the behavioral change in the mobility area is achievable with Smart Governance actions on, in relatively brief, time frames.

The findings for all five outcome indicators indicate that better sustainable urban development has been possible thanks to smart governance initiatives – as indicated by a 17.9% to 24.8% increase in score – in a consistent and measurable way. The improvements shown reflect the fact that there are areas of improvement which will be more directly felt from interventions through digital governance, whereas others such as water resource management require complementing with other investments in physical infrastructures and institutional capacities to fully harness the gains of the digital investments. These findings hence corroborates in theory the statement that "governance mechanisms" are one of the key factors that promote sustainable urban development and provide the base for the subsequent inferential analyses which expects to explore further the statistical relationship between the governance mechanisms and sustainably urban development outcomes.

Regression Analysis

A multiple linear regression was carried out, to quantify the predictive ability of the specific smart governance mechanisms on sustainable urban development. As the dependent variable, a composite Urban Sustainability Index was created based on factors such as waste management efficiency, air quality index, energy consumed per capita, Green Space index, water resource management and more. The Independent variables comprised of the four main constructs that were assumed to be independent predictors and these were: Smart Governance Implementation (as manifested by the over-all Smart Governance Index), Citizen Participation score, Digital Public Services utilization score, and the Environment Monitoring Systems index. These predictors were chosen because of theoretical background identified through the literature review that sees digital governance mechanisms, participatory processes, and environmental monitoring as the key levers that enable sustainability outcomes (Almulhim & Yigitcanlar, 2025).

Sustainable urban development measures for the 20 smart cities was regressed on the four predictor variables and the model was a good fit, $\alpha^2 = 0.731$, that is 73.1% of the variance in sustainable urban development of the 20 smart cities was explained by the four predictor variables. Such high explanatory power suggests that certain dimensions of smart governance are highly relevant in explaining sustainability performance development, but also that other factors not included in this model may explain the remaining 27% of the variance, for example economic factors, historical investments in infrastructure and climate factors (Hatuka et al., 2018). The diagnostic plots showed good model fulfillment: The linearity of the relationships is satisfactory, the random errors follow a normal distribution, and the variance of the random errors is homogeneous, thus supporting the validity of the estimates of the regression coefficients.

Table 3. Multiple regression analysis results predicting the Urban Sustainability Index.

Predictor Variable		Standardized β	t-value	p-value
Smart Governance Implementation		0.44	12.84	<0.001
Citizen Participation		0.36	10.21	<0.001
Digital Public Services		0.31	8.92	<0.001

Predictor Variable		Standardized β	t-value	p-value
Environmental Systems	Monitoring	0.27	3.12	0.002

Note: Dependent variable is the Urban Sustainability Index. Model $R^2 = 0.731$, adjusted $R^2 = 0.725$, $F(4,1163) = 314.27$, $p < 0.001$.

Table 3 shows that all four become were statistically significant and made a contribution to the model. Smart Governance Implementation had the biggest standardized beta coefficient of (). The result reveals that generally, the availability of open data platforms, the digitisation of services and the presence of digital platforms (generally called 'digital governance maturity') is the main way in which smart governance helps achieve sustainability outcomes. This size of the effect suggests that cities with more comprehensive digital governance systems, overall, are more effective in terms of sustainability performance, which underscores the importance of adopting a holistic approach to digital transformation, rather than focusing on any one technology (see Tomor et al., 2019).

The second highest standardized beta was that for Citizen Participation (). This finding is pointing towards the importance of inclusive governance processes in sustainable urban development. Independently from other factors such as the overall level of smart governance implementation, engagement of citizens with policy-making and participatory budgeting and digital consultation is linked to better sustainability outcomes. This discovery confirms previous studies that insist that participatory governance strengthens the legitimacy, relevance, and effectiveness of urban policy; in particular, urban waste management and public transport, which require changes in people's behavior.

A significant predictor was also that of Digital Public Services utilization, (). This is an outcome that indicates that the adoption and use of digital municipal, such as applying for permits, paying bills or making a request via a digital platform, have a positive impact on sustainability outcomes. These connections can be understood by improvements in urban performance metrics, primarily service efficiency and reduction in resource consumption via digitalisation and by enhancing the convenience of the citizen (Varzeshi et al., 2025).

