

Role of Construction Management in the Development of Smart Cities

Srajan Seth Jain^{*1}, Ragini Mishra^{*2}

^{*1} M.Tech Scholar, Dept. of Civil Engineering, Babulal Tarabai Institute of Research and Technology, Sagar, M.P.

^{*2} Asst. Prof. and HOD, Dept. of Civil Engineering, Babulal Tarabai Institute of Research and Technology, Sagar, M.P.

Abstract—

Smart cities have become the main solution for meeting the challenge of rapid urbanisation. The challenge of rapid urbanisation has overwhelmed the ability of traditional planning and construction methods. However, the physical systems which smart cities rely on, such as smart transport, smart utilities, energy-efficient building and digital command centres, need to be planned, coordinated and delivered with effective construction management (CM). This paper addresses the contribution of CM towards the development of smart city, along with the review of the principles of CM and policy enabling technologies, quantitative evaluation of Building Information Modelling (BIM), lean construction, sustainable construction, risk and stakeholder management, and a case study of Sagar Smart City in Madhya Pradesh, India. The outcome reveals that use of BIM based coordination reduced the design errors to 8 from 25, rework cost reduced by 64%, project duration reduced by 30 days, reduction in material waste using lean just in time practices reduced from 60–67% and saving of 3,400 kWh (equivalent to ₹27,200) per month using smart building systems. The intelligent traffic management system reduced the delay at junctions by 37.5% in Sagar, sensor-based LED street lighting saved about 13,000 kWh (₹1,04,000) per day in Sagar and the Integrated Command and Control Centre reduced the delay in responding to complaints by 75% in Sagar. The most important barriers were: financial risk (20/25), inter-agency coordination (20/25). For future smart city projects, the study suggests that mandatory BIM, public-private partnership (PPP) financing be implemented, and digital monitoring and capacity building and green building standards be established.

Keywords— Construction management; smart city; building information modelling; lean construction; public-private partnership; risk management; Sagar Smart City.

1. Introduction

1.1 Background

The problem of rapid urbanisation has become one of the important challenges both for the developed and the developing countries. Rapid industrialisation and increased jobs in urban areas have resulted in a continuous population shift from rural to urban areas and urban population has grown well beyond the design capacity of the infrastructure. The cities now need to create more houses, transport, water and waste treatment, and energy, but traditional planning strategies have failed to cope with the challenges of congestion, shortage of water, and environmental degradation and inefficient services provision. The smart city concept is a solution for these issues that is based on the combination of information and communication technology (ICT), Internet of Things (IoT) and data analytics in urban infrastructure to make it more efficient and comfortable for the inhabitants. For instance, a smart traffic system can help with traffic

congestion, and sensor-equipped water networks can alert to water leaks [3].

However, technology alone is not the key to a smart city [4]. All smart services are built upon physical infrastructure which needs to be designed, procured, scheduled, built and commissioned. Construction management (CM) is the realm of planning, coordination and control of a project from beginning to end. CM incorporates technical knowledge and managerial techniques (scheduling, resource planning, cost control, quality control and safety) to achieve high level of efficiency and minimise risk. Modern CM also takes advantage of digital technologies like Building Information Modelling (BIM) which enables engineers, planners and contractors to create a picture of a project before construction begins. Smart city infrastructure thus cannot be successful without effective CM. The need for smart cities and the role of CM in these cities will be summarised in Fig. 1 and explained based on the urbanisation pressures.

