

Role of Construction Management in Smart City Infrastructure Development: A Review of Digital Tools, Lean–Sustainable Practices and Implementation Challenges with Evidence from Sagar Smart City, India

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Abstract— The current pace of urbanization has imposed unprecedented strains on transport, water, energy and housing networks and the smart city paradigm has become the key policy response. However, the effectiveness of smart city programmes rely more on the construction management (CM) systems involved in planning, coordination and delivery of the physical infrastructure underpinning smart city programmes. The literature reviewed in the following paper is divided into six themes: smart city concept and smart city components; core functions of CM (planning, scheduling, cost, quality and safety); digital tools (Building Information Modelling (BIM), Internet of Things (IoT), artificial intelligence (AI)); lean and sustainable construction; risk management, stakeholder management, public–private partnership (PPP); and field evidence from smart city Sagar, Madhya Pradesh. The results of the synthesis indicate that the use of BIM-based coordination in the project reduced the number of design errors from 25 to 8 and rework cost by 64%, while lean JIT delivery reduced material waste by 60-67% and smart building systems reduced the energy demand by 40%. The adaptive traffic control in Sagar reduced junction delay by 37.5 %; sensor-based LED street lighting reduced connected load by 52 % and the Integrated Command and Control Centre (ICCC) reduced complaint response by 75 %. Financial risk (20/25) and inter-agency coordination (20/25) were identified as the main barriers. A challenge–strategy framework and an agenda of future research are suggested on digital twins, AI-assisted scheduling and capacity building.

Keywords— Smart city; construction management; building information modelling; lean construction; risk management; public–private partnership; integrated command and control centre.

1. Introduction

Industrial development and the creation of new urban jobs over the last few decades has resulted in a steady movement of people from the countryside to the cities leading to populations which are many times higher than those they were designed for. Traditional, mostly fixed planning approaches have fallen behind and the typical issues that most urban areas face are well known: water scarcity and leakage, traffic congestion, waste management and environmental degradation, energy supply inefficiency. The smart city concept addresses these challenges by integrating and linking information and communication technology (ICT), sensing and data analytics to city systems in order to be able to monitor and manage service in real time [1, 2]. Smart cities are thus defined not just as technologically-savvy regions, but also as urban systems which aim to achieve improvements in efficiency, sustainability and quality of life, at the same time [3]. However, there are concerns that the term is used broadly and that technology is not enough to create a smart city [4].

The Smart Cities Mission, launched in 2015 for developing 100 cities through area-based and pan city projects delivered by special purpose vehicles (SPVs) is one of the biggest programmes of this kind in India. The intelligent transport, smart utilities, energy efficient buildings and digital governance are all construction projects and its core components. They have to be designed, procured, scheduled, built and commissioned within a strict budget and time

frame, and frequently in a dense operating urban location. Cost overruns, delays, and lack of benefits are common issues to large-scale infrastructure projects around the world [6, 7] and managerial causes of delay predominate over technical causes [8]. The quality of the construction administration (CM) is thus a crucial, but not yet studied, factor in determining whether smart city goals become reality with a workable infrastructure.

Construction management is a technical and managerial practice that can be used to plan, coordinate and control a construction project from the beginning to the completion. It is an increasingly digital tool that combines with classical functions like planning, scheduling, resource and cost control, quality assurance, safety, etc., with the help of Building Information Modelling (BIM), IoT-based site monitoring and data-driven decision support. The tools enable engineers, planners and contractors to simulate and validate a project before it is constructed, particularly in the case of smart cities where systems are often tightly coupled.

