

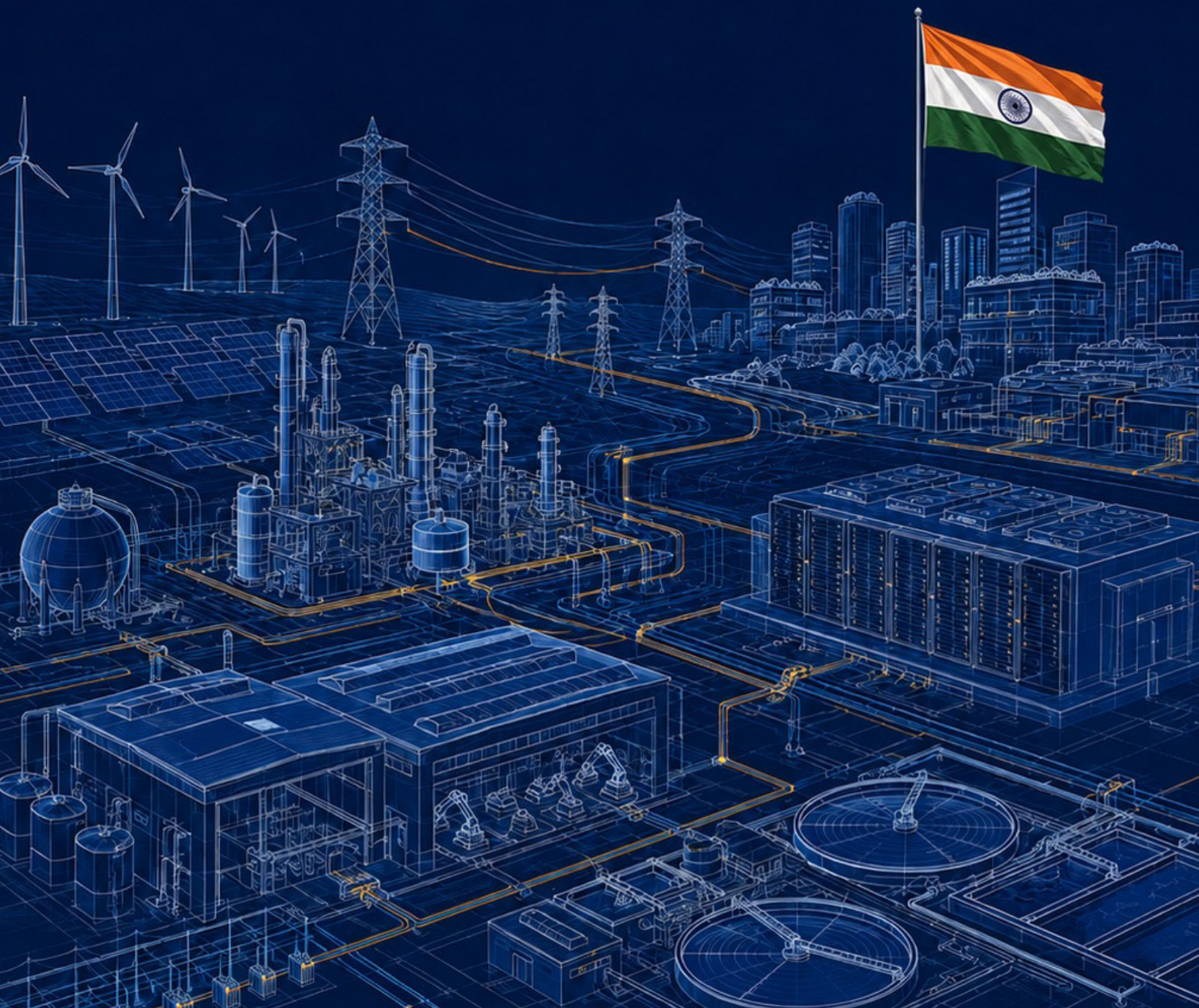


TATA CONSULTING ENGINEERS
ENGINEERING A BETTER TOMORROW™

India 2047

The Ascent to Design Leadership and Strategic Sovereignty

From Make in India to Made in India



Foreword



Professor Shireesh B. Kedare

Director
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India's aspiration to become a developed nation by 2047 will be shaped not only by the scale of its economy, but also by the depth of its knowledge, the originality of its ideas and its ability to translate scientific and technological capability into solutions that serve society. India has built a strong foundation for this journey. Its universities, research institutions, national laboratories, industries and technology enterprises have contributed to achievements across space, energy, healthcare, digital infrastructure, advanced manufacturing and several other strategic domains. Indian scientists and engineers are recognised globally for their knowledge and problem-solving ability. The opportunity before us now is to create an ecosystem in which this capability can lead more consistently to original research, indigenous technologies, intellectual property and globally relevant innovations.

India 2047: The Ascent to Design Leadership and Strategic Sovereignty places this opportunity within the larger context of national sovereignty. It makes an important distinction between the ability to execute and the ability to conceive, design and exercise informed authority over critical systems. This distinction deserves careful consideration as technology becomes increasingly integral to economic resilience, national security, public services and everyday life. Design sovereignty does not imply that every technology must be developed independently or that India should distance itself from international collaboration. Knowledge advances through openness, exchange and cooperation. However, meaningful collaboration requires strong domestic institutions and the ability to contribute intellectual value. India must be capable of understanding the technologies it adopts, adapting them to its requirements, protecting critical knowledge and participating in global partnerships as an equal contributor.

Academic institutions have a central role in enabling this transition. They must continue to advance fundamental research while also creating pathways through which knowledge can address national and industrial challenges. Students should be encouraged not only to understand established technologies, but also to question assumptions, work across disciplines, build prototypes and pursue solutions to complex real-world problems. Research translation, entrepreneurship and engagement with industry must become natural extensions of academic excellence. Industry has an equally important responsibility. Sustainable innovation requires long-term investment, tolerance for uncertainty and a willingness to work with academic institutions beyond immediate project requirements. Stronger industry-academia partnerships can bring together scientific inquiry, engineering experience, entrepreneurial initiative and an understanding of implementation at scale. Clear frameworks for intellectual property, technology transfer and commercialisation can help these partnerships create value for all participants while advancing the national interest.

The paper rightly recognises that design sovereignty is an ecosystem outcome. It depends on research funding, talent development, advanced infrastructure, public procurement, professional recognition, data governance and institutional collaboration. These elements must reinforce one another if India is to convert isolated achievements into enduring national capability. As we approach 2047, our ambition should extend beyond reducing dependence. India should aspire to become a trusted global source of knowledge, technology and responsible innovation. Our institutions must create solutions suited to India's needs while also contributing ideas and technologies that benefit the wider world. This white paper offers a timely framework for reflection and dialogue. Its value will ultimately lie in the conversations, collaborations and actions it inspires across academia, industry, government and society. India has the talent and institutional foundations required for this transformation. The task before us is to connect them with purpose, persistence and confidence.

Foreword



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India's journey since Independence has been marked by an extraordinary expansion of scientific capability, engineering competence and technological ambition. From space exploration and nuclear energy to digital public infrastructure and advanced manufacturing, the country has repeatedly demonstrated its ability to address complex challenges at scale. As India looks towards 2047, the question before us is no longer whether Indian talent can deliver. The more important question is whether we can create the institutions, policies and partnerships that enable this talent to define priorities, develop original solutions and exercise design authority.

This white paper, *India 2047: The Ascent to Design Leadership and Strategic Sovereignty*, addresses that question with clarity and purpose. It argues that sovereignty in the twenty-first century extends beyond political and territorial independence. It includes the ability to generate knowledge, own critical technologies, protect strategic data and make informed decisions based on national priorities. Design sovereignty should not be interpreted as isolation from the world. Science and technology have always advanced through the exchange of knowledge. India must continue to participate actively in international research, technology partnerships and global markets. However, such engagement becomes more valuable when it is supported by strong domestic capabilities. Collaboration must expand India's knowledge base and decision-making capacity rather than create enduring dependencies.

India has built an impressive network of academic institutions, national laboratories, technology enterprises and engineering organisations. The next challenge is to connect these strengths more effectively. Research must move more readily from the laboratory to practical application. Industry must invest more consistently in long-term research and technology development. Academic institutions must be encouraged to work on complex national and industrial challenges while continuing to pursue fundamental research. Clearer frameworks for intellectual property, technology transfer and commercialisation will be essential to this transition.

Experience across research, indigenous technology development and industry demonstrates that innovation acquires lasting value only when knowledge is translated into solutions that can be deployed, scaled and continuously improved. This calls for strong institutional bridges between researchers, engineers, entrepreneurs, industry and government. It also requires an environment that supports experimentation, recognises patient research and enables promising technologies to cross the difficult distance between proof of concept and meaningful application.

The paper also draws attention to the importance of public procurement, research funding, professional recognition and opportunities for Indian knowledge enterprises. These are not merely administrative matters. They determine whether domestic organisations can build experience, scale their capabilities and eventually compete as global leaders. The roadmap presented here is ambitious, but the ambition is appropriate for a nation approaching the centenary of its Independence. India possesses the scientific talent, engineering depth, entrepreneurial energy and institutional foundations required to achieve design leadership. What is now needed is sustained collaboration among government, academia and industry, supported by patient investment and a shared sense of national purpose.

This white paper is a timely contribution to that conversation. It invites us to move beyond measuring progress through execution alone and to consider a more consequential aspiration: an India that conceives, designs, owns and shares solutions for its people and the world.

Foreword



Mr Amit Sharma
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By 2047, India should possess the confidence and capability to shape the technologies and systems central to its development. This does not mean producing everything independently. It means knowing where design authority matters, investing in the capabilities that must be retained and engaging with the world as a contributor of knowledge rather than only as a market or delivery base.

Industry has a decisive role in making this possible. Indian enterprises have benefited from the country's scientific institutions, engineering talent and expanding markets. They must now invest more deliberately in the knowledge base from which future competitiveness will emerge. Research, intellectual property and advanced engineering cannot remain peripheral activities. They must become part of long term business strategy.

This responsibility begins within every engineering and technology organisation. Project delivery should do more than meet the immediate requirements of cost, schedule, quality and safety. It should build methods, strengthen data, develop people and leave behind knowledge that can be applied to the next challenge. Engineers must be given the space to question established approaches, connect disciplines and create solutions suited to Indian conditions while meeting global standards.

Government and academia are essential partners in this effort, but their roles are different. Government can create direction and confidence through sustained research funding, enabling policy and procurement that gives credible Indian solutions an opportunity to demonstrate value. Academic institutions can pursue fundamental inquiry while building stronger pathways towards application. Industry must help define relevant problems, support patient development and carry promising solutions towards deployment and scale.

At Tata Consulting Engineers, this ambition is closely connected with our own purpose. Since 1962, we have contributed engineering knowledge to critical sectors and complex national programmes. That experience has taught us that the most valuable outcome of engineering is not only the asset delivered, but the capability created around it. Our work with academic and research institutions has reinforced the same conviction. Scientific depth and engineering application create greater value when they advance together.

The transition will require patience and continuity. Some technologies will succeed and others will need to be reworked. A mature innovation ecosystem must accept measured risk and retain the learning generated along the way. Success must be assessed not only through short term commercial outcomes, but through the technologies, institutions and people India develops.

India 2047: The Ascent to Design Leadership and Strategic Sovereignty, is offered as TCE's contribution to this national effort. It brings together the choices, institutions and partnerships that can help India move from capability to authorship. Our hope is that it encourages serious discussion and, more importantly, sustained action towards an India that originates, engineers and shares trusted solutions with the world.

Foreword



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When we began working on this white paper, one question kept returning: why does a country whose engineers help create some of the world's most complex technologies still depend on external design authority in many critical systems? India's technical ability is not in doubt. The unfinished task is to convert that ability into sustained ownership of knowledge, architecture, intellectual property and the decisions that shape a system over its life.

This question led us to distinguish between manufacturing and design leadership. A product may be manufactured in India while its core technology, standards, software or critical design choices remain externally controlled. Domestic production is valuable, but it does not automatically create the knowledge needed to adapt the technology, resolve failures, improve performance or develop the next generation.

Design sovereignty is therefore the capacity to understand a problem in its entirety, define the governing architecture, make critical technical choices and retain the knowledge required for continuous improvement. Strategic sovereignty is the confidence and institutional ability to decide which capabilities India must own, which it should develop through partnership and which it may responsibly source while retaining informed control.

These choices cannot be identical across sectors. The path for semiconductors will differ from that for energy, transport, healthcare, space, defence or the built environment. The requirement is clarity about where dependence creates material risk and where domestic design capability will generate lasting economic, technological or strategic value.

Engineering teaches us that capability is cumulative. It grows when organisations remain involved from concept and design through implementation, operation and improvement. Research must progress through prototypes and demonstrators to commercial application. Lessons from the field must return to designers and researchers. When this cycle remains connected, each project adds to the nation's knowledge base. When it is fragmented, valuable learning is lost.

The paper consequently examines more than research funding. It considers intellectual property, procurement, professional institutions, digital infrastructure, talent and the relationship between capital creation and long term operating knowledge. These are parts of one system. Progress in isolation will create pockets of excellence, but not design leadership at national scale.