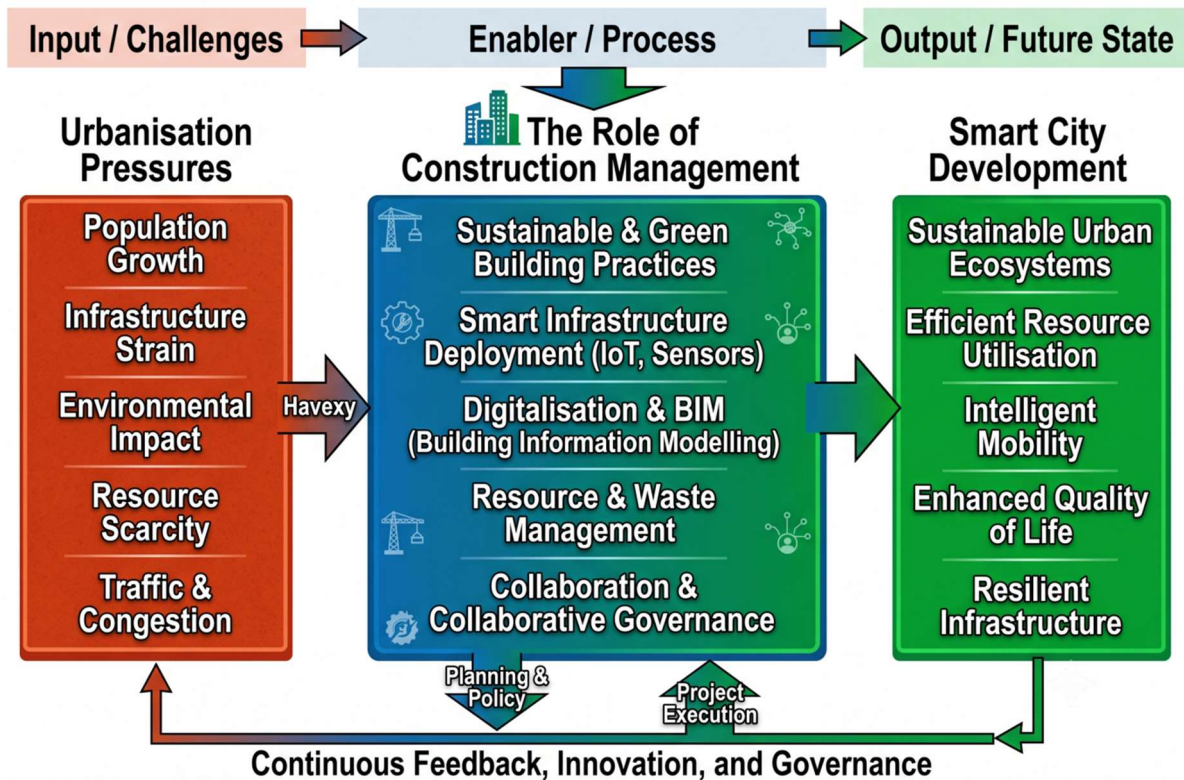


Fig. 1. From urbanisation pressure to smart city development: the role of construction management.

1.2 Need for the Study

It is very difficult to develop a smart infrastructure project compared with traditional projects, as it includes interdependent systems of transport, water, energy and communication, which all need to be in operation. They are expected to integrate advanced technologies like BIM, IoT, smart sensors and automated monitoring, and they need to fulfill the sustainability needs regarding materials, waste and energy consumption. Poor planning, underutilization, and coordination of resources can lead to cost overruns and delays in large-scale infrastructure projects, across the world [5]–[7]. Financial, technical, safety and environmental risks are very high for mega-projects. All these factors make it imperative to systematically analyze the role of CM for the better delivery of smart city projects, in the context of India's Smart Cities Mission [8].

1.3 Objectives and Scope

The main goals of this study are: understanding the concept of smart cities, understanding the concepts of CM and its application in smart city infrastructure construction, analysis of digital tools (BIM, automation, IoT) in the process of project execution, identification of project construction difficulties in the implementation of smart cities and proposals for management strategies for their successful realization. The study concentrates on the planning, scheduling, cost control, quality and safety management of transport, urban utility and housing infrastructure, and

only includes the construction period; the area of urban policy formulation and long-term operation is not included.

2. Literature Review

2.1 Smart City Concept and Components

A smart city is generally described as a city that implements the use of digital technologies to manage its resources and services in an efficient manner, enhancing governance, mobility, the environment, the economy and quality of life [1, 2]. According to the Government of India it is a city that delivers core infrastructure, a clean and sustainable environment and smart solutions for improved services and governance, with area-based and pan-city development to be implemented by special purpose vehicles (SPVs) with 100 cities targeted under the Smart Cities Mission launched in 2015 [8]. The five components of smartness that have been identified in the reviews are smart infrastructure, smart governance, smart mobility, smart environment and smart energy and challenges are identified as cost, privacy, integration and digital divide issues [9, 10]. Real-time data is supplied by IoT networks, big-data platforms transform the data into operational decisions, intelligent traffic management systems enhance mobility, and green buildings and smart grids support the energy and environment aspects. These components are summarised in Fig. 2.

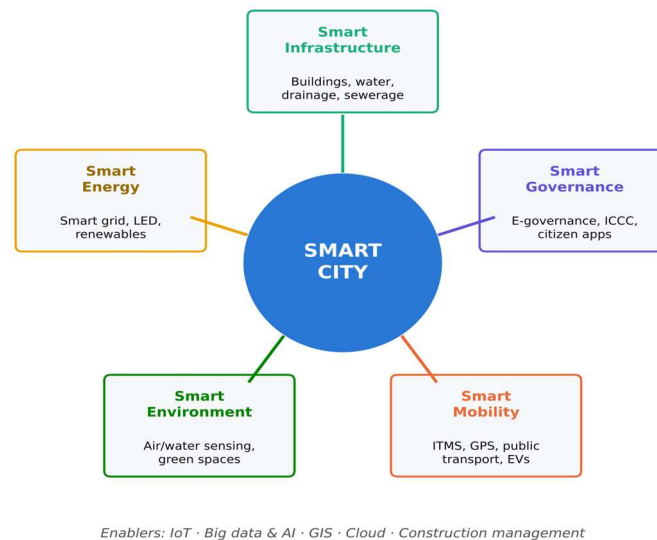


Fig. 2. Five components of a smart city and their enablers.

2.2 Construction Management Principles

CM rests on five core functions. Planning proceeds from feasibility study to a Detailed Project Report (DPR), resource allocation and a Work Breakdown Structure (WBS). Scheduling relies on Gantt charts, the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT), supported by Primavera and MS Project; CPM is widely regarded as the industry standard for large projects [15]. Cost management covers estimation, control, value engineering and life-cycle costing, and its importance is underlined by the systematic underestimation of costs in public works [6]. Quality management combines Quality Assurance and Quality Control within ISO-based systems [16], while safety management addresses hazard identification, personal protective equipment, training and accident prevention [17].