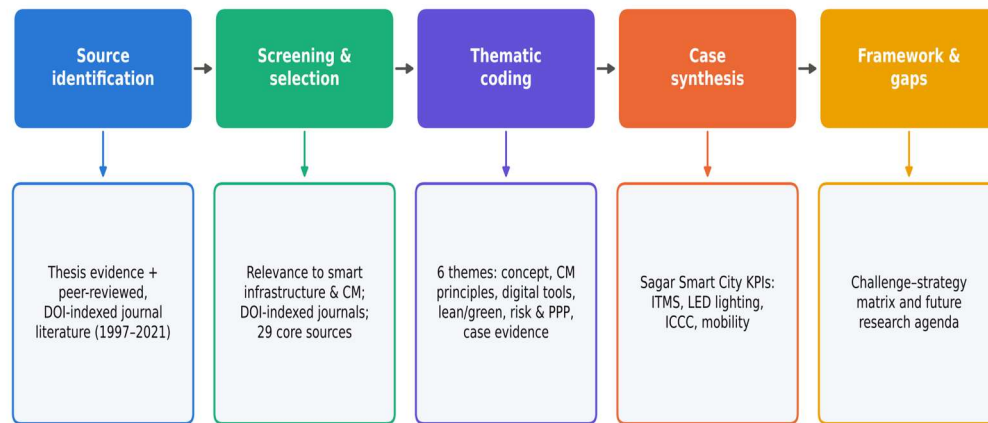
In this context, the purpose of this review is to: (i) summarise the concept and elements of smart cities from a delivery point of view; (ii) look at the application of CM principles to smart infrastructure; (iii) analyse the use of digital technologies, such as BIM, automation and IoT, in project delivery; (iv) identify the challenges of smart city project delivery; and (v) propose management strategies for successful delivery. The review only considers the construction phase, and urban policy formulation and long term operations are only

mentioned where they have an impact on the construction results.

2. Review Methodology

The review is conducted in a structured narrative style in five stages (Fig. 1). The evidence base was developed by integrating the results of a postgraduate research project focused on construction management in smart cities (secondary observation of the Sagar Smart City programme)

and peer-reviewed DOI-indexed journal literature on smart cities, construction management, digital construction, lean and green building, risk and PPP. The sources were selected for direct relevance to the provision of smart urban infrastructure and 29 core sources were used. All sources were coded into the six themes listed in Table 1 and the quantitative indicators were combined and relative improvements were calculated for Sagar; the results were then incorporated into a challenge–strategy framework.



Output: integrated construction-management framework for smart city infrastructure delivery

Fig. 1. Five-stage review framework adopted in this study.

Table 1. Thematic structure of the review and principal sources

Theme	Focus of synthesis	Section
T1 Smart city concept	Definitions, dimensions, components, India's mission	3
T2 CM principles	Planning/WBS, CPM/PERT scheduling, cost, quality, safety	4
T3 Digital tools	BIM, IoT, big data, digital twins, AI	5
T4 Lean & sustainable	Waste reduction, JIT, green building, energy	6
T5 Risk, stakeholders, PPP	Risk scoring, stakeholder influence, PPP success factors	7
T6 Case evidence	ITMS, smart lighting, ICCS, urban mobility in Sagar	8

3. Smart City Concept and Components

3.1 Definition and Objectives

In the context of smart cities, there are various definitions that describe how a smart city is defined, such as a city that uses digital technologies to manage resources and services optimally and improve citizens' quality of life, governance, mobility and the environment of the city, and its economy [1, 2]. The Government of India views it more practically as a city which offers the core infrastructure, a clean and sustainable environment, and “smart solutions” for more efficient service and governance [5]. For all definitions, the purposes are similar, such as enhancing quality of life, increasing the efficiency of urban services, supporting sustainable development and economic innovation, increasing transparency, and reducing environmental impact and natural-resource consumption [9, 10].

3.2 Key Components

The literature consistently names 5 interdependent components, which are summarised in Fig. 2. Smart infrastructure includes energy-efficient buildings and sensor-instrumented water supply, distribution, drainage and sewerage and communication networks that consume fewer resources at a lower life-cycle cost. Smart governance is driven by e-governance platforms, live monitoring and mobile applications to boost transparency and citizen engagement. Smart mobility combines intelligent traffic control, geospatial passenger information, public transport integration, electric vehicles and non-motorised transportation with the aim of easing traffic flow, decreasing accidents and emissions [11]. Smart environment is targeted at the surveillance of air and water quality, the use of green spaces, and climate resilient infrastructure, whereas smart energy is based on the smart grid with two-way communication, consumer monitoring, renewable energy production and use of efficient technologies like LED street lighting [12].