Both the regression analysis and the partial regression analysis results indicate that smart governance is a complex predictor of sustainable urban development, as well as the types of governance separately and significantly contribute to the prediction of smart governance. The strong model fit () suggests that the theoretical argument – the four variables (digital governance implementation, citizen participation, digital services, environmental monitoring) collectively make up the key levers for urban sustainability – finds high empirical support. Based on the above findings, the following correlation analysis and a structural equation model will be developed, which will help explain the relationships between these variables.

Correlation Analysis

To explore the multivariate relationships of key factors of smart governance and sustainable urban development an analysis of the Pearson correlation was performed on the composite index that emerged from the principal component analysis. The main objective of this analysis was to establish, quantify and explain the direction and strength of association between the Smart Governance Index and Urban Sustainability Index as well as exploring correlation between the components of the smart governance and the various sustainability outcome indicators.

The overall Smart Governance Index had a statistical correlation result of positive and significant at $r = 0.81$, $p < 0.001$ and with the Urban Sustainability Index. This correlation was found to apply in many sustainability indicators including waste-management efficiency, air quality, energy consumptions, green spaces and water-resource management. This correlation value was particularly important because it showed that there was relatively high common variance between the two constructs comprising 65.6% of the variance in the urban sustainability outcomes, caused by the variance in the smart governance performance. This result is thus closely linked to the main hypothesis of this study: digital governance and participatory policymaking is strongly associated with the sustainability outcomes in different urban contexts (Tomor et al., 2019).

Correlation was further analyzed between every dimension of the concept of smart governance and the actual Urban Sustainability Index and showed a complex network in each of the dimensions. The results of the regression ($r=0.74$ and $p<0.001$) were confirmed by the strong positive correlation between Citizen Participation and the sustainability index score. The correlation shows that there are relationships between cities having digital consultations, participatory budgeting, and policy co-creation, resulting in environmental outcomes, quality of infrastructure, and efficient use of resources. The existing correlation could be linked to a growing sense about the legitimacy of the policy (Przebylłowicz et al., 2022), citizens' engagement with sustainable solutions and the incorporation of a variety of local information into the decision process for urban planning.

There was also a strong positive relationship between the utilization of Digital Public Services and the Urban Sustainability Index ($r=0.69$ with a p value <0.001). The findings revealed a correlation between the use and adoption of digital municipal services, such as electronic applications, with the sustainability performance, as did online payments, electronic requests for municipal services, profile data and the use of mobile apps. The relation could be related to the improvements in efficiency as well as resources gained because of digitization in the administration function and/or to the ease of digitization for citizens facilitating a PDF-based sustainability approach such as segregation and conservation (Varzeshi et al., 2025).

Environmental Monitoring Systems index and Urban Sustainability Index was highly moderate correlated ($r = 0.63$; $p<0.001$). This correlation is a bit lower than others in relation to dimensions of governance overall, but it remains statistically significant and substantively significant. This relatively weak association can be explained by the fact that the environmental monitoring is very important in assessing environmental conditions and guiding to the environmental policy, however, it cannot result to outcomes of sustainability without systemic policy responses and behavioural changes; therefore, outcomes of sustainability are co-produced with environmental monitoring (Hatuka et al., 2018).

The interrelationships among the governance dimensions were also correlated to understand the correlations among the four predictor variables. The Smart Governance Implementation index was also significantly and highly related to Citizen Participation ($r=0.78$, $p<0.001$), Digital Public Services ($r=0.82$, $p<0.001$), and Environmental Monitoring Systems ($r=0.71$, $p<0.001$). These high inter-correlation values between the governance predictors are not unexpected as they are aspects of a Smart governance system. Cities that have well-established digital services for facilities, from end-to-end, will also be more likely to implement participatory tools and environment monitors, which will create a synergical effect – a city with one system will be more likely to implement the others. It should be noted that the multicollinearity problem does not affect the regression results; rather reflect the importance of interpreting the contribution level of each predictor with discretion as each predictor contain part of the amount of variance that is not shared with other predictors (Almulhim & Yigitcanlar, 2025).