2.3 Digital Technologies in Construction

BIM creates a shared digital model of an asset, enabling clash detection, 3D visualisation and better coordination among architects, engineers and contractors [18]. Case-based studies report cost reduction and time savings as BIM's most frequent benefits [19]. The integration of BIM with IoT sensor data is evolving into construction digital twins [20], while artificial intelligence is increasingly used for schedule and cost prediction, risk analysis and safety monitoring [21]. BIM also supports green building design through energy simulation [22].

2.4 Lean, Sustainable, Risk and PPP Management

Lean Construction minimizes waste and enhances workflows through Just In Time (JIT) delivery and pull planning and is highly synergistic with BIM [23] whilst

material waste in building is caused largely by poor planning and handling which can be managed [24]. The financial, contractual and technical risks of large construction works are among the most crucial risks identified in risk studies [25] and stakeholder influence is a major factor in the outcomes of implementation [26]. Public-private partnerships (PPPs) are a means of attracting private finance and expertise to infrastructure [27] and their success depends on risk allocation, a robust private consortium and political will [28, 29].

2.5 Research Gap

Most previous studies focus on a specific CM tool or smart technology, while very few offer quantitative field studies in Indian Tier-II smart cities. This study aims to fill the gap by evaluating the measured outcomes of smart interventions along with the CM tools in the Sagar Smart City.

3. Research Methodology

The study followed a six-stage methodology (Fig. 3). After identifying the research problem and reviewing the literature, data were collected through site observation of the Sagar Smart City programme, project records of the implemented interventions and field photographs. The CM tools were evaluated using before-and-after comparisons on representative project data, risks were scored with a probability-impact ($P \times I$) matrix on a five-point scale, and cost savings were estimated from energy and fuel savings at prevailing tariffs (₹8/kWh for electricity and ₹100/L for fuel). The results were then interpreted to formulate recommendations.

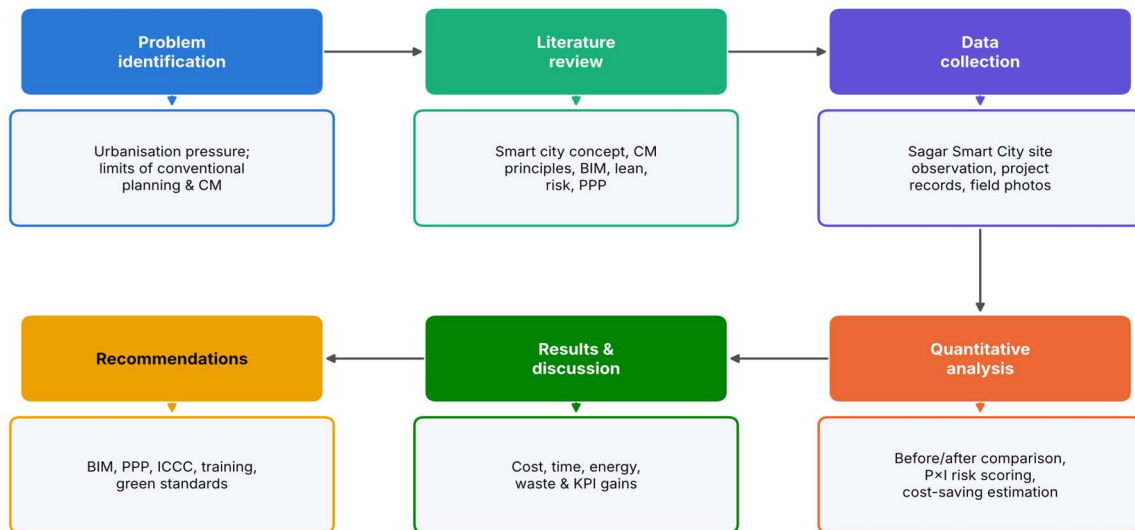


Fig. 3. Research methodology adopted in the study.

The analysis used CM process will be done as presented in Fig. 4: planning, scheduling, resource allocation, execution, monitoring and control of the process, and quality and safety check before completion.

Construction Management Flowchart



Fig. 4. Construction management process flowchart.

4. Analysis of Construction Management Tools

4.1 BIM-Based Planning and Coordination

BIM (e.g., Autodesk Revit) enables architects, structural engineers, MEP designers and contractors to work on a single model. Clash detection identifies conflicts between structures, pipes and wiring before construction starts, avoiding rework. Table 1 and Fig. 5 compare a representative urban infrastructure package executed with and without BIM.

Table 1. Cost and time savings with BIM

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

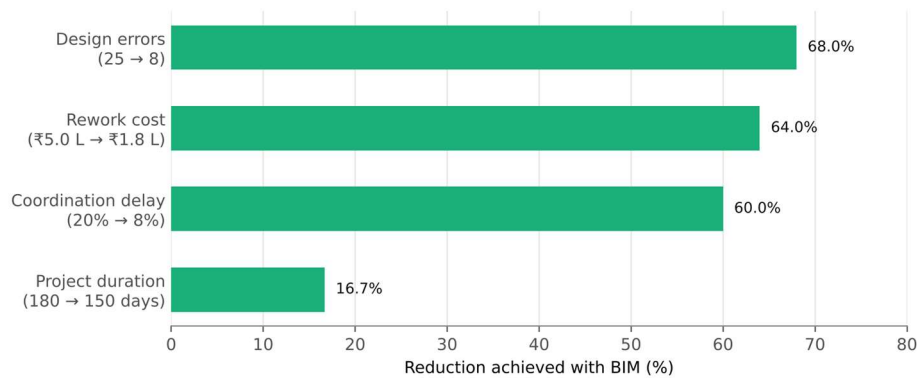


Fig. 5. Reduction in design errors, rework cost, coordination delay and project duration achieved with BIM.