Fig. 2. Key aspects of smart cities: components, benefits and challenges.

3.3 Enabling Technologies

These components are united by technology. Continuous data gathering from the urban fabric by IoT devices [13]; the use of big-data platforms and artificial intelligence to derive operational decisions from that data [14]; spatial planning and mapping using geographic information system (GIS) [15]; secure and scalable storage in the cloud [16]. These advantages have been listed as better resource use, less pollution, better security, job creation, and civic engagement. These are the problems that are also predictable: high capital costs, privacy and cyber-security issues, the problem of connecting different systems, lack of technical know-how, and the risk of a growing urban gap or urban divide [4, 9].

4. Construction Management Principles for Smart Infrastructure

Construction management is the systematic planning, co-ordinating and controlling of resources in order to meet the project objectives within time, cost and quality. These functions are heightened by smart infrastructure which integrates civil works with electronics, software and communication networks, as well as by the need to ship a multitude of packages simultaneously from a variety of agencies. In Fig. 3, the core functions and their enablers in the form of digital and managerial tools are shown.



Fig. 3. Core construction management functions and enablers for smart infrastructure.

4.1 Project Planning

Planning sets goals, scope and execution plan for a project. It usually follows a feasibility study, a Detailed Project Report (DPR) is prepared, and then resources are allocated and a Work Breakdown Structure (WBS) is drawn up that breaks a project down into manageable work packages. The WBS needs to clearly show the connections between civil, electrical and ICT packages for smart city projects because many of the failures are at these boundaries.

4.2 Scheduling

Gantt charts represent a visual schedule, the Critical Path Method (CPM) is used to determine the sequence of activities that control the project duration and the Program Evaluation and Review Technique (PERT) is used for activities with uncertain durations. Monitoring and updating is supported by software like Primavera P6 and MS Project. Despite the fact that the effectiveness of CPM has been dependent on the regular updating and skilled schedulers, industry surveys

have confirmed its use as the standard method for planning and controlling large construction projects [15].

4.3 Cost Management

Cost management includes estimation, budgeting, cost control, value engineering and life cycle costing. Indications that its importance is not random but systematic are provided by evidence of public infrastructure cost underestimation due to optimism bias and strategic misrepresentation [7]. Life-cycle costing is especially relevant in smart projects, where the operating savings of the sensors and automation payback for the added expense.

4.4 Quality and Safety Management

Quality management involves a combination of Quality Assurance (QA) and Quality Control (QC) both of which involve preventive measures, and usually in the framework of an ISO 9001 system. The application of the principles of total quality management in the design and construction of buildings has long been established as a means to achieving better construction results [16]. Safety management deals with hazard identification, personal protective equipment (PPE), safety training and accident prevention planning [17]

and there has been a growing focus on technology assisted monitoring and proactive leading indicators recently. The handling of live urban corridors – which is quite common in projects of smart roads, utilities and lights – is the most important aspect for safety planning.

5. Digital Technologies in Smart Infrastructure Delivery

5.1 Building Information Modelling

BIM enables the digitization of the real world and functional properties of an asset, and provides it to the architects, engineers, contractors and project managers within a same platform (Fig. 4). Its most frequently mentioned advantages are clash detection (to identify conflicts between structural, mechanical, electrical and plumbing (MEP) systems and utility systems before construction), improved 3D visualisation and communication and better-informed decisions [18]. Multiple case projects were analyzed and cost reduction and control were found to be the most common benefits of BIM during the project life cycle, along with time savings [19].