Global collaboration remains fundamental to this journey. The objective is not technological isolation, but stronger participation. India should enter partnerships with the ability to contribute intellectual value, absorb knowledge, make accountable decisions and continue developing a system independently where necessary. *India 2047: The Ascent to Design Leadership and Strategic Sovereignty*, is our attempt to frame this transition and invite deeper discussion. It is not presented as a finished prescription. It is a call to connect India's research excellence, engineering experience and industrial scale so that capability becomes authorship and execution becomes enduring design leadership.

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Executive Summary

Sovereignty in the twenty-first century extends beyond territorial security and economic strength. It is also reflected in a nation's ability to generate ideas, shape policy, develop technology and design the systems that influence its future. This intellectual and technological capacity enables countries to make informed choices, respond confidently to emerging challenges and participate in global partnerships from a position of strength. For India, with its scale, talent and ambition, developing this capacity will be an important part of its journey towards *Viksit Bharat 2047*.



Since Independence, India has pursued partnerships and collaborations based on its national interests, strategic priorities, geopolitical considerations and the best available options. These choices have contributed to several remarkable successes, although some initiatives have not achieved their intended outcomes or full potential.

As India embarks on its *Viksit Bharat 2047* mission, the choices it makes today, particularly in critical sectors, will have a lasting impact. Many will require substantial and sustained investment, with results becoming visible only over the next five to ten years.

It is with this understanding, and with the aim of encouraging informed debate and careful consideration, that this paper is presented to citizens, policymakers, academic institutions, entrepreneurs, innovators, scientists, engineers, professionals, industry leaders and other stakeholders.

India's task is to strike the right balance between engaging with global partners and developing strong domestic capabilities and national champions. This requires a considered assessment of national priorities, existing strengths and long-term consequences.

International collaboration must continue, but it should also strengthen India's strategic interests, expand indigenous capabilities and institutional competence, and support mutually beneficial trade and global partnerships.

From Partnership to Capability

At different stages of its development, India has drawn upon international advisers, imported technologies and external systems to support reforms, build institutions and deliver major projects. Such partnerships helped the country access specialised knowledge, accelerate learning and benefit from global experience while domestic capabilities were still developing. They contributed to progress across infrastructure, industry, public health, agriculture, technology and governance.

Over time, India has built substantial capabilities of its own. Indian professionals now lead global corporations, research institutions and technology enterprises. Within the country, public institutions, private enterprises, universities, start-ups and scientific organisations have delivered advances in space exploration, digital public infrastructure, pharmaceuticals, nuclear technology, engineering and information technology. These achievements demonstrate that India possesses the talent and institutional foundations required to conceive and deliver solutions of national and global significance.

The next stage is to convert these strengths into broader and more enduring design capability. India has established a strong reputation for execution. It now has the opportunity to capture more of the value associated with originating ideas, defining systems, setting standards and owning intellectual property. In several knowledge-intensive sectors, enabling domestic organisations to achieve greater scale, visibility, market access and sustained investment can help them emerge as global leaders.

This is not a question of replacing international expertise with domestic participation in every instance. It is about ensuring that strategic programmes create lasting value within India through knowledge transfer, local leadership, institutional learning and ownership of critical capabilities.

Global partnerships will remain valuable, particularly where they provide access to advanced knowledge and experience. Their long-term contribution should also be assessed by the strength they help build within India.

The Case for Design Sovereignty

This paper describes the capability to conceive, design, develop and govern critical systems as design sovereignty. It is not a call for isolation, protectionism or complete self-sufficiency. It is the ability to make informed choices, retain command over strategically important knowledge and systems, and engage with the world from a position of capability and confidence.

Design sovereignty matters because the organisations that define concepts, architectures and standards influence how technologies are developed, how data is governed and where economic value is created. When domestic participation extends from execution to design leadership, more knowledge and intellectual property can become embedded within the country. This creates opportunities to deepen talent, strengthen institutions and build globally competitive enterprises.

The implications are particularly significant in sectors such as digital infrastructure, energy, healthcare, defence, semiconductors, transportation, advanced manufacturing and public systems. India need not develop every technology independently. It must, however, identify the capabilities that are strategically important, determine where domestic ownership or leadership is essential, and establish appropriate models of international collaboration, co-development and knowledge transfer.

Stronger design capability will enable India to respond more effectively to supply disruptions, technological restrictions and changing geopolitical conditions. More importantly, it will allow the country to create solutions suited to its own scale, diversity and development priorities, while contributing affordable, sustainable and inclusive innovations to the world.

India's Foundations and the Opportunity Ahead

India enters this journey with substantial strengths. Its space and nuclear programmes demonstrate sustained indigenous design capability. Digital public infrastructure such as Aadhaar, UPI and CoWIN has shown that Indian institutions can create secure and inclusive platforms at population scale. The country has also developed globally recognised capabilities in pharmaceuticals, information technology, engineering services, renewable energy and advanced scientific research. These achievements share an important characteristic. They emerged where national purpose, institutional commitment, patient investment and responsibility for outcomes came together. They demonstrate how Indian capability can flourish when organisations are trusted to lead, supported with sustained resources and connected through collaboration among government, industry and academia.

The opportunity now is to extend these successes across a wider range of sectors and create stronger pathways from research to practical application. Increasing investment in research and development, strengthening translational infrastructure and connecting promising ideas with industry can help more Indian innovations progress from laboratories and prototypes to scalable technologies and global markets. Procurement can become an important instrument for encouraging innovation, contextual knowledge and domestic value creation. Academic and professional systems can place greater emphasis on patents, prototypes, commercial outcomes and real-world impact. Stronger research careers, competitive opportunities and modern infrastructure can also help India attract and retain specialised talent. Together, these measures can create an ecosystem in which Indian ideas are developed, tested, protected, deployed and taken confidently to the world.

Learning from Global Experience

Global experience shows that strong domestic capability is built through deliberate and sustained choices. Countries including the United States, Finland, Singapore, the United Kingdom, Japan and South Korea have used different combinations of public research funding, academic institutions, industrial policy, procurement and intellectual property frameworks to convert knowledge into technologies, enterprises and national advantage.

The lesson is not that countries progress by turning inward. Leading innovation economies remain deeply connected to international knowledge, talent and markets. Their strength lies in combining global collaboration with sustained investment in domestic institutions and the ability to retain, apply and commercialise the knowledge generated. India can adapt these lessons to its own democratic, federal and diverse context, building a model that is open to the world and grounded in national priorities.

Connecting Research, Industry and Intellectual Property

A central theme of this paper is the need to strengthen the journey from research to real-world application. The Anusandhan National Research Foundation provides an important foundation for expanding research and encouraging collaboration. Its impact can be amplified through sustained funding, mission-led programmes, shared research facilities and stronger participation by industry, universities, national laboratories and start-ups.

Clearer frameworks for ownership, licensing and commercialisation of intellectual property can further strengthen this ecosystem. International experience, including Bayh-Dole-style approaches, shows how appropriate incentives can help publicly supported research move from laboratories into products and enterprises while protecting the public interest. India can develop a framework suited to its own legal and institutional context, including carefully structured pathways for CSR-supported research and industry-academia collaboration.

Such an approach can encourage private capital to support longer-term research, reward institutions and inventors for successful translation, and enable Indian enterprises to take promising technologies to market. It can also ensure that public investment generates wider benefits through new capabilities, high-value employment, exportable technologies and solutions aligned with national priorities.



A Roadmap to 2047

The paper proposes a phased pathway to design leadership. The period to 2030 should focus on strengthening the foundations through procurement reform, greater research investment, clearer intellectual property mechanisms, modern research infrastructure, improved talent pathways and secure digital capabilities. Strategic programmes should create meaningful roles for Indian organisations while encouraging global partners to contribute to co-development, training and knowledge transfer.

Between 2030 and 2040, the emphasis should shift to scale, credibility and global reach. Domestic design, engineering, technology and knowledge enterprises should be enabled to lead larger assignments, build international footprints and participate in global standards. Research institutions should produce a growing pipeline of patents, prototypes and deployable technologies, supported by patient capital and transparent pathways to commercialisation.

From 2040 to 2047, India should aim to demonstrate design leadership at scale. Indian institutions and enterprises should help shape global standards, offer trusted digital and physical infrastructure solutions, and contribute knowledge and technology to other countries. Progress should be supported by clear milestones, independent evaluation and regular measurement of research outcomes, domestic participation, technology deployment, intellectual property creation and international impact.

The Vision for 2047

By the centenary of Independence, India can be recognised not only for the scale of what it builds, but also for the originality of what it designs. Indian research institutions can generate technologies that strengthen domestic industry and contribute to global knowledge. Indian enterprises can advise governments and industries around the world, while indigenous platforms and technologies can become benchmarks for inclusion, affordability, sustainability, security and scale.

Achieving this vision will require shared responsibility. Government must provide enabling policy, fair procurement, strategic investment and effective governance. Industry must invest in research, design and talent with a long-term perspective. Academia must connect knowledge with national and societal needs while preserving the value of fundamental research. Citizens and professionals must contribute through informed debate, confidence in Indian capability and a commitment to continuous improvement.

The journey from dependency to design sovereignty is therefore not a retreat from the world. It is a progression towards more confident and mutually valuable engagement with it. By investing patiently, collaborating wisely and building institutions that can convert ideas into impact, India can enter 2047 as a nation that makes its own strategic choices, creates solutions for its people and contributes intellectual and technological leadership to the world.

Design Sovereignty: India's Path to Intellectual Independence by 2047

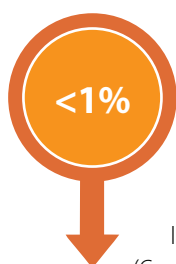
From Technology Adopter to Global Leader in Design, Policy, and Innovation

The Sovereignty Gap



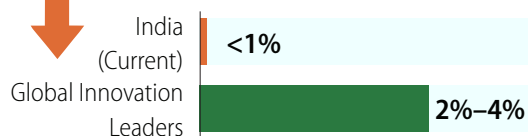
The Paradox of Intellectual Talent

India leads global corporations yet relies on foreign institutions for domestic strategic advisory.



The 1% R&D Investment Barrier

India invests <1% of GDP in R&D, while innovation leaders spend 2%–4%.



Risks of External Dependence

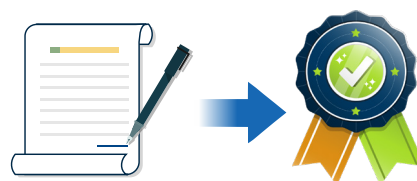
Reliance on foreign platforms for data and policy compromises national resilience and security.

The Roadmap to 2047



Transitioning from User to Producer

Shifting from importing machinery and systems to designing and exporting indigenous solutions.



Strategic Regulatory Reform

Reforming procurement and professional regulations to empower domestic firms and showcase excellence.



Achieving Design Sovereignty

Building an ecosystem wherein Indian consulting and technology firms lead global value chains.

Data Comparison: India Vs. Global Innovation Leaders

Category	India (Current)	Global Innovation Leaders
GDP Spend on R&D	Less than 1%	2%–4%
Core Focus	Execution & Services	Design & IP Ownership
Technology Role	Technology Adopter	Technology Creator

A Note on Perspective and Interpretation

This whitepaper is intended as a contribution to the broader discourse on India's journey towards 2047. The ideas, constructs, institutional arrangements, frameworks and illustrative models presented herein are offered as thought-leadership perspectives to stimulate discussion, challenge existing assumptions and explore potential pathways for strengthening India's design, innovation and technological sovereignty.

Where the paper describes possible councils, institutes, knowledge networks, mission structures, collaborative platforms, governance mechanisms or ecosystem arrangements, these should be interpreted as conceptual constructs intended to facilitate discussion and examination of alternative futures. They are not presented as implementation proposals, organisational commitments, policy prescriptions or programmes intended to be established, operated or coordinated by the authors or their affiliated organisations.