4.2 Lean and Sustainable Construction

Lean practice – minimising material wastage, effective use of materials and JIT supply reduce storage costs, site congestion and improve coordination. Recyclable materials, LED lighting, efficient HVAC use, rainwater harvesting and solar energy are sustainable construction practices. Table 2 shows the energy and material savings measured.

Table 2. Material waste reduction and energy savings

Item	Conventional	Lean / smart	Saving
Cement waste (bags)	80	30	50 (62.5%)
Steel waste (kg)	300	120	180 (60.0%)
Sand waste (m ³)	15	5	10 (66.7%)
Lighting (kWh/month)	2,000	900	1,100 (55.0%)
HVAC (kWh/month)	5,000	3,200	1,800 (36.0%)
Water pumping (kWh/month)	1,500	1,000	500 (33.3%)

4.3 Risk Management

Smart city projects have financial risks (overspending, funding delays), contractual risks (contract disputes, miscommunication), technical risks (technical errors, equipment failures) and environmental risks (environmental hazards, regulatory challenges). The probability (P) and impact (I) were each rated on a 1–5 scale for each risk (Table 3).

Table 3. Risk assessment matrix

Risk type	Probability (P)	Impact (I)	Risk score (P × I)
Financial	4	5	20
Technical	3	4	12
Environmental	2	5	10
Contractual	3	3	9

4.4 Stakeholder Management

Smart city projects engage the government, contractors, consultants, technology providers and citizens. The costs of delay, by each stakeholder group, are estimated in Table 4, and are comparable to the costs of executing the delay.

Table 4. Stakeholder roles and delay cost impact

Stakeholder	Role	Delay impact (₹/day)	Contribution
Government	Approval & policy	50,000	High
Contractor	Execution	40,000	High
Consultant	Design & planning	20,000	Medium
Technology provider	Smart systems	15,000	Medium
Citizens	End users	Indirect	High

5. Case Study: Sagar Smart City

Sagar, Madhya Pradesh has been chosen under the Smart Cities Mission. The city has introduced an intelligent traffic management system (ITMS), smart street lighting and an Integrated Command and Control Centre (ICCC), all designed to improve the quality of street traffic in the city, reduce operating costs and enhance the quality of life of its citizens. The concept of the integrated system architecture is shown in Fig. 6.

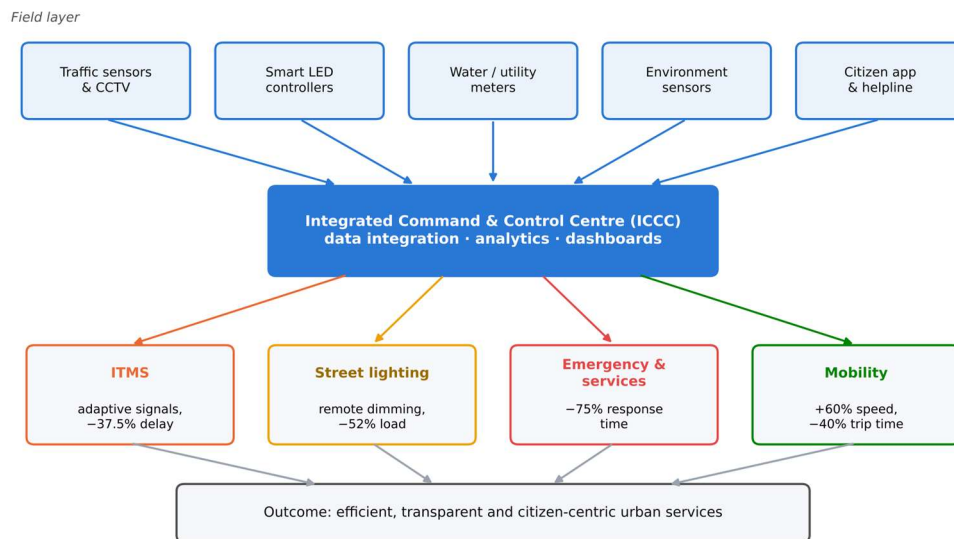


Fig. 6. ICCC-centred architecture of Sagar Smart City: field devices, integrated control and service outcomes.

5.1 Intelligent Traffic Management System

The vehicle sensors, CCTV cameras, and adaptive signal control at major junctions like Civil Lines Square (Fig. 7a), are implemented in ITMS. The average delay reduced from 120 to 75 s/veh, throughput rose from 1,800 to 2,200 veh/h, and the idling fuel consumption was reduced from 300 to 220 L/h. The fuel saving is $80 \text{ L/h} \times ₹100 = ₹8,000$ per hour.