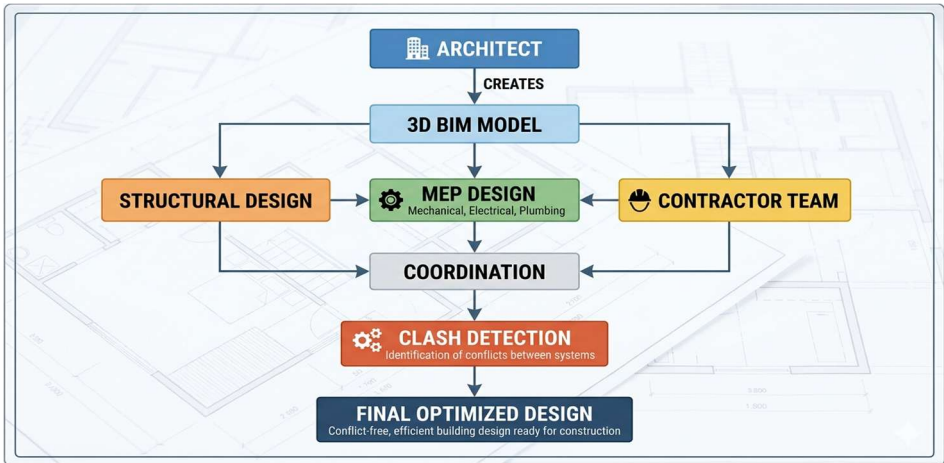


Fig. 4. BIM coordination model: multi-disciplinary design integration and clash detection.

These benefits were quantified for a representative urban infrastructure package in the source study (Table 2). BIM-based coordination reduced design errors from 25 to 8 (68%), rework cost from ₹5,00,000 to ₹1,80,000 (64%), project duration from 180 to 150 days (16.7%) and coordination delay from 20% to 8%. These magnitudes are in line with the international evidence [18, 19] and suggest that the majority of savings are made at the design phase and not on site.

Table 2. Effect of BIM-based coordination on project performance

Parameter	Without BIM	With BIM	Reduction
Design errors (no.)	25	8	17 (68.0%)
Rework cost (₹)	5,00,000	1,80,000	3,20,000 (64.0%)
Project duration (days)	180	150	30 (16.7%)
Coordination delay (%)	20	8	12 percentage points

5.2 IoT, Digital Monitoring and Digital Twins

Smart services rely on real-time data coming from IoT sensors, CCTV networks and adaptive controllers [13]. In the construction phase, they can be used to monitor progress automatically, manage equipment and ensure environmental compliance, and in operation, they are connected to central platforms like the Integrated Command and Control Centre (ICCC). A combination of BIM and live sensor data is

heading towards the creation of construction digital twins—a semantically rich model, synchronized with the physical asset and used for simulation and predictive decision-making [20].

5.3 Artificial Intelligence and Automation

AI technologies are now being used to assist in making a schedule and cost prediction, risk analysis, computer vision based safety and progress monitoring and optimisation of

resource allocation during the construction engineering and management process [21]. These tools, coupled with automation and robotics, provide a pathway to help solve chronic productivity and safety issues, but data quality, interoperability and workforce skills continue to be significant challenges.

6. Lean and Sustainable Construction

6.1 Lean Construction

Lean construction aims to reduce waste and enhance productivity, such as through just-in-time delivery (JIT) and pull planning & use of materials. JIT helps to keep on-site space requirements low and the site tidy, which is significant on a limited site in the city, and enhances coordination and communication between trades. Lean and BIM are synergistic in nature; BIM delivers reliable information and visualisation to support lean flow [22]. Poor planning, handling and over-ordering are important factors that contribute to material waste in building and are controllable by managerial action [23].