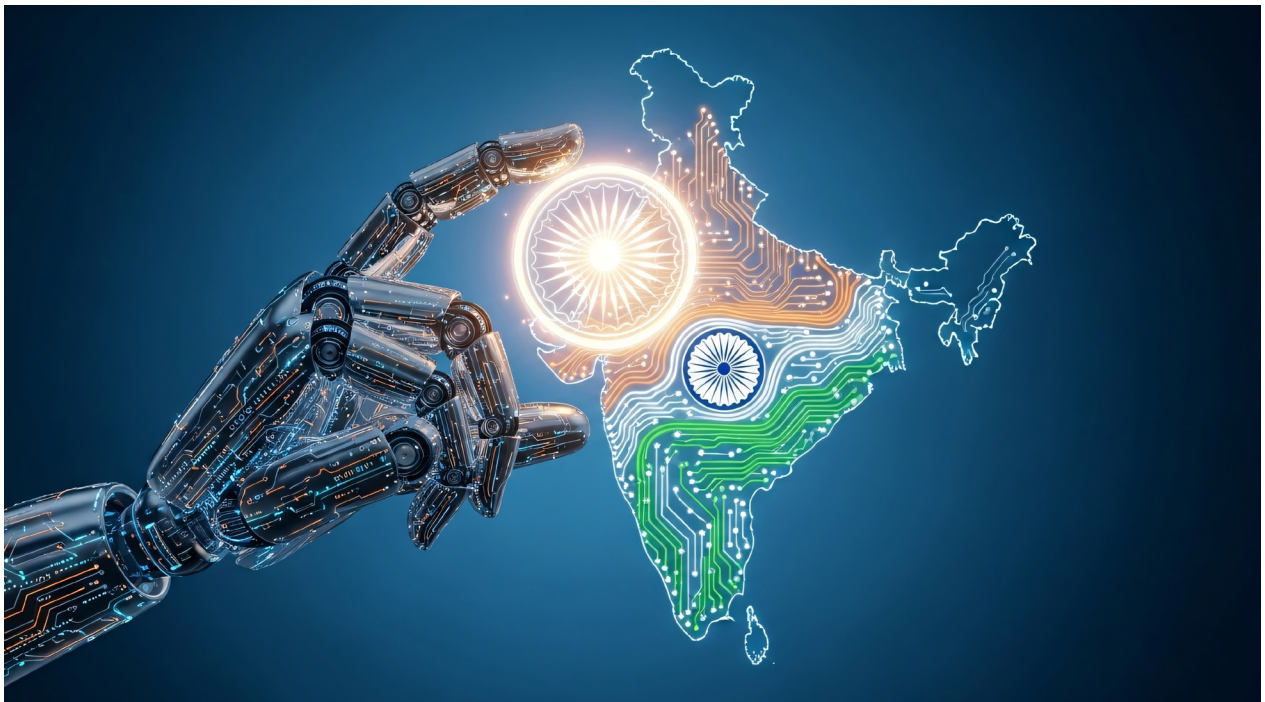
The objective of the whitepaper is not to advocate any specific institutional solution, but to encourage constructive dialogue among academia, industry, government, professional bodies and civil society on the opportunities, challenges and choices that may shape India's future trajectory.

Accordingly, the frameworks and examples discussed throughout the document should be viewed as perspectives for consideration and debate rather than as implementation roadmaps. The value of these ideas lies not in their adoption in any particular form, but in their ability to provoke informed discussion on how India may build enduring national capabilities in the decades ahead.

Chapter 1: The Architecture of Sovereignty - India's First Hundred Years

Every nation seeks to protect its independence, but in the 21st century, sovereignty depends as much on ideas as on armies. Borders may be guarded by soldiers, yet the strength of a country lies in its ability to design policies, build infrastructure and manage knowledge with confidence. In a world that is deeply connected, influence flows through technology, trade and ideas.

For India, this is not a challenge to fear but an opportunity to lead. Since Independence, India's journey has been marked by ambition and resilience.



From the early years of nation-building to the reforms of the 1990s and the digital age of today, India has embraced partnerships to accelerate progress. The next step is to transform these partnerships into platforms for innovation and shared design.

This chapter explores how India can shape sovereignty in a connected world by moving from reliance to collaboration, and by building the capacity to design and lead systems that matter for its future.

It traces the history from the first decades of nation-building, through the liberalisation reforms of the 1990s, to the new digital realities of today. It highlights the paradox of a nation whose professionals lead global corporations while domestic firms still seek greater recognition at home. It also examines examples in taxation, aviation, infrastructure, digital governance and education to show how collaboration has evolved and how India can now move towards knowledge-rich partnerships that strengthen sovereignty.

1.1 The Foundations of Partnership (1947 to 1980)

The first decades after Independence were years of determination and construction. India inherited a fragile economy, low industrial capacity, limited foreign exchange and a small cadre of trained professionals. Leaders faced the twin tasks of building the state and building the nation. They needed to feed a growing population, expand public health and education, and create an industrial base capable of producing steel, cement, power equipment, and fertilisers.

In this context, inviting global expertise was a practical and visionary choice. International institutions assisted with economic planning, public finance, dam design, power systems and setting up heavy industries. Bilateral partners helped set up large projects and trained Indian engineers and administrators. The early Five-Year Plans reflected global economic and public policy thinking, and foreign consultants often worked alongside Indian technocrats. This was not a loss of sovereignty. It was a strategic decision by a young state that needed knowledge, technology and capital to move forward.

As the state expanded its role in the economy during the 1960s and 1970s, external advice continued to support many programmes. Public sector enterprises dominated heavy industry, but the design of large plants often drew on overseas blueprints and engineering services. Agricultural transformation during the Green Revolution combined the work of Indian scientists with imported seed strains and international agronomy. Public health campaigns received technical guidance from global agencies. In each of these areas, international partners brought genuine value through experience, standards and technology that would have been difficult to develop overnight in a newly independent country.

These decades created institutional habits, procurement templates and professional networks that made global partnerships a regular part of policy and project design. These habits were understandable for a country that was still building capacity. The challenge today is not that such partnerships existed or continue, but that they did not evolve consistently into structured technology transfer, joint authorship, and shared design responsibilities.

The foundations laid in this period would become more visible and more debated in the next phase of economic change.

1.2 Liberalisation and Expanding Horizons (1991 to 2010)

The balance-of-payments crisis in 1991 became a turning point. Liberalisation, deregulation and a move towards market-based allocation reshaped the economy. This shift required new skills in competition policy, taxation, corporate restructuring, infrastructure finance and public-private partnerships. International consulting and advisory firms entered with global experience and proven templates. They advised on privatisation transactions, helped redraft regulatory frameworks and supported governments and state enterprises through complex sectoral reforms.

The presence of global advisors brought valuable exposure to international practice and, in many areas, accelerated the spread of high-quality methods and standards. International partners helped India learn quickly from reforms undertaken elsewhere and avoid mistakes that other economies had made. At the same time, their prominence created a view inside many ministries, regulators and public enterprises that the most credible answers came from outside. Procurement rules began to favour global footprints and long overseas track records. Indian firms that were technically capable but young or domestically focused struggled to qualify for leadership roles.

The two decades after reform also coincided with rapid globalisation. Financial markets integrated, capital moved more freely, and technology supply chains stretched across continents. Indian companies expanded abroad, and foreign firms deepened their presence in India. In this environment, international advisory brands became visible not only in central ministries but also in state governments, regulators, public sector undertakings and private boardrooms. The practice of outsourcing design and strategy to foreign advisors matured into a common choice for many large programmes.

In parallel, Indian information technology and engineering companies were quietly building world-class delivery engines. They executed projects across geographies and sectors, often in partnership with global firms.

Yet the intellectual framing of many national reforms continued to rely on teams that sat outside the domestic ecosystem. The result was a widening gap between India's ability to execute and its confidence in its design capabilities.

The issue was not the presence of foreign experts, who continue to play a valuable role, but the absence of deliberate mechanisms that would place Indian institutions as equal partners in the design, authorship, and long-term ownership of the resulting systems.

1.3 The Paradox of Global Talent and Local Invisibility

Indian talent is celebrated worldwide. Graduates from Indian institutions lead technology corporations, manage international banks and direct advanced research laboratories. Alumni design semiconductors, build spacecraft and run multinational enterprises. This success is a source of confidence and shows what Indian capability can achieve when institutions, capital and opportunity align.

At home, however, domestic consulting and knowledge firms often remain small and less visible. Regulations limit responsible promotion and thought leadership. Procurement norms require presence in many countries and decades of global experience that only the most significant foreign firms can show. Governments and corporate boards frequently equate external labels with credibility. The brightest graduates pursue prestige and higher pay abroad, making it harder for Indian firms to attract and retain top talent.

A cycle emerges. Low visibility feeds low trust. Low trust limits opportunity. Limited opportunity constrains growth. The cycle then repeats, even when capability exists. This paradox is not inevitable. It is shaped by rules, habits and narratives. Rules that discount domestic experience. Habits that default to imported frameworks. Narratives that assume foreign equals superior and do not always recognise the genuine strengths of local firms.

Breaking this pattern requires more than financial support. It needs proof-of-delivery at scale from Indian firms, policy conditions that allow fair competition, and structured collaboration with international partners.

It also calls for a cultural shift that recognises intellectual leadership within India as prestigious and rewarding. The future must see Indian institutions working with global peers as equal contributors, not as perpetual implementers.

Building Confidence and Capability

1947 to 1980: Foundations of Partnership

- Fragile economy and limited industrial base
- Global advisors supported planning, dams, health and heavy industry
- The Green Revolution combined Indian science with international inputs
- External consultants became part of the state machinery as trusted partners

1991 to 2010: Liberalisation and Expanding Horizons

- Entry of international consulting firms during reforms and privatisation
- Advisory support in public-private partnerships, taxation and regulatory change
- Procurement norms began to favour global experience and large footprints
- Indian firms are often confined to execution roles with limited leadership mandates

2011 to Present: Digital Collaboration

- Aadhaar, UPI and CoWIN show Indian talent, scale and frugal innovation
- Global platforms continue to dominate cloud, computing and advanced analytics
- Reliance shifts from hardware and physical infrastructure to software, platforms and advisory frameworks
- Growing need for co-created architectures, knowledge transfer and domestic capability in critical layers

1.4 Sectoral Illustrations and Real Consequences

Taxation and public finance offer a clear example. Over two decades, India has modernised its tax administration, harmonised indirect taxes and digitised compliance. External advisors contributed practical methods and global experience. Indian officials and domestic firms executed much of the work and adapted systems to local realities. Yet leadership of major design assignments often rested with foreign entities. This limited the accumulation of intellectual property inside India and reduced opportunities for local firms to build recognisable brands in fiscal design.

Health systems show a similar pattern. Strategy documents for hospital networks, insurance schemes and digital health platforms have often drawn on international templates. These references can be helpful, particularly where safety and clinical standards are involved, but they can also impose cost structures that poorly align with Indian realities. During the pandemic, the limits of global reliance became clear.

International supply chains for oxygen and medical devices were strained. Indian engineers and companies stepped in to repurpose plants, design low-cost equipment and build modular facilities. The episode showed that when responsibility is local, ingenuity follows. It also showed that long chains of advisory dependence can slow response and dilute accountability when decisions must be taken quickly.

Aviation and logistics have modernised rapidly. India now operates busy international airports and an extended network that carries millions of passengers and vast cargo volumes. Many master plans for airports and freight hubs were designed with external help. International experience matters in safety and air traffic management, and India has rightly drawn on it.

At the same time, domestic engineering and consulting capabilities have grown and deserve leadership roles that enable learning-by-doing at scale. When leadership remains outside, Indian firms struggle to build reputational capital that would allow them to export services to other markets, even though they already contribute significantly as partners.

Urban development and infrastructure carry large advisory footprints because projects are complex and capital-intensive. Western planning templates often assume land markets, utility pricing, and civic institutions that differ from those in Indian conditions. When these templates are imported without adaptation, cities end up with glossy plans that underperform in practice. Indian planners and consulting firms can calibrate design to local economics, climate and social patterns.

They can also create maintenance and governance models that are affordable and durable. The barrier is not knowledge. The barrier is procurement language that privileges scale over relevance and does not always insist on genuine technology and know-how transfer from international consortia working on Indian soil. The energy and climate transition deepens the stakes. India must add reliable power, expand transmission, decarbonise industry and integrate renewable generation while preserving affordability. Advisory models for power markets and carbon pricing travel easily across borders, but the political economy of energy is intensely local. Domestic capability in power systems planning, industrial decarbonisation, carbon management, and nuclear energy is growing within Indian firms, universities, and public institutions. Solar, wind and pumped hydro projects now show how India can combine local design, international partnerships and domestic execution to strengthen energy resilience. Work on small modular reactors and Bharat Small Reactor concepts illustrates how global technology dialogues and indigenous engineering can be combined to create options that support long-term energy security. These teams need mandates, responsibility and structured collaboration, not just support roles.

Digital governance is another domain where both capability and exposure are visible. India has led the world with identity, payments and consent platforms that reach hundreds of millions of people. Yet the data centres, chipsets and tools that underpin some parts of this architecture often originate abroad. A more balanced approach would treat foreign providers as partners in a journey in which India gradually increases its share of domestic design and control, without cutting itself off from global innovation.

Education and skills shape the pipeline. Curriculum reforms, outcome measurement and digital learning platforms have sometimes followed imported approaches that reflect different class sizes, teacher training levels and funding norms. Indian educators and edtech firms have shown that content, pedagogy and assessment can be designed for scale and diversity. When they drive the design, the results fit better and cost less. When external blueprints dominate, pilots look impressive but fade when budgets tighten.

Agriculture and food systems complete the picture. Advisory templates for supply chains, crop insurance and market design often import assumptions about farm size, climate and logistics that do not match well. Indian institutions, start-ups and cooperatives can tailor solutions to monsoon variability, smallholder risk and local demand. When they implement plans written elsewhere, the result is under-delivery and weak ownership. When they co-create those plans with global experts, drawing on both local knowledge and international science, resilience improves.

1.5 Understanding the Risks in Economy, Security and Confidence

Recognising these patterns is not about denying the value of global partners. It is about understanding the risks of an unbalanced relationship where responsibility and ownership sit essentially outside the country.

- 1. Economic continuity** is the first area of risk. If sanctions, trade restrictions or a global crisis interrupt access to external platforms or advisory services, programmes can stall, and critical operations can fail. A payment rail cannot pause. A grid cannot wait for new licences. A public health registry cannot go dark. When key layers are controlled elsewhere, continuity depends on decisions outside the country. The stronger India's domestic capability and the more equal its partnerships, the less vulnerable it will be to such disruptions.