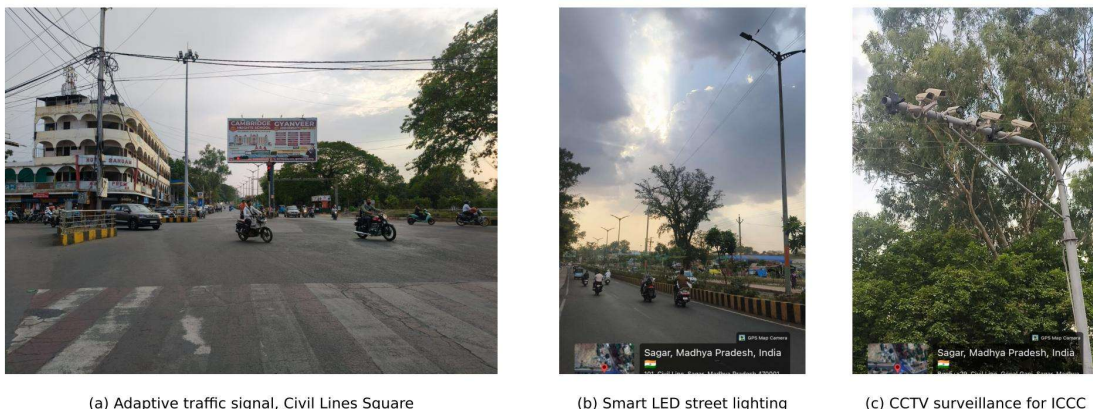


Fig. 7. Smart installations in Sagar Smart City: (a) adaptive traffic signal at Civil Lines Square; (b) smart LED street lighting; (c) CCTV surveillance linked to the ICCC.

5.2 Smart Street Lighting

The luminaires in this case are LED light sources which are controlled by sensors and monitored remotely (Fig. 7b). Replacing 10,000 lights of 250 W with 120 W LEDs reduced total load from 2,500 kW to 1,200 kW. The daily energy saving is $1,300 \text{ kW} \times 10 \text{ h} = 13,000 \text{ kWh}$, and the cost saving is $13,000 \times ₹8 = ₹1,04,000$ per day.

5.3 Integrated Command and Control Centre

This platform is able to control traffic, surveillance, lighting and emergency response for the city through CCTV and sensor feeds from city-wide sources (Fig.

7c), managed by ICCC. Complaint response time was reduced from 24 hours to 6 hours, which is 75% faster response time; real-time service monitoring was increased from 50% to 90% and manual work was reduced from 70% to 30%.

5.4 Urban Mobility

Smart road, footpaths and bicycle paths increased average speed from 25 to 40 km/h, and travel time from 30 to 18 minutes, resulting in a saving of 12 minutes per trip and reduction of accident rate from high to medium. The indicators for the case studies are compiled into one table (Table 5).

Table 5. Performance indicators of smart interventions in Sagar

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 – fuel consumption (L/h)	300	220	–26.7%
Street lighting – total load (kW)	2,500	1,200	–52.0%

ICCC – complaint response (h)	24	6	–75.0%
ICCC – service monitoring (%)	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%

6. Results and Discussion

6.1 BIM-Based Planning

BIM produced the largest relative gains in design quality: design errors fell by 68% and rework cost by 64% (₹3,20,000), and the project was completed 30 days earlier. Because the savings stem from early clash detection and better coordination, BIM strengthens decision-making at the planning stage itself. These results agree with international evidence that cost and time control are BIM's most frequent benefits [18], [19], and they support mandatory BIM adoption for smart city projects.

6.2 Lean Construction and Green Building

Lean methods produced nearly uniform waste reductions—66.7% for sand, 62.5% for cement and 60.0% for steel (Fig. 8)—indicating that the gains arise from system-level improvements in planning and JIT delivery rather than material-specific measures, consistent with [23], [24]. Smart building systems reduced energy demand from 8,500 to 5,100 kWh per month, saving 3,400 kWh or about ₹27,200 per month and lowering carbon emissions, in line with green building research [14], [22].

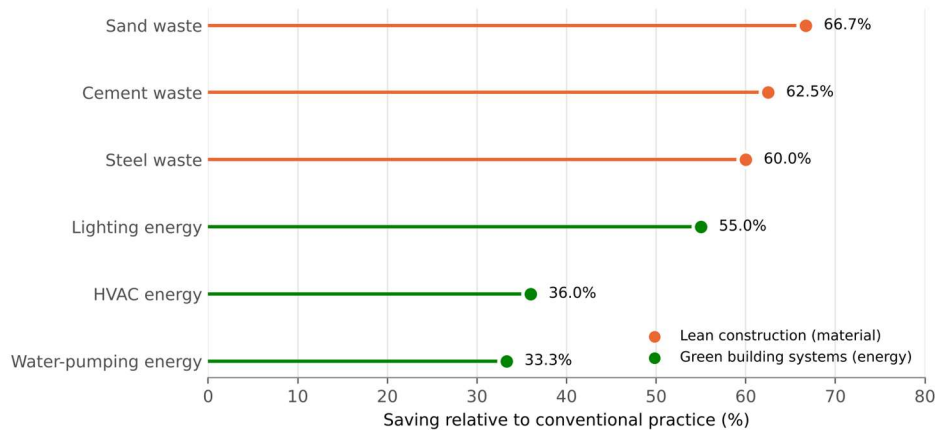


Fig. 8. Percentage savings from lean construction (materials) and green building systems (energy).

6.3 Risk Analysis

Financial risk (20), then technical risk (12), environmental risk (10) and contractual risk (9) (Fig. 9) were highest. The financial risk is in the critical zone and must be taken care of with a phased funding strategy, contingency reserves and risk-sharing contracts. This is in line with large public project studies which determine financial and contractual risks as the top two issues [25].