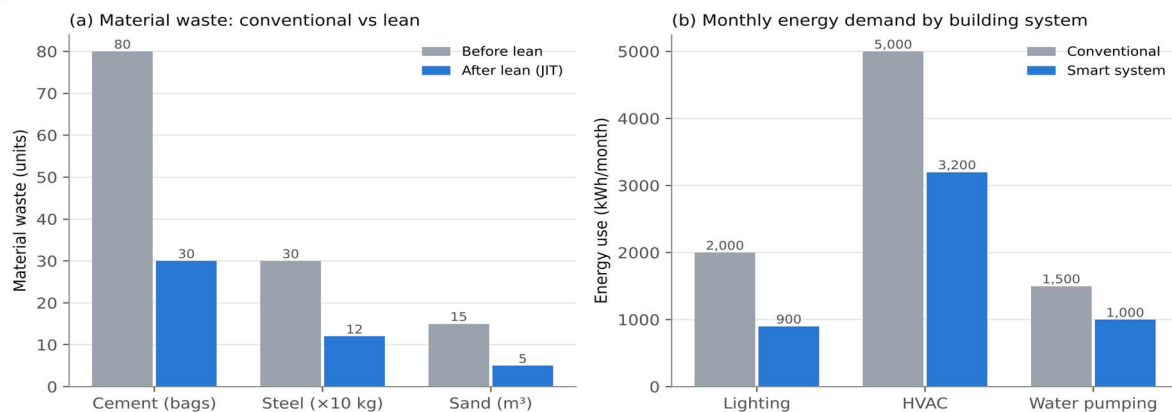


Fig. 5. (a) Material waste before and after lean practices; (b) monthly energy demand of conventional versus smart building systems.

Table 3. Resource savings from lean and sustainable construction practices

Item	Conventional	Lean / smart	Saving (%)
Cement waste (bags)	80	30	62.5
Steel waste (kg)	300	120	60.0
Sand waste (m³)	15	5	66.7
Lighting energy (kWh/month)	2,000	900	55.0
HVAC energy (kWh/month)	5,000	3,200	36.0
Water pumping energy (kWh/month)	1,500	1,000	33.3

7. Risk, Stakeholder and Financing Management

7.1 Risk Management

Smart city projects have a large scope and can be very complex, which introduces financial risks (funds overrun, fund release delayed), contractual risks (disagreements, unclear scope), technical risks (design mistakes, equipment failure, system integration) and environmental risks (naturally occurring hazards, regulatory issues). It is well acknowledged that systematic risk management (identification, analysis,

The source study indicated that significant waste reductions were achieved after implementation of the lean practices: 80 to 30 bags of cement (62.5%), 300 to 120 kg of steel (60.0 %), and 15 to 5 m³ of sand (66.7 %). The overall declines by material type are fairly similar, suggesting that the improvements are system-level, and not specific to the material.

6.2 Sustainable and Green Construction

Sustainable construction uses materials that are recyclable and that have a low impact on the environment, uses energy efficient lighting and HVAC systems, recycles rainwater and uses renewable energy to reduce environmental impact [12]. Energy simulation and performance analysis are another key feature in BIM that can aid in green design [24]. In the same study, smart building systems saved 1,100 kWh in lighting, 1,800 kWh in HVAC and 500 kWh in water use (pumping) saving an average of 40% of the total energy demand, or about ₹27,200 per month for a monthly energy cost of ₹8/kWh.

evaluation, mitigation and monitoring) is crucial and research on large public works projects invariably includes financial, contractual and stakeholder-related risks as among the most critical [25]. The financial risk was rated highest ($4 \times 5 = 20$), followed by technical risk ($3 \times 4 = 12$), environmental risk ($2 \times 5 = 10$) and contractual risk ($3 \times 3 = 9$), using a probability-impact ($P \times I$) matrix on a five-point scale, as illustrated in Fig. 6. Financial risk is in the risk critical zone, and needs to be addressed first in a phased manner with contingency reserves and risk-sharing contracts.