The correlation analysis also examined the correlation between Smart Governance Index with the certain sustainability outcome indicators. A high positive correlation was found between the index and the service delivery time reduction that was observed in the cities ($r=-0.79$, $p<0.001$) that indicates an association: the higher a city's digital governance is, the more it reduces service delivery time. The correlation coefficient was negative, suggesting that the scores for the introduced product's governance are related to the metric of time, but in opposite directions. Similarly, high correlations could be seen between the Smart Governance Index and the efficiency of air quality monitoring ($r=0.76$, $p<0.001$); the public transportation utilization ($r=0.72$, $p<0.001$); and efficiency of water resource management ($r=0.68$, $p<0.001$). The findings always confirm that benefits of smart governance are not limited and not only in terms of specific types of urban sustainability.

The outputs of the correlation analysis provide an interesting insight into the positive and strong correlation between sustainable urban development and smart governance. The decisive finding is a value of $r=0.81$ in the correlation between the respective correlation for the composite index, which gives us a very good empirical evidence for the causal relationship of the above described structural equation. The improving sustainability outcomes trend is identified as not just a coincidence – but a systematic linkage of the digital governance, participatory mechanisms and environmental monitoring systems to this improvement in the sustainability outcomes is identified.

Structural Equation Modeling

Given the association of the two variables, the bivariate association and a series of predictor relationships based on regression and correlation analysis, the structural equation modelling (SEM) was applied to investigate the hypothesized causal relationships between the smart governance mechanisms and sustainable urban development outcomes. The SEM model was selected as the analytical tool because it accounts for the possibility of measuring multiple regression equations, the specification of latent variables to represent measurement error as part of the present study, and the ability to evaluate more complex mediational pathways in order to include the essence of the theoretical model which underlies the current study (Han et al., 2025).

Adopting a conceptual approach of the SEM model, the following indicators were defined: Smart Governance Index, Citizen participation Score, and Digital Public service utilization rate and Sustainable urban development outcomes were considered direct and indirect results of a latent/construct of smart governance. The direct pathway denotes the direct impact of governance mechanisms on sustainability outcomes, the indirect pathway denotes the impact of the mediating factors which were hypothesized to mediate between the governance mechanisms and the tangible improvements in the resource management processes, infrastructure quality and environmental quality.

The results of the hypothesized model fit were favourable for the model fit indices (the maximum likelihood estimation approach). The value of the Chi-square per degree of freedom ratio (χ^2/df) was 2.06, and was lower than the widely accepted value of 3.0 as the standard for acceptable model fit (Han et al., 2025). The ratio is a measure of how close observed covariance matrix is to the model-implied covariance matrix and suggests the possibility of being realistic in assuming the causal structure provided by the model set as true. The hypothesized model was compared with the null model (without anything that could link the variables) using the Comparative Fit Index (CFI) and was obtained a value of 0.97 (better than the recommended value of 0.95, by Fornell & Larcker, 1981). Similarly, the Tucker-Lewis Index (TLI) was 0.96 which is above the “standard” 0.95, and indicates further that the model was a good fit to the data and that model complexity was penalised (Lin et al., 2017). The Root mean square error of Approximation (RMSEA) was 0.044 (90% confidence interval [0.038; 0.050]). This is

significantly lower than the 0.05 level deemed to be a close fit and the level under 0.08 (L. Hu & Bentler, 1998) considered as an acceptable fit.

In general, the fit indices suggested by the model are very good, with an admissible statistical support towards the theoretical construction of the model of Smart Government as a great conditioner of the sustainable development of cities. The relatively small RMSEA value of 0.044 is very promising, representing an excellent fit between the real and the modeled relationships in the population. To the contrary, RMSEA scores of >0.10 would indicate that the model was not a good fit and hence the hypothesized causal structure may not be valid (Kaplan, 2008). The CFI indicators (0.97) and TLI (0.96) indicate that the model explains a high proportion of variance observed in the data, and further, the directionality assumed by the model (proposed mediators between the variables) were found to be supported by the observed data.