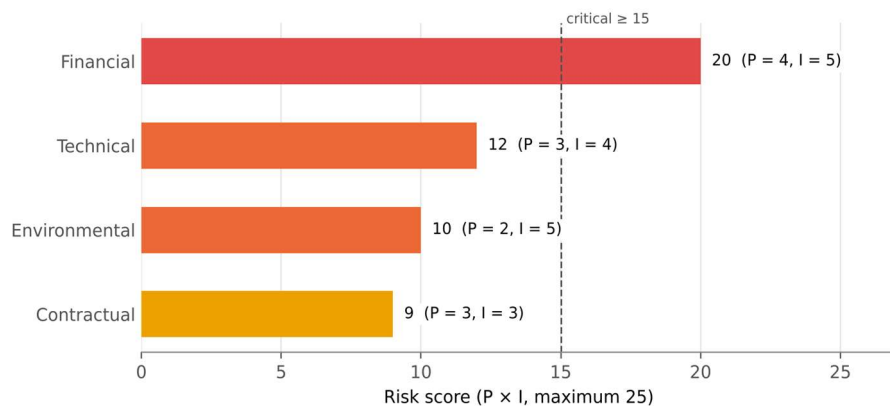


Fig. 9. Ranked risk scores ($P \times I$) of major risks in smart city projects.

6.4 Enhancing PPP Models

The investments needed to develop a smart city can frequently be larger than the capacity of governments. In PPP schemes the cost of the project is covered by the private sector which builds and operates the infrastructure, while the government takes on the regulatory role, bearing financial risk in conjunction with the private sector [27]. The smart street lighting savings of approximately ₹1,04,000 per day is proof of how savings can be quantified that can be returned to the investors through a performance-based contract. PPPs therefore result in lower costs to government, improved efficiency, faster project delivery and better

accountability, if the risks are appropriately managed [28] [29].

6.5 Digital Monitoring through the ICCC and ITMS

Digital monitoring resulted in the highest level of service-level improvements in Sagar, with a 75% faster complaint response, an 80% increase in monitoring coverage, a 57.1% decrease in manual work, and a 37.5% decrease in junction delay. The information gathered in real-time from sensors and IoT devices enables authorities to respond quickly and wisely [12], [13]. The street lighting retrofit reduced connected load by 52%, while the mobility improvements increased the average travel speed by 60% and reduced the travel time by 40%.

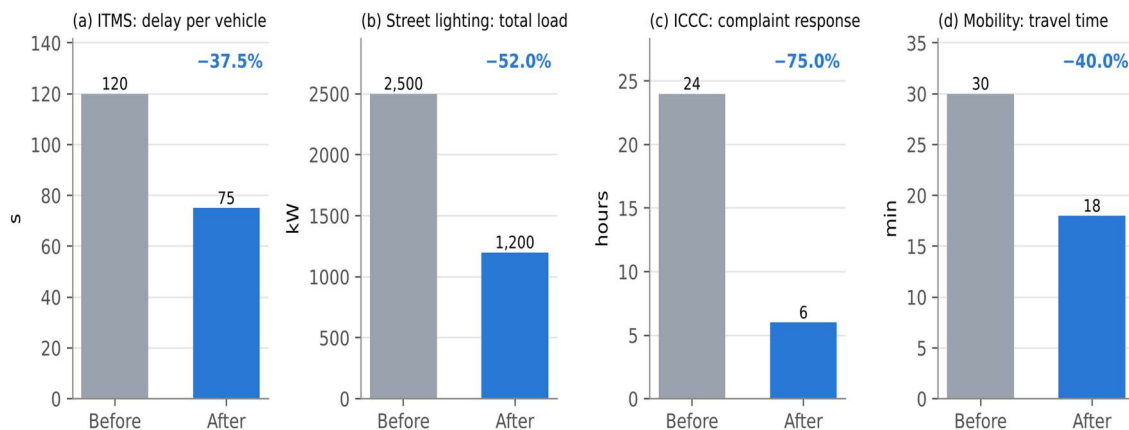


Fig. 10. Before-and-after performance of the four smart interventions in Sagar.

6.6 Capacity Building and Coordination

Despite these gains, the case study revealed delays caused by poor coordination among implementing agencies, confirming that managerial integration rather than technology is often the binding constraint [26]. Training programmes in BIM software, ICCC and IoT operation and maintenance, project coordination, and safety and quality procedures are therefore essential. They are expected to improve stakeholder coordination, reduce errors and delays, ensure optimal use of advanced technologies and improve adaptability to new tools such as digital twins and AI [20], [21].

7. Conclusion

The study indicates that construction management is one of the key roles in the development of smart city. For interconnected, complex urban infrastructure, conventional construction methods are no longer enough and advanced technologies, sustainable methods and effective project management tools are required. The main findings are:

- BIM was instrumental in reducing design errors from 25 on the old system to 8, and rework expenses from ₹5,00,000 to ₹1,80,000 while saving on the project duration by 30 days – all

of which should be done for all future smart city projects.