Domain	Indian Role	Foreign Dependence	Impact
Taxation	Development of compliance and digitisation systems	Strategy and design are often led by global advisors	Weak retention of intellectual property within India
Health	Design of low-cost equipment and modular hospitals	Use of global templates for insurance and hospital networks	Cost structures are often misaligned with Indian realities
Aviation and logistics	Rapid expansion through domestic execution	Master planning and advisory roles held by foreign firms	Limited visibility for Indian firms despite strong delivery roles
Urban development	Local planners capable of context-specific design	Reliance on imported blueprints and Western models	Plans appear modern but perform poorly when not adapted
Energy and climate	Growth in renewables and emerging nuclear design	Dependence on international models for market design	Partnerships can speed technology adoption, but need local adaptation
Digital governance	Leadership in Aadhaar, UPI and CoWIN platforms	Cloud and analytics are dominated by global providers	Strategic exposure due to reliance on external platforms
Education and skills	Indian educators building scalable solutions	Imported frameworks for testing and measurement	Pilots may not sustain if not adapted to Indian classrooms
Agriculture	Local institutions designing context-specific models	Global templates for supply chains and risk management	Underperformance when local realities are not incorporated

Table 1.1: Sectoral Snapshot

2. **Security** is the next area of risk. In a world where malicious actors can attack networks, manipulate data and disrupt essential services, control over infrastructure and the ability to audit and harden the stack become matters of national defence. Hosting critical data on systems governed by external law creates exposure. Even when providers are trusted, forced disclosure regimes and lawful access provisions can make visible and invisible leakage. Strategic autonomy today includes the ability to operate, secure and recover digital and advisory systems without external permission, even as India continues to participate fully in global trade and technology.
3. **Innovation capacity** is a third area. When design work, analytical frameworks are repeatedly imported, the domestic ecosystem learns to execute rather than to originate. Students internalise the lesson that the smartest work is done elsewhere. Investors conclude that local advisory brands will always be subcontractors. Over time, the country risks losing the habit of invention in public systems and high-value consulting, even as it retains immense talent in delivery. Reversing that drift requires local firms and institutions to lead complex work, to share authorship with global partners on an equal footing and to own outcomes visibly.
4. **Public trust** is the final area. Citizens infer capability from who gets responsibility. When they see domestic firms lead and succeed, confidence grows, and a culture of self-reliance strengthens. When they see imported logos on every reform, trust migrates outward. Confidence is not a soft variable. It shapes career choices, purchasing decisions and the willingness of public leaders to back local institutions. A nation that wishes to lead must be seen by its own people as capable of leadership, including in settings where it works closely with international collaborators.

Dependence not only threatens continuity but also erodes confidence. True security lies in control over knowledge, data and design, alongside wise engagement with the world. Nations that command their own systems, while learning and borrowing intelligently from others, command their own future.

1.6 Evidence of Indian Capability and the Basis for Confidence

India's own record offers ample evidence that domestic institutions can deliver originality and scale while working with global partners. The space programme has placed probes around Mars and on the lunar surface, built reliable launch vehicles, and supported a growing private sector in space components. Nuclear energy programmes have developed indigenous reactor designs. They are now exploring small modular reactors and Bharat Small Reactor concepts that can enhance resilience and long-term energy security in partnership with other nations. Digital public infrastructure has connected identity, payments and consent into a stack that delivers inclusion at a population scale. Fintech and healthtech firms have built services that sit confidently on those rails.

During the pandemic, Indian engineers, hospitals, public agencies and companies worked together to create new supply chains, new equipment and new treatment capacities within weeks. These achievements were not accidents. They were the product of a long investment in talent, institutional memory, and a culture of problem-solving that values frugality, speed, and public purpose. They show that when responsibility is local, and outcomes are visible, Indian capability rises to the challenge, even as it draws on global science and technology.

India's tradition of frugal and human-centred innovation strengthens this confidence. The Jaipur Foot transformed access to prosthetics for low-income patients worldwide by combining engineering ingenuity with empathy. Low-cost cataract surgery models, community-based eye care, affordable cardiac care and public health innovations have demonstrated that it is possible to deliver world-class outcomes at a fraction of global costs. These examples illustrate that design leadership can emerge from real constraints and a deep understanding of local needs.

The consulting and engineering ecosystem contains pockets of excellence similar to these. Indian firms have designed complex refineries, power plants, transportation assets and industrial facilities. They have delivered large programmes in water, sanitation and housing. They have built analytics platforms for tax administration and social protection.

Where Indian firms have led projects, often in partnership with international organisations, they have demonstrated quality and value. What they lack is consistent access to leadership mandates that allow brands to grow, reputations to form and young professionals to see a future within domestic firms that is equal in prestige to opportunities abroad. Global realities further explain why dependence persists, and why the solution lies in building strength at home while engaging purposefully with the world.

1. **Global technological division of labour:** India has become a leader in software and digital services, but critical areas such as advanced hardware, chip fabrication and high precision manufacturing remain concentrated outside the country.

This pattern reflects decades of specialisation within global supply chains, which have positioned India as a service provider rather than a system designer in many sectors. Shifting this balance will require patient investment and long term relationships.

2. **High barriers to entry:** Advanced technologies such as semiconductors, sensors and systems on chip demand significant capital, sustained research effort and deep supply chain coordination. These barriers limit late entry, even where technical talent exists.

For India, overcoming them will require long term partnerships, coordinated policy support and predictable investment, including co development and technology transfer arrangements with countries that already possess these capabilities.

3. **Intellectual property and export controls:** Advanced economies maintain strict export controls on high value manufacturing equipment and sensitive technologies, such as advanced lithography systems.

These restrictions limit access to essential tools and slow domestic capability building. Addressing this challenge will require diplomatic engagement, indigenous capability development, regional alliances and shared manufacturing platforms that respect legitimate security concerns on all sides.

4. **Talent and collaboration:** Sustained innovation depends on strong connections between academia, research institutions and industry. India's universities produce high quality graduates, but structured pathways are needed to translate research into technology and commercialise indigenous design.

Strengthening these linkages will increase the country's ability to convert talent into technological independence, while continuing to benefit from international research partnerships and global scientific networks.

Together, these interlinked challenges show that dependence is not merely historical but structural. Building resilience therefore requires sustained investment in research capability, consistent policy direction and long term institutional cooperation. Domestic design and manufacturing strength must be nurtured deliberately, with external expertise used as a complement rather than a crutch.

The silent battle for sovereignty is also a story of opportunity. India has the talent and the ambition to lead. What it requires are stronger foundations that allow domestic firms and institutions to take ownership, work as equal partners with global experts, deliver outcomes and build intellectual property. These foundations lie in fair procurement, adequate research funding, enabling regulation and secure digital governance.

The Architecture of Sovereignty: India's Journey from Reliance to Design Leadership

The Evolution of Partnership (1947–Present)

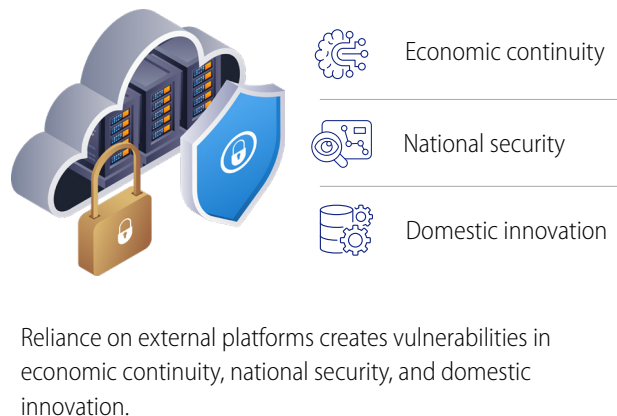


Breaking the Paradox: Risks & Opportunities

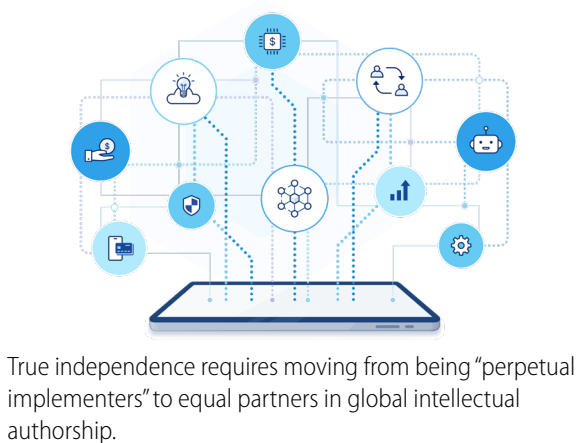
The Global-Local Paradox



The Risks of Intellectual Dependence



Sovereignty Through Shared Design



The Design Gap: A Snapshot of Sectors

	Indian strength	Ongoing dependency
Digital Governance	UPI, Aadhaar, CoWIN	Reliance on global cloud and analytics
Energy & Climate	Solar, wind, nuclear	Dependence on external financing and market models
Health	Modular, low-cost medical equipment	Use of global insurance and hospital templates

Chapter 2: Policy as the Architecture of Sovereignty

The pursuit of sovereignty is not achieved through declarations or announcements. It is realised by building strong policy foundations that empower a nation to design, decide and deliver on its own terms while engaging confidently with the world. For India, this is a moment of opportunity to create frameworks that unlock domestic capability and nurture intellectual independence. India has the talent, ambition and experience to lead globally. What is needed now is an enabling environment where procurement systems encourage innovation, research funding drives discovery, professional regulations support visibility and digital governance safeguards national interests.



These conditions will allow Indian firms and institutions to move from the margins to the centre of reforms and projects of national importance. This chapter focuses on the policies that shape intellectual and technological independence. It examines procurement, research funding, professional regulation, digital governance and talent development, and proposes a consolidated framework for technological sovereignty that combines domestic strength with purposeful international collaboration. The goal is to create a future where India leads with confidence, innovates with ambition and partners globally from a position of strength.

2.1 Procurement Frameworks and the Question of Trust

Public procurement in India represents a significant opportunity, accounting for nearly 20% of the national GDP. It is through this gateway that most consulting and advisory projects flow, whether in energy, transport, health or infrastructure. This scale gives India a powerful lever to shape capability and confidence. However, current eligibility norms often favour global presence over contextual expertise.

Tender documents, especially for new, emerging and strategically important complex projects, frequently specify conditions such as decades of international experience, operations in 20 or more countries, or a turnover of several thousand crore rupees. These requirements are typically designed for large global firms. Indian firms with strong technical expertise and deep local knowledge are often excluded, not because they lack capability, but because of rigid and restrictive eligibility criteria.

This approach has consequences. It prevents domestic firms from gaining leadership experience on nationally important projects. It denies them the chance to build reputational capital that could be leveraged in other markets. It pushes young graduates towards multinational firms that promise prestige and large assignments. Most importantly, it sustains the perception that foreign firms design reforms while Indian firms only implement them.

A shift in procurement philosophy is therefore essential. Instead of equating global presence with quality, tender conditions should place meaningful weight on contextual relevance, past performance in India, and innovative approaches that respond to local realities.

In emerging technologies where markets are still developing, eligibility norms should include an exception pathway so that capability, safety and contextual relevance count more than age or global footprint. Prior deliveries at comparable complexity within India should be treated as scale-equivalent for qualification, even when the absolute contract size is smaller than overseas benchmarks.

Government contracts can also introduce weighted scoring that recognises domestic experience, responsible innovation and partnerships with academic and research institutions. In strategic areas such as advanced manufacturing, clean energy, nuclear energy, transport modernisation, and digital public infrastructure, at least one Indian firm should hold a leadership role in the consortium to ensure ownership of design and accountability are built within national systems. Foreign partners should be encouraged and welcomed, with explicit provisions for technology transfer, joint authorship of solutions and capacity building inside Indian institutions.

India's own information technology sector offers a compelling precedent. In the 1990s, government projects allowed Indian IT firms to compete on relatively equal terms. Over time, these firms built capability, exported services and became global leaders, often in partnership with international clients. A similar approach in consulting and advisory services could enable Indian firms to expand capacity, demonstrate competence, work as equals with global peers and eventually establish an international presence of their own.

2.2 Research Funding and Translation from Lab to Field

India invests 1% of its GDP in research and development, which is far below that of countries such as South Korea (4.5%), Israel (4.9%), and the United States (3.5%). This level of investment means that many promising ideas are not able to move beyond the laboratory. Universities lack stable funding; research projects are fragmented, and collaboration with industry is limited. As a result, India often excels in execution but not in design.

The creation of the Anusandhan National Research Foundation is an encouraging step. Still, its potential will only be realised if substantial resources, autonomy and long-term commitment support it. Research funding must support not only basic science but also the critical middle stage of technology readiness, where many innovations falter for want of capital. Grants should incentivise collaboration among academia, industry, and government on national priorities, including green hydrogen, advanced materials, semiconductors, biotechnology, nuclear technology (including small modular reactors and Bharat Small Reactor concepts), clean energy, smart manufacturing, artificial intelligence, and digital sovereignty.

India already has a rich record of frugal and socially oriented innovation, from the Jaipur Foot to low-cost cataract surgery models and affordable cardiac care. These examples show what can happen when engineering ingenuity, clinical science, philanthropy and policy support come together. A modern research and translation framework should treat such models as national assets and create pathways for similar ideas in health, agriculture, mobility, materials and energy to move from prototype to nationwide deployment.