As for the direct path, the common latent variable model "smart governance" was statistically significant for the common latent variable "sustainable urban development" based on the standardized path coefficient which is 0.52 with statistical significance $p < 0.001$. This study has revealed that in stages as far as measures of sustainability are concerned, the SA_{4} significantly impacts the measures of sustainability directly after introducing the mediating variables of PE and EM. The indirect pathway through public service efficiency also was important, though, with a standardized indirect effect of 0.18 ($p < 0.05$), and the pathway constrained by environmental monitoring systems, of 0.12 ($p < 0.05$). Direct and indirect effects were summed to achieve the overall effect of smart governance on sustainable urban development; The effect achieved is $r = 0.82$ which is very near the effect obtained while conducting Bivariate analysis ($r = 0.81$). This homogeneity of the bivariate and multivariate results gives a greater validity to the results.

It is important that the mediations paths obtained from SEM bring in relevant knowledge on how smart governance helps to achieve sustainability. Fourth, there would seem to be a significant indirect channel of public service efficiency – efficiency gains arising from public service digitisation (in terms of reduced processing times and reduced administrative costs, etc.) are not ends in themselves, but are important mediators between governance improvements and their downstream effects in terms of sustainability. Similarly, data from environmental monitoring networks and dashboards can assist in improved environmental management practices for improved air quality, water resource management and waste reduction. In addition to predicting sustainability, the findings expand on the regression findings and reveal how smart governance relates to sustainability or how it affects it in other ways.

The results showed that the findings from of the central findings of the SEM supported the results of regression and correlation analysis and can be known in detail with respect to the causality of the relationship between smart governance and urban sustainability. The good model fit indices and high scores of the path coefficients indicate empirical evidence that supporting cities' digital governance ability encompasses the three dimensions as its main tools to ensure measurable progress towards sustainability goals.

Discussion

The findings of the empirical comparative study presented here are clear: "smart governance" is a game-changer that has a crucial role to play in promoting sustainable urban development, while, in turn, technology as enabler is no longer a one-way street- abandoning the technology for the better, but changing the perception of sustainable urban development for technology providers as well. Modelling good fit indicators, such as the CFI of 0.97 and RMSEA of 0.044, provided statistically sound validation of the test of the hypothesized causal paths, from digital governance its consequences at sustainability. The findings have important theoretical significance given the pervasive view that sustainability can be realized in the city largely through technological investments in infrastructure. However, our results indicate that the governance framework of technology implementation and citizens' engagement are what can make the difference to realize sustainability outcomes (Almulhim & Yigitcanlar, 2025). This conceptual shift is from the issue of "digital tools are there" to the issue of "digital tool quality of institutional set-ups and participatory processes that drive their use. The strong findings also highlight that citizens' engagement (and not just smart governance in general) has a major impact on the results of sustainability, so indicating that citizen engagement is not a byproduct of smart governance, but a significant factor in affecting better outcomes for the environment and infrastructures.

The advantages for the practice are twofold: firstly, the results provide a baseline for policymakers and urban planners; and secondly, the practical recommendations are ways to help shift investments in digital governance towards measurable benefits of sustainability. The regression analysis also showed that smart governance implementation was the most significant variable among other variables with standardized beta value 0.44, meaning that the implementation of the smart governance framework concepts in cities must not be developed from each technological project individually, but smart governance frameworks should be developed integrately. On the municipal side, this should include coordination and linkage of cross-departmental data sharing, and digitisation of services, with investments in open data platforms, to reap the greatest benefit from synergies. The impact of citizen involvement is clear, as digital consultation platforms and participatory budgeting processes are forms of meaningful engagement with citizens that can have a direct positive impact on unsustainable waste management, public transport systems and environmental quality, with a beta of 0.36. Practitioners will then require investing in hardware and software, capacity building, as well as building a participatory protocol that does include the marginalised groups. Furthermore, the indirect effect of the SEM environmental monitoring pathway has been identified as 0.12 i.e. sensor networks should not be gathered solely for notification purposes but with the aim of informing policy decisions. Interventions can be dictated by monitoring data, such as closing streets during high pollution periods or water conservation efforts during drought, included through feedback loops that will allow municipalities to harness these insights.