- The amount of material waste reduced in Lean Construction was 60-67% and the amount saved in Green Building systems was 3400 kWh ($\approx$ ₹27200) per month.
- Financial risk (score 20) is the most important risk; PPP models offer financial security, speed of implementation and increased accountability.
- The use of digital monitoring via the ICCC cut complaint response time by 75%, while the use of the ITMS cut the traffic delay by 37.5% and the fuel use by 80 L/h.
- Smart Street Lighting in Sagar Smart City is using approximately 13,000 kWh/day (₹1,04,000), and the Mobility projects had a saving of 12 minutes per trip, with coordination and supervision of the system remaining the biggest challenges.

Summarily, modern CM practices help save project time and cost, optimise the use of resources, support sustainability, enhance urban governance and boost citizens' quality of life.

7.1 Future Scope

For the planning, transportation, energy and waste management of future smart city projects, BIM, Artificial Intelligence, IoT, Cloud technology and Digital Twins are becoming more and more relevant and real-time monitoring and automatic decision-making are at the top of the agenda [20, 21]. There will be more focus on renewable energy, on green buildings, on electric mobility, on lean construction and on digital governance. The current analysis should be expanded to other cities and time periods to validate the findings.

References

- [1] V. Albino, U. Berardi, and R. M. Dangelico, "Smart cities: Definitions, dimensions, performance, and initiatives," *J. Urban Technol.*, vol. 22, no. 1, pp. 3–21, 2015, doi: [10.1080/10630732.2014.942092](https://doi.org/10.1080/10630732.2014.942092).
- [2] A. Caragliu, C. Del Bo, and P. Nijkamp, "Smart cities in Europe," *J. Urban Technol.*, vol. 18, no. 2, pp. 65–82, 2011, doi: [10.1080/10630732.2011.601117](https://doi.org/10.1080/10630732.2011.601117).
- [3] M. Batty et al., "Smart cities of the future," *Eur. Phys. J. Spec. Top.*, vol. 214, no. 1, pp. 481–518, 2012, doi: [10.1140/epjst/e2012-01703-3](https://doi.org/10.1140/epjst/e2012-01703-3).
- [4] R. G. Hollands, "Will the real smart city please stand up? Intelligent, progressive or entrepreneurial?," *City*, vol. 12, no. 3, pp. 303–320, 2008, doi: [10.1080/13604810802479126](https://doi.org/10.1080/13604810802479126).
- [5] B. Flyvbjerg, "What you should know about megaprojects and why: An overview," *Proj. Manag. J.*, vol. 45, no. 2, pp. 6–19, 2014, doi: [10.1002/pmj.21409](https://doi.org/10.1002/pmj.21409).
- [6] B. Flyvbjerg, M. S. Holm, and S. Buhl, "Underestimating costs in public works projects: Error or lie?," *J. Am. Plann. Assoc.*, vol. 68, no. 3, pp. 279–295, 2002, doi: [10.1080/01944360208976273](https://doi.org/10.1080/01944360208976273).
- [7] S. A. Assaf and S. Al-Hejji, "Causes of delay in large construction projects," *Int. J. Proj. Manag.*, vol. 24, no. 4, pp. 349–357, 2006, doi: [10.1016/j.ijproman.2005.11.010](https://doi.org/10.1016/j.ijproman.2005.11.010).
- [8] K. Hoelscher, "The evolution of the smart cities agenda in India," *Int. Area Stud. Rev.*, vol. 19, no. 1, pp. 28–44, 2016, doi: [10.1177/2233865916632089](https://doi.org/10.1177/2233865916632089).
- [9] S. E. Bibri and J. Krogstie, "Smart sustainable cities of the future: An extensive interdisciplinary literature review," *Sustain. Cities Soc.*, vol. 31, pp. 183–212, 2017, doi: [10.1016/j.scs.2017.02.016](https://doi.org/10.1016/j.scs.2017.02.016).
- [10] B. N. Silva, M. Khan, and K. Han, "Towards sustainable smart cities: A review of trends, architectures, components, and open challenges in smart cities," *Sustain. Cities Soc.*, vol. 38, pp. 697–713, 2018, doi: [10.1016/j.scs.2018.01.053](https://doi.org/10.1016/j.scs.2018.01.053).
- [11] A. Zanella, N. Bui, A. Castellani, L. Vangelista, and M. Zorzi, "Internet of Things for smart cities," *IEEE Internet Things J.*, vol. 1, no. 1, pp. 22–32, 2014, doi: [10.1109/JIOT.2014.2306328](https://doi.org/10.1109/JIOT.2014.2306328).
- [12] R. Kitchin, "The real-time city? Big data and smart urbanism," *GeoJournal*, vol. 79, no. 1, pp. 1–14, 2014, doi: [10.1007/s10708-013-9516-8](https://doi.org/10.1007/s10708-013-9516-8).
- [13] S. Djahel, R. Doolan, G.-M. Muntean, and J. Murphy, "A communications-oriented perspective on traffic management systems for smart cities: Challenges and innovative approaches," *IEEE Commun. Surveys Tuts.*, vol. 17, no. 1, pp. 125–151, 2015, doi: [10.1109/COMST.2014.2339817](https://doi.org/10.1109/COMST.2014.2339817).