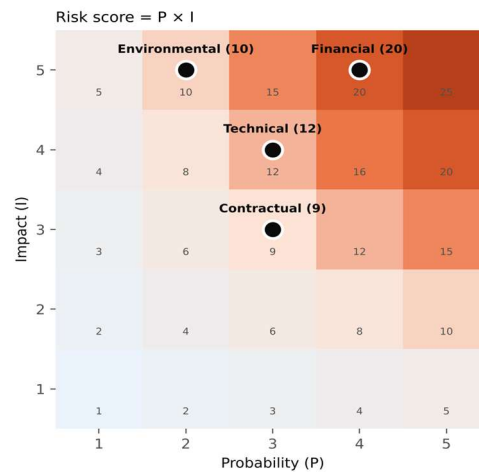


Fig. 6. Probability–impact matrix of major risks in smart city infrastructure projects.

7.2 Stakeholder Management

The project of a smart city is implemented by the involvement of various stakeholders with varying levels of influence and priorities, including government departments, SPVs, contractors, consultants, technology providers and citizens. There is evidence that stakeholder involvement can have a significant impact on implementation outcomes, therefore, systematic identification and involvement of stakeholders needs to occur from the earliest stages of implementation [26]. The source study estimated the daily cost of delays by each party as follows: government approvals and policy (₹50,000/day), contractors (₹40,000/day), consultants (₹20,000/day) and technology providers (₹15,000/day); citizens have indirect, but high influence as end users. These statistics make it clear that approval and coordination delays are as expensive as execution delays.

7.3 Public–Private Partnerships

Public budgets are not adequate to cover the investment that is needed for smart infrastructure. PPP models utilise private funds and knowledge to mobilise investment, construction and upkeep of infrastructure and distribute risks among the party most capable of handling them [27]. Risk allocation, a

powerful private consortium, political backing and transparent procurement and sound economic policy are found to be key success factors in PPP reviews [28] and empirical investigations stress the importance of providing a clear and balanced risk allocation between the public and private sectors, with the contractor preferring to take the construction risk and the public sector to take the market risk [29]. The savings stream is most suited to performance-based PPP or energy-service contracts, where revenue-generating smart services like LEDs which provide measurable energy savings are used.

8. Evidence from Sagar Smart City, Madhya Pradesh

The city of Sagar in Madhya Pradesh has been picked up for the Smart Cities Mission and has implemented an intelligent traffic management system (ITMS), smart street lighting, ICCC and urban mobility development. The integrated architecture integrates sensing devices with the ICCC and sector specific control systems and enhanced citizen services (Fig. 7). The performance indicators measured in the source study are summarised in Table 4 and Fig. 9.

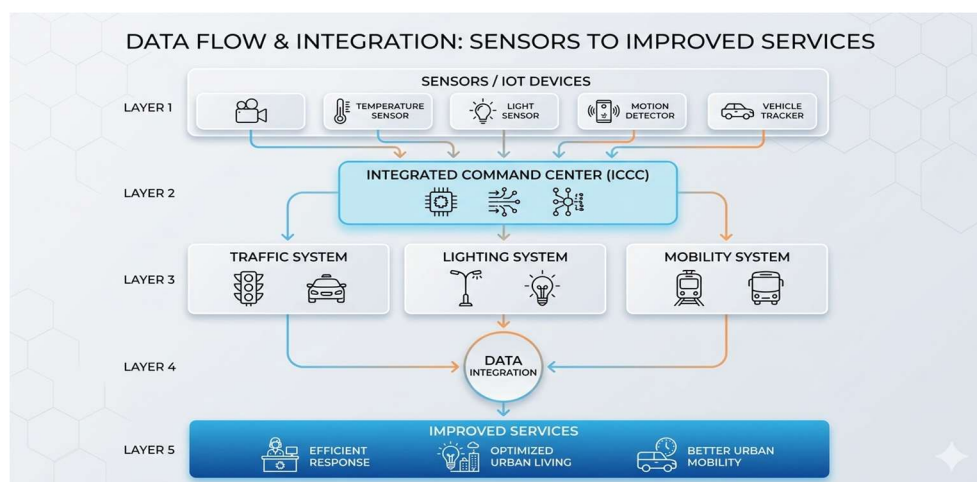


Fig. 7. Integrated smart city system: data flow from sensors and IoT devices through the ICCC to improved services.