Scheme	Allocation (Rs crore)	Utilisation (Rs crore)
Science and Technology Institutional and Human Capacity Building	543.91	542.38
Research and Development	49.13	48.41
Innovation, Technology Development and Deployment	326.21	325.56
National Mission on Interdisciplinary Cyber Physical Systems	815.00	715.97
National Quantum Mission	86.00	62.36
VigyanDhara	330.75	271.98
National Super Computing Mission	242.80	221.00
Total	2393.80	2187.66

Table 2.1 | Government Schemes for Science and Technology (2024–25)

Source: Budget 2024–25, Department of Science and Technology

As shown in Table 2.1, investment in R and D remains highly utilised, reflecting both efficiency and constraints within current institutions. To move from execution to invention, India must increase investment levels and ensure continuity of funding across financial years.

Country	R&D Expenditure (% of GDP)	Approx Annual Outlay (US\$ bn)
South Korea	4.5	90
Israel	4.9	25
United States	3.5	700
China	2.4	550
India	<1	18

Table 2.2 | Global Investment in R&D

Source: UNESCO Institute for Statistics and OECD Data (2024)

India's R and D investment is modest compared with global leaders. Sustained innovation requires multi year planning, predictable budgets and a clear path for translating research into market ready solutions. Thematic missions should explicitly cover advanced manufacturing, clean energy, nuclear technologies, smart manufacturing, artificial intelligence and semiconductors, with funding lines that do not lapse at year's end.

Each mission should publish annual metrics on technology readiness, pilots deployed at scale, patents licensed to Indian firms, joint intellectual property created with international partners and domestic value addition achieved.

Global experience shows that institutional design matters. The United States created the National Science Foundation and the Defence Advanced Research Projects Agency to support high risk research. Finland established Tekes to connect universities with industry, and Singapore established A*STAR to align research with economic goals. China strengthened its design and innovation capability through institutions such as the Chinese Academy of Sciences and programmes like the Torch initiative, which systematically linked research, industrial application and regional development at scale.

India can adapt these models by creating sectoral missions under the Anusandhan Foundation with assured multi-year funding, clear accountability and explicit requirements for technology transfer and local manufacturing opportunities whenever foreign collaborators are involved. With these reforms, India can move from execution to creation and ensure that the ideas behind new technologies, including in nuclear, digital and health domains, are increasingly shaped and owned within the country while still benefiting from global science.

2.3 Professional Regulation and Visibility of Domestic Firms

The visibility of Indian professional firms depends not only on their performance but also on the rules that govern communication. Bodies such as the Institute of Chartered Accountants of India, the Institute of Company Secretaries of India, and the Bar Council impose restrictions on advertising, marketing, and public outreach. These rules were created to maintain dignity and prevent unethical practices. However, they have also limited Indian firms' ability to share their work, while global firms promote themselves through reports, campaigns, and thought leadership.

This situation creates an uneven field. Domestic firms often deliver excellent work but struggle to showcase their expertise, publish insights, or build strong brands that attract talent. Clients sometimes assume that foreign firms are more credible simply because they are more visible and appear in international rankings and conferences. Change is necessary. Visibility does not mean compromising ethics. It means creating clear, responsible guidelines that enable firms to share knowledge, host events, publish reports, and present achievements transparently. These guidelines can include disclosure norms, peer review for significant publications and grievance mechanisms for clients. Penalties should apply to false claims, but genuine expertise should be encouraged.

If Indian firms cannot build their reputation, they will remain dependent on subcontracting. With fair rules for visibility, they can become trusted partners to Indian institutions and international clients, and help strengthen design authority in the country.

2.4 Digital Governance and Control over Critical Infrastructure

Sovereignty in the twenty-first century is closely linked to digital infrastructure. India has created inclusive systems such as Aadhaar for identity, UPI for payments and CoWIN for health management. These platforms show that India can design and operate digital public goods at a national scale. However, much of the underlying infrastructure relies on global cloud platforms operating under foreign laws. Data stored on these platforms can be accessed by external agencies under their domestic legal systems, creating risks to financial security, citizen records, and overall security.

India has begun to move towards data localisation, but further action is needed. Domestic cloud providers should be encouraged to grow through government procurement, assured demand and clear security standards. Public sector data centres should be modernised and expanded. Domestic capabilities in cybersecurity, encryption and privacy-preserving technologies need strong support. Policies should ensure that sensitive projects in health, finance, defence, and critical infrastructure maintain a substantial component hosted in India, with precise control over keys, logs, and incident response.

The European Union offers a valuable example. Through the General Data Protection Regulation and its cloud sovereignty initiatives, it ensures that European data is governed by European law. India can learn from this approach while creating safeguards suited to its own scale, diversity and development needs. At the same time, India should remain an active participant in global digital trade, negotiating fair terms for cross-border data flows and building international arrangements for reciprocal protection of sensitive data.

Digital governance must also prepare for the spread of artificial intelligence. Large models and decision systems that influence credit, healthcare, education and public services cannot remain as black boxes owned entirely outside the country. India will need standards for transparency, explainability and audit, supported by a mix of domestic and international certification mechanisms that protect citizens while encouraging innovation.

2.5 Funding Talent and Creating Career Paths

Talent is at the heart of intellectual independence. India produces millions of engineers, accountants and management graduates, yet many of the best work abroad or for multinational firms. This is due to limited opportunities and perceptions of prestige. Foreign firms offer higher pay, global exposure and prestigious projects. Domestic firms, constrained by procurement rules, research funding gaps, and low visibility, cannot always compete.



Figure 2.1 | Five Policy Levers for Accelerating Sovereignty

If India wants its best minds to serve national priorities, it must create career paths that offer both pay and purpose. Government agencies can build elite groups of professionals in areas such as digital infrastructure, nuclear and clean energy, semiconductor policy, defence technology and advanced manufacturing. These groups should be paid at market-linked rates and protected from frequent transfers. They can work closely with international organisations while ensuring that core expertise and decision-making remain anchored in Indian institutions.

Domestic firms should receive tax credits, co-funding and training grants to invest in research, skills development and global exposure for their staff. Universities should expand partnerships with industry to prepare students for domestic careers through internships, joint laboratories, and problem statements drawn from the Indian public sector. Visiting professorships and co-teaching by practitioners can help align education with the needs of a design-led and technology-intensive economy.

The Indian Administrative Service in the early decades of Independence provides a valuable example. It is prestigious because it combined pay, power and public purpose. If a similar ecosystem is created for engineering, technology and consulting professionals, graduates will see a future in building India's intellectual independence rather than preferring to join foreign brands. International experience will remain important, but more of it can be channelled through exchanges, joint projects, and sabbaticals rather than permanent migration of capability.

2.6 Building the Policy Foundation for Technological Sovereignty

For India to secure its future in a world shaped by data, computation and knowledge systems, technological sovereignty must move from aspiration to action. It means a nation's ability to design, produce, govern, and safeguard technologies that influence its economy, security, and society on its own terms, while remaining an active and trusted member of the international community.

A strong foundation begins with a clear definition and institutionalisation. India should adopt a National Technology Sovereignty Policy with the same status as the National Education Policy and the frameworks that guided atomic energy and space development. This policy must identify critical technologies and set measurable national goals for their growth, adoption and governance. These include semiconductors, advanced materials, artificial intelligence, quantum technologies, secure communications, nuclear technologies, including small modular reactors and Bharat Small Reactor designs, critical minerals, advanced manufacturing and secure digital public infrastructure.

To make this vision operational, India needs a dedicated institutional architecture to coordinate, fund and measure progress across the technology spectrum.



Figure 2.2 | Institutional Framework for Technological Sovereignty

A national framework for technological sovereignty

India would benefit from a clear national framework to guide its technology journey. An apex body such as a National Technological Sovereignty Council could align ministries, research agencies and industry around a shared vision. Positioned at the highest political level and supported by legal authority, the council could help identify priority technologies, guide funding choices and publish an annual sovereignty dashboard that reflects India's autonomy across critical technology value chains.

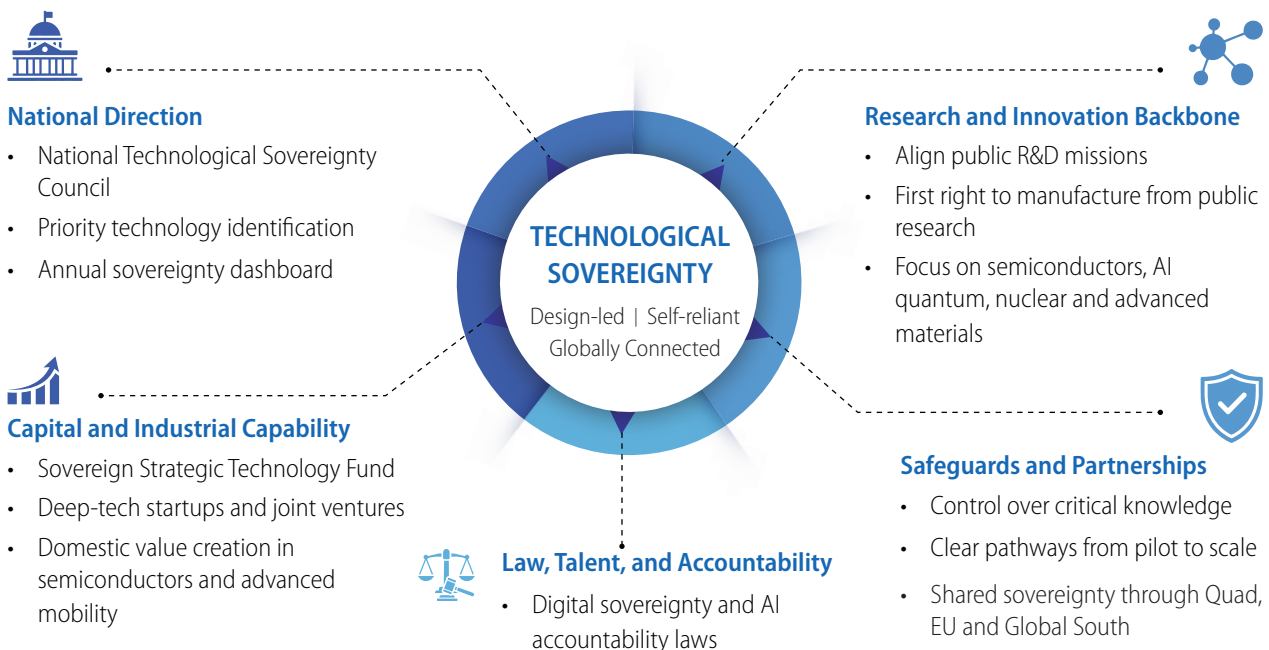
Such a framework must be supported by a renewed research and innovation ecosystem. At present, public research and development efforts are spread across ministries and often lack coordination. A modern R and D Alignment Act could bring coherence by aligning the missions of MEITY, DST, DRDO, ISRO and CSIR under common national goals. Publicly funded research would then consistently serve long term national interests by ensuring India has first rights to manufacture, along with sustained access to design knowledge and know how. The institutional model that once enabled the atomic energy and space programmes can now guide emerging domains such as semiconductors, quantum computing, artificial intelligence, nuclear technologies and advanced materials. Indigenous intellectual property can be encouraged through fiscal incentives, simpler intellectual property courts and a research culture that values patents and deployable designs alongside academic publications.

Capital and industrial policy as capability builders

Strategic ambition also requires patient capital. India could consider establishing a Sovereign Strategic Technology Fund, inspired by government owned investment institutions such as Temasek in Singapore and Mubadala in the United Arab Emirates. Such a fund could support deep technology start ups, enable joint ventures with global leaders that generate local intellectual property and finance high risk frontier research in defence, quantum science, nuclear energy and advanced energy systems.

Operating with the agility of a venture investor and the commitment of a national institution, it could bridge the gap between laboratory innovation and industrial scale while sharing risk with private capital.

Industrial policy is the mechanism through which this ambition becomes capability. In semiconductors, the emphasis can move beyond assembly towards genuine domestic value creation through electronics clusters, trusted foundries and advanced packaging centres supported by long term public procurement. In energy and mobility, incentives can integrate research obligations so that imported technologies become foundations for domestic innovation rather than sources of dependence. Nuclear energy policy can follow a similar approach by linking international cooperation on reactors and fuel cycles with focused programmes that deepen Indian capabilities in design, safety analysis and manufacturing.



Safeguards, scale and partnerships

Defence and dual use technologies require strong governance frameworks. Transparency, traceability and continued access to critical knowledge should remain central principles. Even within international collaborations, source code, design rights, test data and manufacturing knowledge can remain accessible within the country, with contracts structured to ensure joint ownership of improvements arising from work carried out in India.

Closer alignment between procurement, funding and regulation can further accelerate scale. A national sandbox approach could allow successful pilots to progress smoothly from testing to limited production with assured public offtake, and then into open market competition. This structured pathway can translate research into products, nurture Indian suppliers across the value chain and maintain quality and public accountability. International partners can participate at each stage with clear expectations on localisation, technology sharing and joint export opportunities.