- [14] J. Zuo and Z.-Y. Zhao, "Green building research—current status and future agenda: A review," *Renew. Sustain. Energy Rev.*, vol. 30, pp. 271–281, 2014, doi: [10.1016/j.rser.2013.10.021](https://doi.org/10.1016/j.rser.2013.10.021).
- [15] P. D. Galloway, "Survey of the construction industry relative to the use of CPM scheduling for construction projects," *J. Constr. Eng. Manag.*, vol. 132, no. 7, pp. 697–711, 2006, doi: [10.1061/\(ASCE\)0733-9364\(2006\)132:7\(697\)](https://doi.org/10.1061/(ASCE)0733-9364(2006)132:7(697)).
- [16] D. Arditi and H. M. Gunaydin, "Total quality management in the construction process," *Int. J. Proj. Manag.*, vol. 15, no. 4, pp. 235–243, 1997, doi: [10.1016/S0263-7863\(96\)00076-2](https://doi.org/10.1016/S0263-7863(96)00076-2).
- [17] Z. Zhou, Y. M. Goh, and Q. Li, "Overview and analysis of safety management studies in the construction industry," *Saf. Sci.*, vol. 72, pp. 337–350, 2015, doi: [10.1016/j.ssci.2014.10.006](https://doi.org/10.1016/j.ssci.2014.10.006).
- [18] S. Azhar, "Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry," *Leadersh. Manag. Eng.*, vol. 11, no. 3, pp. 241–252, 2011, doi: [10.1061/\(ASCE\)LM.1943-5630.0000127](https://doi.org/10.1061/(ASCE)LM.1943-5630.0000127).
- [19] D. Bryde, M. Broquetas, and J. M. Volm, "The project benefits of building information modelling (BIM)," *Int. J. Proj. Manag.*, vol. 31, no. 7, pp. 971–980, 2013, doi: [10.1016/j.ijproman.2012.12.001](https://doi.org/10.1016/j.ijproman.2012.12.001).
- [20] C. Boje, A. Guerriero, S. Kubicki, and Y. Rezgui, "Towards a semantic construction digital twin: Directions for future research," *Autom. Constr.*, vol. 114, Art. no. 103179, 2020, doi: [10.1016/j.autcon.2020.103179](https://doi.org/10.1016/j.autcon.2020.103179).
- [21] Y. Pan and L. Zhang, "Roles of artificial intelligence in construction engineering and management: A critical review and future trends," *Autom. Constr.*, vol. 122, Art. no. 103517, 2021, doi: [10.1016/j.autcon.2020.103517](https://doi.org/10.1016/j.autcon.2020.103517).
- [22] Y. Lu, Z. Wu, R. Chang, and Y. Li, "Building information modeling (BIM) for green buildings: A critical review and future directions," *Autom. Constr.*, vol. 83, pp. 134–148, 2017, doi: [10.1016/j.autcon.2017.08.024](https://doi.org/10.1016/j.autcon.2017.08.024).
- [23] R. Sacks, L. Koskela, B. A. Dave, and R. Owen, "Interaction of lean and building information modeling in construction," *J. Constr. Eng. Manag.*, vol. 136, no. 9, pp. 968–980, 2010, doi: [10.1061/\(ASCE\)CO.1943-7862.0000203](https://doi.org/10.1061/(ASCE)CO.1943-7862.0000203).
- [24] C. T. Formoso, L. Soibelman, C. De Cesare, and E. L. Isatto, "Material waste in building industry: Main causes and prevention," *J. Constr. Eng. Manag.*, vol. 128, no. 4, pp. 316–325, 2002, doi: [10.1061/\(ASCE\)0733-9364\(2002\)128:4\(316\)](https://doi.org/10.1061/(ASCE)0733-9364(2002)128:4(316)).
- [25] P. X. W. Zou, G. Zhang, and J. Wang, "Understanding the key risks in construction projects in China," *Int. J. Proj. Manag.*, vol. 25, no. 6, pp. 601–614, 2007, doi: [10.1016/j.ijproman.2007.03.001](https://doi.org/10.1016/j.ijproman.2007.03.001).
- [26] S. Olander and A. Landin, "Evaluation of stakeholder influence in the implementation of construction projects," *Int. J. Proj. Manag.*, vol. 23, no. 4, pp. 321–328, 2005, doi: [10.1016/j.ijproman.2005.02.002](https://doi.org/10.1016/j.ijproman.2005.02.002).

- [27] Y. H. Kwak, Y. Chih, and C. W. Ibbs, "Towards a comprehensive understanding of public private partnerships for infrastructure development," *Calif. Manag. Rev.*, vol. 51, no. 2, pp. 51–78, 2009, doi: [10.2307/41166480](https://doi.org/10.2307/41166480).
- [28] R. Osei-Kyei and A. P. C. Chan, "Review of studies on the critical success factors for public–private partnership (PPP) projects from 1990 to 2013," *Int. J. Proj. Manag.*, vol. 33, no. 6, pp. 1335–1346, 2015, doi: [10.1016/j.ijproman.2015.02.008](https://doi.org/10.1016/j.ijproman.2015.02.008).
- [29] B.-G. Hwang, X. Zhao, and M. J. S. Gay, "Public private partnership projects in Singapore: Factors, critical risks and preferred risk allocation from the perspective of contractors," *Int. J. Proj. Manag.*, vol. 31, no. 3, pp. 424–433, 2013, doi: [10.1016/j.ijproman.2012.08.003](https://doi.org/10.1016/j.ijproman.2012.08.003).