8.1 Intelligent Traffic Management System

The vehicle sensors, CCTV cameras and adaptive signal control at key locations like Civil Lines Square are used in the ITMS. Average delay fell from 120 to 75 s per vehicle (37.5%), throughput rose from 1,800 to 2,200 vehicles per hour (22.2%), and idling fuel consumption declined from 300 to 220 L/h, a saving of about ₹8,000 per hour at ₹100/L. These findings are in line with the communication-oriented review of adaptive traffic management in smart cities [11].



Fig. 8. Sensor-controlled LED street lighting on an arterial road in Sagar Smart City.

8.3 Integrated Command and Control Centre

The ICCC is the city's nerve centre and centralises traffic, surveillance, lighting, and emergency responses. The time taken to respond to complaints dropped from 24 to 6 hours (75%), real time service monitoring coverage rose from 50% to 90% and manual tasks reduced from 70% to 30% of operational tasks. This centralisation, based on data, is an example of the “real-time city” as referred to in the

8.2 Smart Street Lighting

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The connected load dropped from 2,500 kW for 10,000 traditional 250 W luminaires to 1,200 kW (52%) for replacing them with 120 W sensor-controlled LED lights. This can save 13,000 kWh per day (assuming 10 hours per day) which works out to about ₹1,04,000 per day at Rs. 8/kWh. Maintenance visits and outage times are further minimised with remote monitoring and adaptive dimming.

literature and raises the questions of governance and privacy that accompany it [14].

8.4 Urban Mobility

Smart roads, footpaths and cycle tracks improved average travel speed on improved corridors to 25 to 40 km/h (60%) and typical trip time to 30 to 18 minutes, saving 12 minutes per trip. The accident rate was subjectively judged to be in a downward trend from high to medium.

Table 4. Performance indicators of smart interventions in Sagar Smart City

Intervention / indicator	Before	After	Change
ITMS – delay per vehicle (s)	120	75	–37.5%
ITMS – throughput (veh/h)	1,800	2,200	+22.2%
ITMS – idling fuel (L/h)	300	220	–26.7%
Street lighting – connected load (kW)	2,500	1,200	–52.0%
ICCC – complaint response (h)	24	6	–75.0%
ICCC – monitoring coverage (%)	50	90	+80.0%
ICCC – manual work (%)	70	30	–57.1%
Mobility – average speed (km/h)	25	40	+60.0%
Mobility – travel time (min)	30	18	–40.0%

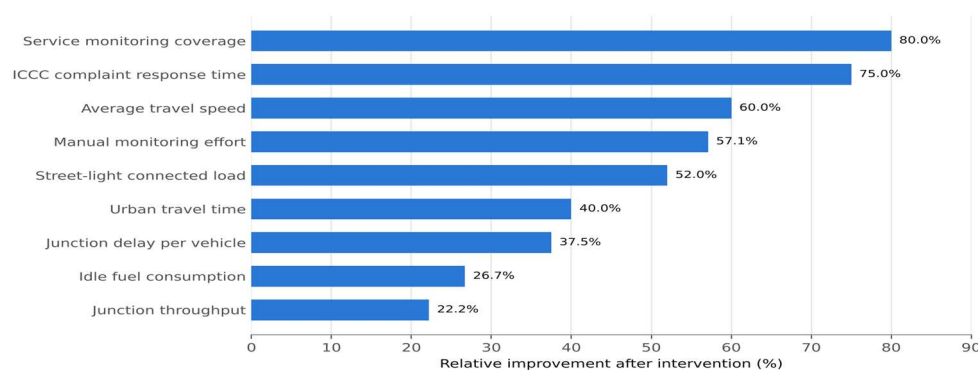


Fig. 9. Relative improvement in key performance indicators after smart interventions in Sagar.