India's policy approach can be anchored in shared sovereignty, where partnerships strengthen collective capability without long term dependency. Through the Quad, India can collaborate on chip design, secure supply chains and undersea communications. With the European Union, there is scope to co develop trusted digital standards, privacy frameworks and green technologies. Engagement with the Global South, particularly Africa, can focus on sharing sovereign digital platforms for identity, payments and health, strengthening development cooperation and influence.

Law, regulation and human capital

Legal and regulatory systems must evolve alongside technological ambition. A Digital Sovereignty Law can ensure that critical data remains within Indian jurisdiction, that foreign cloud and artificial intelligence platforms operate under appropriate oversight and that cybersecurity certification is treated as a matter of national assurance. An AI Accountability Act could promote transparency in algorithmic decision making, protect citizens from bias and require audit of major models used in sensitive public systems. In parallel, cryptography and cybersecurity policies can support indigenous certificate authorities and root servers across the digital ecosystem.

Human capital remains the true engine of sovereignty. India can invest in next generation universities and research centres focused on semiconductors, quantum computing, nuclear engineering and advanced artificial intelligence, comparable in ambition to leading global institutions. Fellowship programmes can support engineers transitioning into research roles, while scientists from the diaspora can be enabled through independent grants and clear intellectual property frameworks that serve national interests. The idea of designing for sovereignty can become part of technical education so that engineers see themselves not only as users of technology but as creators and custodians of national capability.

Measuring progress and shaping the future

Accountability can anchor ambition over time. An annual Technological Sovereignty Index could track domestic value addition, research spending as a share of GDP, high value patents, critical import dependencies and technology trade balances. Such transparency would support continuity, informed debate and long term commitment beyond electoral cycles.

India's journey towards technological sovereignty represents the next stage in its evolution as a design led economy. It marks a shift from being a market for others' inventions to becoming a source of ideas, technologies and standards. Just as atomic energy and space exploration shaped India's independence in the twentieth century, control over data, computation, energy resilience and advanced technologies will shape its future in the twenty first century.

The foundations outlined in this chapter prepare the ground for that transformation. The next chapter turns to design leadership and institutional capability, exploring how these frameworks can be translated into self reliant innovation and globally competitive enterprises. Sovereignty, at its core, is the freedom to imagine, design and decide on our own terms. The foundation has been laid. The task ahead is to build.

Architecture of Sovereignty: India's Path to Design Leadership

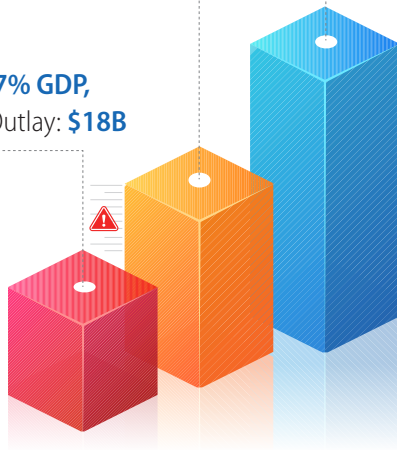
The Gap: Barriers to Intellectual Independence

R&D Investment

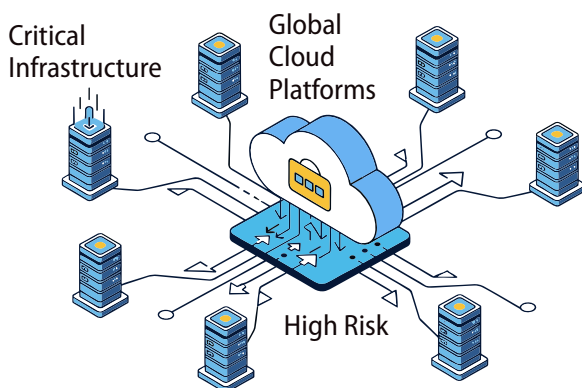
South Korea: **4.5% GDP**,
Annual Outlay: **\$90B**

Israel: **4.8% GDP**,
Annual Outlay: **\$25B**

India: **0.7% GDP**,
Annual Outlay: **\$18B**



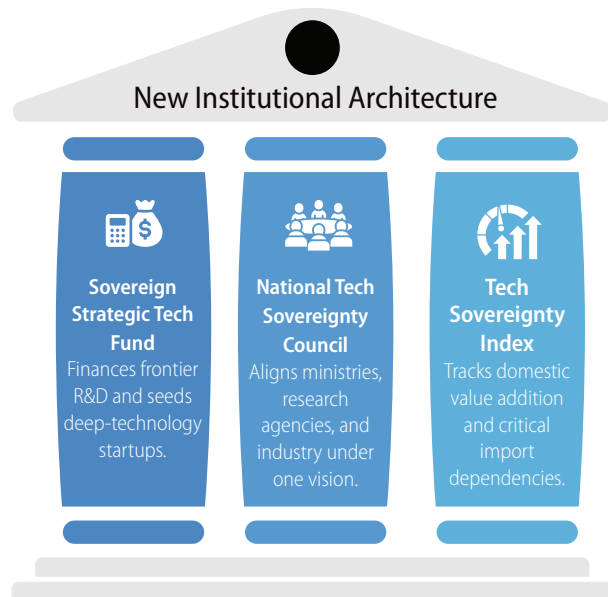
- Procurement favors “Global” over “Contextual”
- Rigid norms exclude expert Indian firms



Risks of Digital Dependency:

Reliance on global platforms creates security vulnerabilities

The Solution: Strategic Levers for Sovereignty



1. Reform Public Procurement

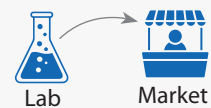
Contextual Relevance

Weight contextual relevance; ensure domestic firms hold leadership roles.



2. The Anusandhan Research Foundation

Bridge the “lab-to-market” gap with stable, multi-year funding cycles.



Multi-Year Funding

3. Digital & Talent Sovereignty

Establish domestic standards; create elite paths for top talent.



Foundation for Technological Sovereignty:

Ability to design, govern, and safeguard critical technologies on its own terms

Chapter 3: The Shift to Design Leadership

India has earned global admiration as one of the most reliable execution engines. Its companies have built power plants, refineries and transport systems, delivered software at scale and managed complex global operations with precision. This strength in execution is a remarkable achievement and a source of national pride. Yet the twenty-first century brings an even greater opportunity. True sovereignty calls for design leadership, which means the ability to imagine, create and own the systems, technologies and intellectual property that will shape national progress. Design leadership is a bold step forward. It moves us from following instructions to writing them, from carrying out someone else's vision to defining our own and from manufacturing efficiently to inventing what is manufactured.



It is the journey from being a service provider to becoming a source of knowledge and innovation. This chapter explores how India can embrace this exciting transition. It explains the roots of our comfort with execution, the limitations of remaining an executor, and the promise that comes when a country begins to own its design and intellectual property. It also draws lessons from global experience and highlights sectors in which design leadership can create a strong national advantage.

3.1 The Historical Comfort with Execution

India's confidence in execution comes from its early development story. After Independence, the country established public-sector enterprises, technical institutes, and industrial infrastructure. These institutions prepared a generation of engineers, managers and administrators who could deliver large national projects with skill and commitment.

By the 1980s and 1990s, as globalisation opened new doors, this trained workforce found fresh opportunities. The services and software industries grew rapidly, powered by Indian talent that delivered consistent quality at competitive cost. The world discovered India as a trusted execution partner, and the outsourcing industry expanded, creating jobs and building global credibility.

This success shaped a mindset. Indian companies became highly skilled at working under specifications set elsewhere, under contracts were made based on foreign practices and within processes designed by global headquarters. Execution excellence was rewarded more than originality. Innovation often remained informal and unrecorded rather than becoming structured intellectual property. As this pattern continued, India became highly proficient in producing goods designed abroad, writing software for systems planned elsewhere, and managing operations for global firms. Even when talent was available for higher-value work, institutions lacked systems to translate that ability into design ownership.

Across the world, countries that moved beyond this execution cycle built strong systems to capture intellectual property from public research. India has a rich pool of scientists and engineers, many of whom lead global organisations, yet domestic institutions have not always turned research into a national advantage. This gap arises partly from weak incentives for universities to commercialise research and partly from the lack of a clear pathway linking funding, research, industrial partnerships, and intellectual property ownership. A look at global approaches shows this:

India's own National Intellectual Property Rights Policy encourages innovation but does not yet provide a single system to turn publicly funded research into commercial applications at scale. As a result, promising knowledge often stays inside laboratories or is commercialised elsewhere.

3.2 Why Design Leadership Matters

Design leadership is not merely a desirable quality; it is a decisive factor in sovereignty, national security, and long-term economic strength. Nations that own the design of technologies and systems do much more than create products. They set global standards, influence supply chains and capture a larger share of value. They decide how products evolve, how data is managed and how services are delivered across borders. This power shapes the future of industries and economies.

When execution happens without design, the most valuable work remains outside national boundaries. The difference is visible in advanced manufacturing, where countries that design aircraft engines, medical devices, advanced materials or robotics systems earn significantly higher margins than those that only assemble them. Design ownership also creates skilled employment and drives innovation ecosystems.

In the digital world, platform creators define the rules governing data flows, pricing models, encryption, and security. They determine how billions of users interact and how businesses operate. In defence and aerospace, design capability is the foundation of strategic autonomy. A nation that owns the design of its weapon systems, sensors and propulsion technologies is far less dependent on external suppliers.

Country or region	Policy or framework	Key feature
United States	Bayh Dole Act	Universities own intellectual property from federally funded research
Japan	Japanese Bayh Dole model	Corporates own intellectual property from government funded research
European Union	Code of Practice on intellectual property management	Harmonised standards for commercialisation
South Africa	Intellectual Property Rights Act	Mandatory management of intellectual property from public funding
China	Intellectual property reforms	Strong institutional ownership of research outputs
OECD members	STIP Compass	Global database of commercialisation policies

Figure 3.1 | Regional Frameworks

In consumer technology, brands that shape design lead global markets, while contract manufacturers operate on thin margins and have little influence over product evolution. For India, design leadership is not simply an economic aspiration. It is a requirement for sovereignty and resilience. A country that designs its own systems is less vulnerable to supply chain disruptions, foreign licensing restrictions or sudden changes in global standards. It can respond faster to emerging challenges and maintain control over critical technologies. Design leadership also inspires a culture of creativity. It encourages young professionals to invent, experiment and take intellectual risks. It builds confidence in local capability and creates role models who demonstrate that innovation can thrive in India. This cultural shift is as significant as the economic benefits because it lays the foundation for a knowledge-driven society.

India stands at a turning point. By embracing design leadership, the nation can move beyond the limitations of execution and claim its place among global innovators. This is not only about competing with others; it is about shaping solutions for a diverse, democratic and rapidly growing economy. It is about developing technologies that reflect our values, meet our unique needs, and contribute to global progress. Design leadership matters because it defines who sets the rules of the future, and India has the talent, ambition and opportunity to lead.

3.3 Lessons from Global Transitions

The transition from an execution-focused economy to a design-led nation is not unique to India. Several countries have successfully made this transition, and their experiences offer valuable lessons. These examples show that progress is possible when there is a clear vision, deliberate policy and confidence in local capability.

South Korea offers one of the most compelling case studies. It began by manufacturing products designed elsewhere, often working as a low-cost assembly hub. Over time, South Korea invested heavily in applied research, industrial policy and partnerships between universities and industry. These efforts were not short-term; they were sustained over decades. The result is visible today in global brands that lead in electronics, automobiles and consumer appliances.

South Korea's success demonstrates that patient investment and strong collaboration can transform a nation's role in global value chains.

Japan followed a similar path but with its own distinctive approach. In the years after the Second World War, Japan learnt from global designs and adapted them. It focused on quality, process engineering and continuous improvement. Japanese firms invested deeply in research and built a culture of precision and reliability. Over time, Japan moved from being a learner to a leader, setting global standards in electronics, precision machinery and automotive engineering. This journey demonstrates how disciplined innovation and a commitment to excellence can foster enduring leadership.

Israel offers another powerful example. It built a design ecosystem by linking defence research, universities and start-ups. The country invested in early-stage high-tech research and development and encouraged entrepreneurship. This approach fostered a vibrant culture of innovation and led to leadership in cybersecurity, medical devices, and water management. Israel's experience highlights the importance of connecting research with commercial application and fostering a risk-taking mindset.

China's story is equally significant. It began as the world's factory, producing goods designed elsewhere. But China did not remain in that role. It invested heavily in indigenous design, standard setting, intellectual property and human capital. Today, China leads in several sectors including electric mobility, renewable energy integration and digital commerce. Its progress shows the power of scale combined with strategic planning and strong institutional frameworks.

Across these examples, one common factor stands out: deliberate policy. Nations that moved up the value chain did so through coordinated institutions, long-term investment and robust intellectual property frameworks. They believed in their own capability and created systems that encouraged innovation. India can draw from these experiences while shaping its own model. Our approach will be democratic, diverse and collaborative, reflecting the strengths of our society.

By learning from global transitions and adapting them to its context, India can build a future in which design leadership becomes a national strength.