There are several methodological limitations in the study that limit the validity of the general conclusions that can be drawn. Outline the cross sectional design, as this was helpful in collecting data in several cities, but no good at determining the time sequence by which smart governance was put into place and sustainability improvements. As was suggested by the analytical framework, a reverse causality effect might have influenced the decision of investing in digital governance: on average, cities that invested in digital governance might have shown higher sustainability performances at baseline. On the other hand, cities with higher baseline sustainability performances might have been more likely to invest in digital governance, as can not be excluded by the analytical framework presented (Hatuka et al., 2018). Some of the sample population, with 72% identified as residents of cities, may be reflecting the views of urban residents and could have a user-centric bias, that does not capture institutional challenges to implementation. Depending on the type of underlying data source material in some

indicators (e.g. municipal reports or environmental records), there may be some aspects of reporting that are biased or inconsistent. Not all municipal surveys employ the same methodology to ensure that data is collected and verified. Furthermore, the smart governance predictors are not independent with each other; relatively high degree of inter-correlation between all predictors ranged between 0.71 - 0.82, and this is the problem that prevents determining the effect of smart governance dimensions each other alone, due to the multicollinearity. The findings are also applicable to smaller cities or regions where the digital infrastructure is less developed, but this is not the case for smaller cities with less developed smart city initiative or for instances in developing regions.

There are a number of limitations of this study. Other studies should further replicate these limitations by also implementing multitemporal designs whereby smart governance and sustainable outcomes would be observed through sustainable periods of time, thereby employing the technique of cross-lagged panel models and enabling temporal precedence and reinforce causal arguments. Comparative studies involving a larger set of heterogeneous cities across various geographic areas and economic development would help establish which relationships would persist across all of the heterogeneous contexts, especially those in fast growing urban areas of the Global South where the impact of digital divides on the success of smart governance interventions could moderate the observed relationships (Varzeshi et al., 2025). Future studies could delve into the moderating role of institutional practices and constructs like the legal framework, political stability, and bureaucratic culture that can influence the potential contribution and limitations of digital governance to sustainability. The present findings suggest a strong impact of citizen involvement; no distinction between the various citizen participation concepts, like deliberative, consultative and co-productive participation, is drawn to illustrate which type proves to have the greatest benefit for sustainability for future use and research. The implications of digital governance, mostly centered around privacy and algorithmic bias in resource distribution and the lack of digitally literate subjects in decision-making process must be studied systematically to ensure inclusive and equitable smart city development. Finally, a pathway between the use of digital tools and the development of sustainable outcomes, which needs to be explored with qualitative and mixed methods research in order to explain the quantitative findings of this study would also warrant further investigation.

Conclusion

This study was conducted with the aim to explore the importance of smart governance actors in enabling sustainable urban development in twenty smart cities while assuming that digital public services, citizens participation and environmental monitoring have a positive impact on smart cities sustainable development outcomes, as also tested in this study. The results obtained showed that smart governance is an important factor for sustainable development and the regression model explained 73.1% of the variance in the Urban Sustainability Index. The functional structural equation model results also validated the hypothesized causal models; that smart governance was directly linked to the sustainability outcomes and indirectly by the public service efficiency as well as environmental monitoring. The results contribute to the knowledge because they are empirical and cross-cities examples that benefit from the quality of governance processes not only the usage of digital technologies – to explain the establishment or failure of sustainability initiatives in the city level.

The current research has some constraints and thus a number of recommendations for future study are presented. Future studies with similar switch to governance digitization involving similar timing would aid in making causal interpretations rather than what a cross-sectional design is able to offer. There is a need for further comparative research in smaller Administrations and between cities in the Global South to define whether there are any other commonalities beyond the smart city contexts described herein.

Moreover, the area of institutional change that takes place in the municipal bureaucracy is a little-studied mechanism that would be illuminated by qualitative case studies. The connection with practice is what needs to be created: a digital governance model which assigns to the servicedigitization and may be associated to participative mechanisms having impact, since they lead to the sustainability benefits documented in this study.

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