8.5 Observations

Three observations are noteworthy. In all four interventions, real-time data collection and processing were shown to have measurable impact on service delivery. Secondly, the technology didn't help with avoidable delays, as various agencies responsible for implementation had not adequately coordinated. (Obviously, this would be the managerial component—integration, not hardware—where things got stuck). Third, centralised supervision by the ICCC helped to reinforce the monitoring and decision-making process, and

this approach should be followed in construction, as well as in operation.

9. Implementation Challenges and Strategic Framework

The main difficulties identified on the basis of literature and case evidence are financial issues, inter-agency coordination, land acquisition, technology integration and interoperability, lack of skilled workers and data privacy and digital divide [4] [5] [8]. Table 5 matches the challenges with management strategies that are supported by the evidence reviewed.

Table 5. Challenge–strategy framework for construction management of smart city projects

Challenge	Manifestation	Recommended CM strategy
Financial risk	Overruns, delayed fund release (risk score 20)	PPP / performance contracts, phased funding, contingency reserves, life-cycle costing [27]–[29]
Coordination failure	Inter-agency delays; approval costs up to ₹50,000/day	Stakeholder mapping, common data environment, SPV-led integrated schedule, ICCC-style project control [26]
Design clashes and rework	Utility and MEP conflicts in dense corridors	Mandatory BIM with clash detection; model-based quantity take-off [18], [19]
Material and energy waste	Over-ordering, storage loss, high energy use	Lean JIT delivery, pull planning, green building standards [12], [22], [23]
Technology integration	Proprietary, non-interoperable systems	Open standards, IoT integration plans in the WBS, digital twin roadmap [13], [20]
Skills gap	Limited BIM, IoT and ICCC capability	Structured training in BIM, IoT/ICCC operation, coordination, safety and quality [21]

Capacity building is an area of special importance. The case study demonstrated that there was no limit to performance because of lack of technology, rather it was due to a lack of coordination and technical know-how. Training should include BIM software, ICCC and IoT operation and maintenance, project coordination methods and safety and quality procedures. The benefits expected are improved coordination of stakeholders, reduced error and delays, optimal use of advanced technologies and adaptability to the next generation of innovations.

10. Research Gaps and Future Directions

- **Empirical, multi-city evidence.** Most smart city performance data are single-case and short-term; longitudinal comparisons across Indian cities are needed to separate technology effects from contextual factors.
- **Digital twins for construction and operation.** Linking BIM with live IoT data could support predictive scheduling, maintenance and handover, but frameworks suited to municipal agencies remain immature [20].
- **AI-assisted planning and control.** Machine learning for cost and delay prediction, risk scoring and computer-vision safety monitoring requires validation on Indian infrastructure datasets [21].
- **Integrated lean–BIM–green delivery.** Quantitative studies of combined lean, BIM and

green practices across the life cycle are scarce [22], [24].

- **Governance, equity and privacy.** CM research should address how data collected during construction and operation is governed, and how benefits reach underserved communities [4], [14].

11. Conclusion

The review has confirmed that construction management is an important facilitator in the development of smart cities. The complexity and interdependence of urban infrastructure and services require a mix of conventional practice and digital tools, lean and sustainable practice, and systematic risk, stakeholder and funding management. The findings show that the use of BIM can reduce the design errors by approximately two-thirds and the rework cost by 64%, while lean can reduce material waste by 60–67% and smart building systems can reduce energy demand by approximately 40%. The field evidence for Sagar Smart City is further validated at city-level with the following gains: 37.5% reduction in junction delay, 52% reduction in street-lighting load, 75% faster response time for complaint, 40% shorter urban travel time.

The review also reveals that technology will not solve the problem. The financial risk and inter-agency coordination became the main obstacles, while evidence from the cases showed that coordination and supervision—rather than hardware—were the limiting factors. The challenge–strategy framework proposed is thus based on PPP financing, compulsory BIM, lean and green delivery, ICCC-like

integrated control during construction, and on-going capacity development. The further development of digital twins, AI-supported project management and multi-city empirical studies will further enhance the evidence base for smart, sustainable and inclusive cities infrastructure.

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