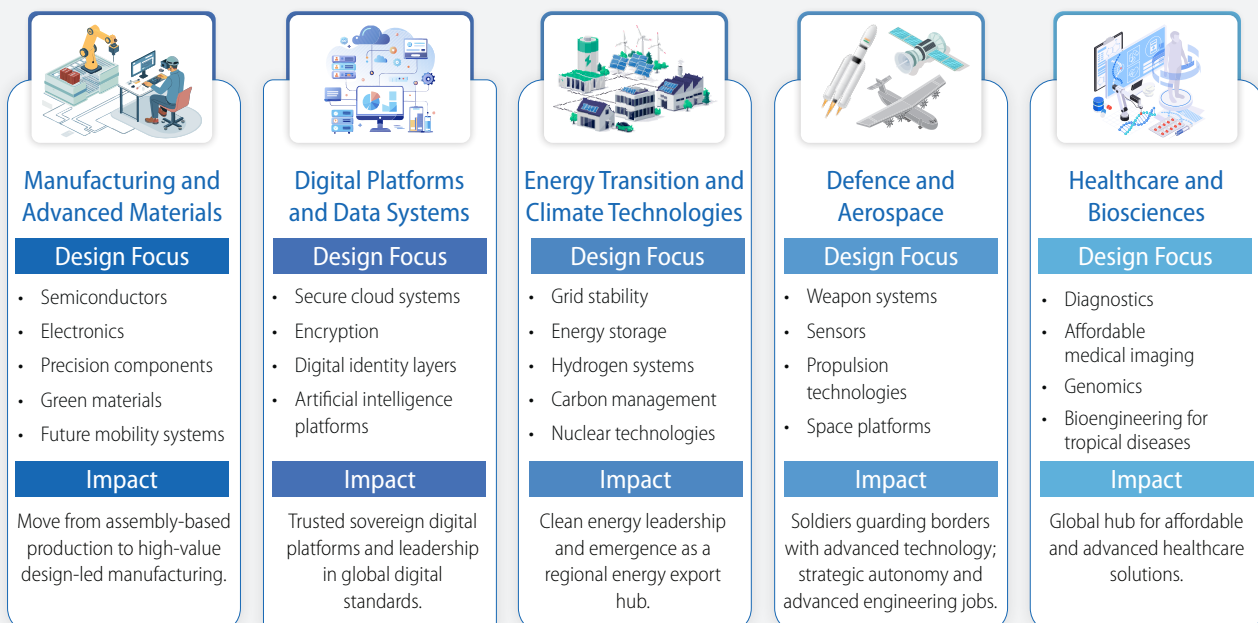
3.4 Strategic Sectors for Design Leadership

India does not need to become a design leader in every sector at once. The journey should begin with areas where the country already has strong capability, where the need is strategic and where design ownership can create long-term advantage. By focusing on these sectors, India can build momentum and demonstrate success that inspires confidence across the economy.

- Manufacturing and advanced materials:** India's manufacturing base is growing steadily, but much of it remains assembly heavy. To move up the value chain, India must develop design capability in semiconductors, electronics, precision components, green materials and future mobility systems. These areas are critical for competitiveness in global markets. Focused national missions, dedicated design centres and partnerships with global leaders can accelerate this shift. By creating an ecosystem that links research institutions, industry and start-ups, India can ensure that innovation translates into products and processes that are designed and owned domestically.
- Digital platforms and data systems:** India has already shown the world its ability to create population-scale digital public infrastructure through initiatives such as Aadhaar and UPI. The next phase of progress lies in designing secure cloud systems, encryption technologies, identity layers and artificial intelligence platforms that can be trusted by governments and citizens worldwide. Owning these designs will allow India to offer sovereign digital platforms to other countries and shape shared global standards. This is not only an economic opportunity but also a way to strengthen digital sovereignty and protect data privacy.
- Energy transition and climate technologies:** As the world moves towards low-carbon solutions, the designs that enable grid stability, storage technologies, hydrogen systems and carbon management will define future markets. India has the scientific and industrial base to create solutions tailored for a tropical, high-density economy. By investing in research and partnering internationally for field trials and rapid scaling, India can lead in technologies that support sustainable growth. Nuclear technologies, including small modular reactors and Bharat Small Reactor concepts, offer opportunities for long-term resilience and export partnerships.
- Defence and Aerospace:** India has already shown the world its ability to create population-scale digital public infrastructure through initiatives such as Aadhaar and UPI. The next phase of progress lies in designing secure cloud systems, encryption technologies, identity layers and artificial intelligence platforms that can be trusted by governments and citizens worldwide. Owning these designs will allow India to offer sovereign digital platforms to other countries and shape shared global standards. This is not only an economic opportunity but also a way to strengthen digital sovereignty and protect data privacy.
- Healthcare and Biosciences:** India has already shown the world its ability to create population-scale digital public infrastructure through initiatives such as Aadhaar and UPI. The next phase of progress lies in designing secure cloud systems, encryption technologies, identity layers and artificial intelligence platforms that can be trusted by governments and citizens worldwide. Owning these designs will allow India to offer sovereign digital platforms to other countries and shape shared global standards. This is not only an economic opportunity but also a way to strengthen digital sovereignty and protect data privacy.

Strategic Sectors For Design Leadership

Where India can build design ownership and long-term advantage



Focused design leadership builds confidence, attracts investment, and strengthens long-term national resilience

These innovations can position India as a trusted provider of clean energy solutions. Together, these advances can enable India to evolve into a regional clean energy export hub, supplying power, fuels, technologies and engineering expertise to energy constrained markets across Asia, Africa and beyond.

- **Defence and aerospace:** Strategic autonomy depends on the ability to design weapon systems, sensors, propulsion technologies and space platforms. Indian organisations have made progress in several areas, but domestic design leadership must expand further. This requires integrated research programmes, strong industry partnerships and procurement models that give Indian designers long-term responsibility. By building indigenous design capability in defence and aerospace, India can ensure security, reduce dependence on imports and create high-value jobs in advanced engineering.
- **Healthcare and biosciences:** India has deep expertise in pharmaceuticals and medical devices, which provides a strong foundation for the next leap forward. Design leadership in diagnostics, low-cost medical imaging, genomics and bioengineering for tropical diseases can transform healthcare delivery. These innovations will not only serve domestic needs but also create opportunities for global collaboration. Partnerships in clinical research and device validation can help India become a hub for affordable and advanced healthcare technologies. By focusing on these areas, India can combine scientific strength with social impact.

India's focus on these strategic sectors will create a ripple effect across the economy. It will build confidence in local capability, attract investment and inspire a generation of innovators. By owning designs in critical areas, India will strengthen its sovereignty, enhance competitiveness and contribute solutions to global challenges. Design leadership in these sectors is not just a goal; it is a pathway to long-term resilience and prosperity.

3.5 Barriers to Design Leadership

India's ambition for design leadership faces several structural challenges that must be addressed urgently and with vision. These barriers arise from systemic gaps that limit the ability to convert ideas into impactful designs.

One major constraint is underinvestment in research and development. Without sustained funding, long-term projects struggle to reach maturity. Fragmentation across institutions and ministries further restricts collaboration, making it difficult to pool resources and expertise. Risk aversion in both public and private systems reduces experimentation, while audit concerns often discourage innovation within government agencies. Procurement rules sometimes favour established global designs even when competitive Indian alternatives exist, thereby disadvantaging domestic innovators.

Many promising designs remain stuck at the prototype stage because there is no structured pathway for trials, field validation and scaling. Universities continue to place greater emphasis on academic publications than on patents or practical design outcomes. Private firms, meanwhile, invest heavily in operations but allocate limited resources to research and innovation. These conditions make design leadership difficult to sustain and slow the creation of intellectual property capable of competing globally.

Overcoming these barriers requires clarity of purpose and patient investment. Research funding must support long-horizon design missions rather than short-term projects. Public institutions should encourage experimentation and protect innovators from punitive consequences when projects fail on the first attempt. Failure should be treated as a learning step, not as a setback. Collaboration between academia, industry, government and start-ups must become institutional rather than incidental. Structured partnerships, shared innovation platforms, and transparent processes can create an environment in which ideas move confidently from concept to market.

India has the talent and ambition to lead in design. By addressing these barriers through bold reforms and sustained commitment, the country can unlock its full creative potential and build a future in which design leadership becomes a defining national strength.

3.6 Building an Ecosystem of Design Leadership

Design leadership cannot thrive through isolated initiatives. It requires a comprehensive, interconnected ecosystem that fosters innovation at every stage. This ecosystem must combine research, education, industry, policy and culture into a coherent framework that supports creativity and rewards risk-taking.

First, research investment must rise substantially and focus on applied design. Missions in semiconductors, green mobility, nuclear systems, advanced materials, digital platforms and clean energy should have assured multi-year funding. These missions must be structured to encourage collaboration between research institutions and industry, ensuring that ideas move quickly from concept to prototype and then to market.

Second, universities must be empowered to innovate. They need incentives to file for patents, build laboratories in collaboration with industry partners, run technology incubators, and commercialise research. Promotion criteria should recognise practical impact and successful technology transfer on par with academic publications. By valuing real-world outcomes, universities can become engines of design leadership rather than remaining confined to theoretical research.

Third, industry must invest in design capability. Firms that aspire to global leadership must build in-house design teams, support long-term research and collaborate actively with start-ups. Shared testbeds, pilot zones and industry-funded research chairs can strengthen this ecosystem. When businesses commit to design, they create demand for innovation and provide the resources needed to scale promising ideas.

Fourth, procurement norms must change. National projects should reserve leadership roles for Indian designs when they meet safety and performance thresholds. A structured scale-up pathway should enable promising domestic designs to progress through pilot, limited deployment, and complete deployment phases. This approach will give innovators confidence that their work can reach the market and make an impact.

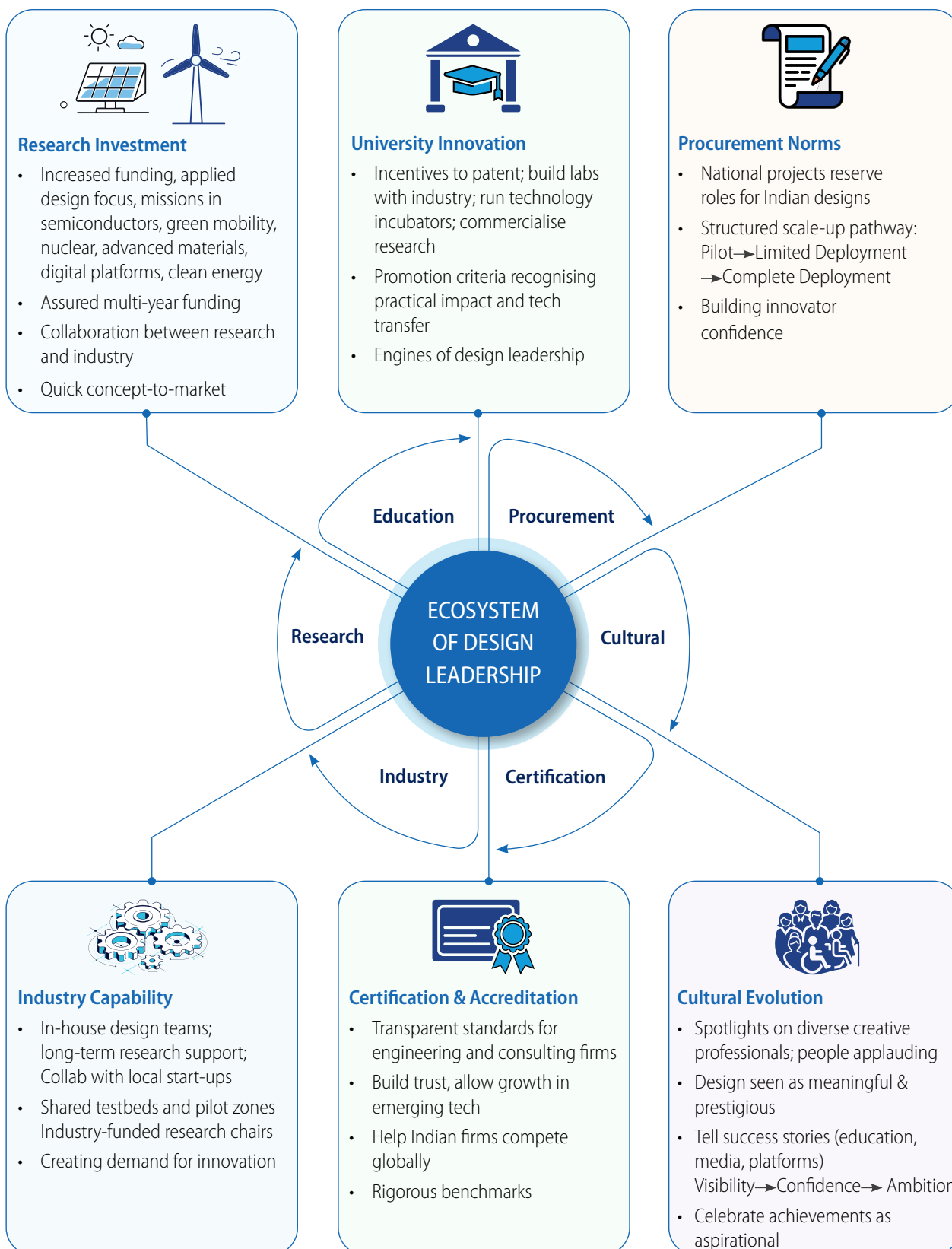
Fifth, professional certification and accreditation can strengthen accountability for design quality. Transparent standards for engineering and consulting firms will build trust and allow domestic capability to grow in emerging technologies. Certification will also help Indian firms compete globally by demonstrating adherence to rigorous benchmarks.

Finally, culture must evolve. Young professionals must see design as meaningful and prestigious. More of India's design success stories should be told through education, media and industry platforms. Visibility creates confidence, and confidence inspires ambition. When design achievements are celebrated, they become aspirational for the next generation.

India's progress in space technology, biosciences, digital public systems and clean energy proves that design leadership is achievable. The challenge is to make such achievements routine. With deliberate policy, sustained research, global partnerships and cultural confidence, India can move from a primarily execution-driven economy to one that shapes the ideas, technologies and systems of the future.

To lead in design is to influence the grammar of emerging technologies before they become global. India's ambition should evolve from making for the world to designing for the world, with confidence, responsibility and partnership. When India becomes a source of design, sovereignty transitions from aspiration to daily practice, and the country reclaims the authorship of its future.

Building an Ecosystem of Design Leadership in India



From “Making for the World” To “Designing for the World”

Move from execution-driven to shaping the future Ideas, technologies, and systems.

India as a source of design.

Sovereign transitions from aspiration to daily practice.

Chapter 4: China's Design Institute Model

Every nation that has achieved technological independence has done so by creating institutions that capture and protect knowledge. China's transformation from an underdeveloped and resource-constrained country into one of the world's largest industrial powers was not driven by factories alone. It was enabled by a structured network of design institutes that acted as hidden engines of innovation, replication and scale. These institutes formalised and institutionalised the act of designing. They ensured that lessons from every project were retained, refined and reused, turning design into a national capability rather than a temporary exercise. This institutional approach was central to China's rise and now offers lessons for India as it navigates its own technological transformation.



This approach demonstrates how engineering design can serve as a foundation for national sovereignty. It also offers valuable insights for India as it seeks to strengthen its design ecosystem in critical sectors, including hydrogen, semiconductors, advanced manufacturing, digital public infrastructure, and energy transition technologies. At the same time, this is not a model to copy blindly. It serves as a reference point for India to adapt to its democratic, federal, and globally connected context.

Design is not just a technical function. It is a strategic capability that shapes sovereignty. This is about adaptation, creating frameworks that blend global learning with local innovation to secure enduring sovereignty. As India enters a decisive decade of industrial and technological change, design capability will determine the pace and resilience of progress.

4.1 The Institutional Backbone of Industrial Power

Technological sovereignty begins with institutions that preserve, improve and reproduce knowledge across generations. In the middle of the 20th century, when China was still technologically dependent, it established permanent, domain-specific design institutes within each industrial ministry. These were not consultancies in the usual commercial sense. They were strategic arms of the state.

The institutes became custodians of process design, plant layout, safety, constructability, maintenance and cost discipline. They prepared feasibility studies, created standard plant and system designs, supervised construction and authored technical codes that the industry followed. In doing so, they internalised what might otherwise have been imported and built the capacity to imagine, certify and defend complex industrial systems. This institutional scaffolding gave China greater control over its development path. Each project captured lessons that were documented and reused. Knowledge became cumulative rather than temporary and project specific.

For India, the lesson is about structure rather than imitation. As the country enters technology intensive sectors such as hydrogen, semiconductor fabrication, battery ecosystems, digital infrastructure and new mobility, control over design will influence capability, cost and autonomy. The structural question is whether design knowledge will remain scattered across individual contracts or be housed in permanent national bodies that serve as repositories of engineering expertise and collaborate with global centres of expertise.

This foundation set the stage for a remarkable evolution in China's design ecosystem.

4.2 Historical Evolution: From Central Planning to Corporate Autonomy

The Chinese design institute system began to take shape in the early 1950s during the First Five-Year Plan, when the country had minimal experience in industrial design and construction. Given the scarcity of technical workforce, the leadership decided that the most effective way to build capacity was to institutionalise design as a permanent function.

The first Electric Power Design Institute was established in 1950 to support electrification in the northeast. Institutes for metallurgy, railways, petrochemicals, building materials, and urban construction soon followed. By the end of the decade, China had created a network of regional power design institutes aligned with provincial grids, along with specialist institutes for coal, machinery and fertilisers. These bodies did far more than produce drawings. They undertook feasibility studies, developed technical standards and trained engineers, creating a foundation for industrial capability.

When the Sino-Soviet split of 1960 abruptly halted technical aid, thousands of Soviet specialists left incomplete blueprints for power plants, fertiliser units, and industrial complexes. The Chinese institutes assumed responsibility for these projects. They translated Russian documents and re-engineered the systems for Chinese conditions. In doing so, they created early domestic design standards and demonstrated that local teams could solve complex problems when given responsibility.

During the 1960s and 1970s, China moved large industrial projects to interior provinces to reduce strategic vulnerability. Design institutes established regional branches in provinces such as Sichuan, Guizhou, and Shaanxi, thereby extending technical capacity nationwide. In the 1980s, the institutes were reorganised as state-owned enterprises, thereby gaining the flexibility to compete commercially while retaining their strategic functions. Partnerships with global firms, including European and American companies, were used as structured opportunities for learning rather than as permanent dependencies.

By the 1990s and 2000s, consolidation brought multiple institutes together under larger enterprise groups such as Energy China, the Metallurgical Corporation of China and China Railway Group. Each group integrated design, construction and manufacturing under a single institutional framework. Despite changes in governance, one principle remained constant: institutional memory. Drawings, calculations and lessons were preserved, refined and reused, creating a living archive of design knowledge.

Today, a feasibility report prepared by a certified Class A design institute is mandatory for all major projects in China, from power generation to semiconductor manufacturing. This requirement ensures that projects meet technical, financial and environmental standards before investment is approved. It has embedded an engineering discipline into policy and planning. For India, this history shows how sustained institutional building can turn external dependence into capability and, in turn, into greater sovereignty, while remaining connected to global partners and markets.

4.3 The Design Mindset: Front-End Engineering and Modular Replication

A defining feature of China's engineering philosophy has been its strong emphasis on front-end design. Recognising that capital was scarce and delivery time critical, the country chose to invest heavily in planning and simulation before construction began.

Design institutes treated front-end engineering design as a serious discipline rather than a mere contractual formality. Multidisciplinary teams of civil, process, electrical, instrumentation and safety engineers worked through detailed design cycles, examining layout, materials, energy efficiency, safety, maintenance access and future expansion. This rigorous approach resulted in greater predictability, fewer changes during construction and lower overall costs. When a design proved successful, it was converted into a standard module ready for replication. A 300 megawatt thermal power unit developed in the 1980s evolved into standard 600 and 1000 megawatt configurations.

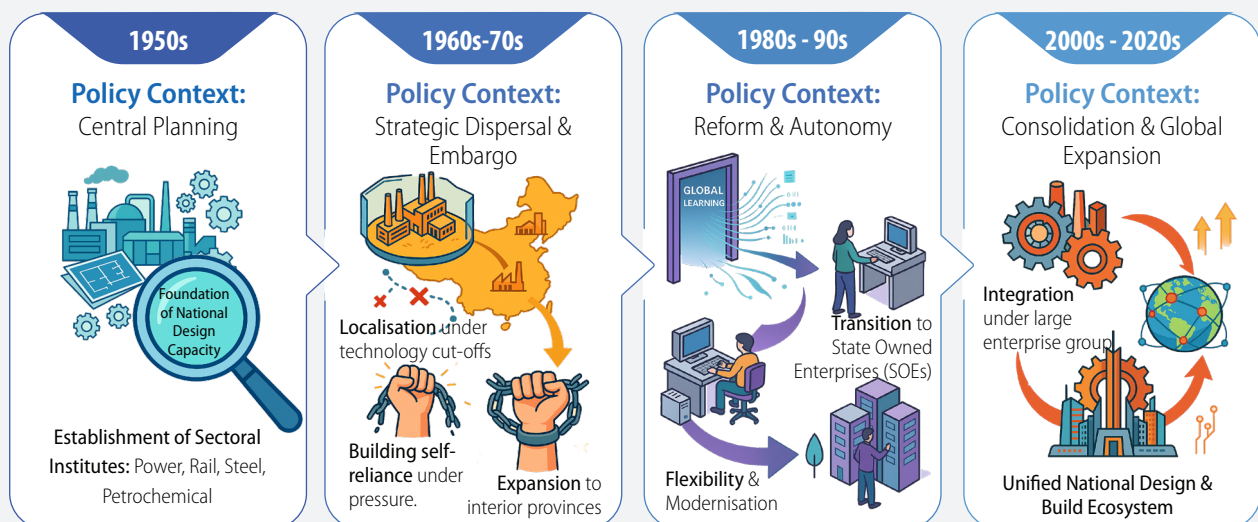
Railways adopted standard viaducts, bridges and station layouts that could be repeated across provinces. Metallurgical institutes created typical steel plant configurations. Metro systems used modular station templates to accelerate implementation. In electronics, institutes such as the China Electronics Engineering Design Institute have developed expertise in cleanroom and utility design for fabrication plants. This reduced reliance on foreign engineering services and strengthened domestic bargaining power. The underlying principle was simple: design once, build many and learn continuously.

For India, this mindset suggests a clear direction. Successful designs for hydrogen hubs, industrial parks, semiconductor facilities, renewable energy parks, transmission corridors and urban systems should be standardised and stored in shared libraries. Design must be treated as a permanent national asset, not merely as a cost item within a single project.

The Design Build Learn Loop

1. **Design creation:** Develop multidisciplinary designs with strong front-end engineering.
2. **Execution:** Build projects using these designs and adapt them to real conditions.
3. **Performance feedback:** Capture operational experience, safety learnings and cost data.
4. **Standardisation and replication:** Refine designs into standard modules and replicate them widely.

Evolution of National Design & Industrial Capacity



4.4 Design and Manufacturing Synergy: Two Wings of the Same System

China's industrial growth rests on a close partnership between design and manufacturing. The two operate as interdependent components of one system. Design institutes were never intended to function as isolated research entities. They were linked to the enterprises that built and operated plants, ensuring that design decisions reflected manufacturing realities and that field experience continually improved design.

In petrochemicals, design institutes work with construction units and equipment divisions to refine layout, safety and operability. In metallurgy, institutes collaborate directly with plant operators to improve automation and maintenance strategies. In aviation, design teams and manufacturing teams work together to develop aircraft, sharing information through the full cycle of design, testing and production.

In nuclear energy, design affiliates and construction units share feedback from every new reactor generation, allowing safety and performance improvements to be built into subsequent projects. This integration has allowed China to compress design cycles, improve consistency and scale innovation more rapidly. In many Indian projects, by contrast, design, procurement and construction are often separated among different entities, which can lead to cost overruns, coordination gaps and loss of learning.

For India, the message is to build stronger bridges between design and manufacturing wherever possible. In sectors such as hydrogen, semiconductors, offshore wind, advanced mobility and grid modernisation, integrated ecosystems can help ensure that every project advances both infrastructure and knowledge.

4.5 Outcomes: Engineering Sovereignty in Action

The results of this institutional strategy are evident at both the scale and the technological depth. Chinese design institutes have contributed to tens of thousands of kilometres of high-speed rail, a substantial installed power capacity, extensive ultra-high-voltage transmission networks, and thousands of metallurgical and petrochemical projects.

They have also supported the design and delivery of semiconductor, photovoltaic and battery facilities. Each project reduced dependence on foreign consultants for core design, preserved local intellectual property and strengthened institutional capability. Over time, China moved from absorbing global know-how to creating, standardising and exporting its own design and engineering services. The important point for India is the underlying principle. Learning from others can be the first step in a deliberate path towards local design ownership and eventual contribution to global knowledge.

This journey can be understood as a deliberate sequence:

Stages of Industrial Knowledge Transfer & Development

Stage 1: Learn Globally

Acquire knowledge through collaborations & joint projects



Stage 2: Localise

Adapt designs for local conditions & constraints



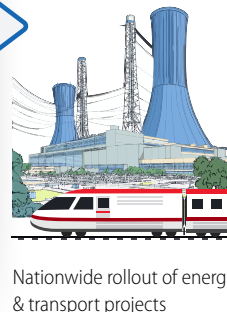
Stage 3: Standardise

Create national modules & templates



Stage 4: Scale

Deploy proven designs across regions at speed



Stage 5: Export Knowledge

Provide design & engineering services abroad



4.6 Strategic Relevance for India: Towards an Indian Design Institute Framework

The Chinese model demonstrates how design capability can serve as the backbone of industrial strength. India already possesses a large engineering workforce and strong academic institutions, yet it lacks permanent multi-sector bodies that consolidate and preserve design knowledge across projects and decades.

To address this gap, India can consider establishing National Design and Engineering Institutes that unite research, industry and policy in selected strategic areas. Each institute would specialise in a domain such as power systems, semiconductors, hydrogen value chains, grid modernisation, transportation corridors or advanced materials. These institutes would not function merely as regulators or commercial consultants. They would combine roles in research, standard-setting, certification, and professional training, while working alongside private firms and international partners.

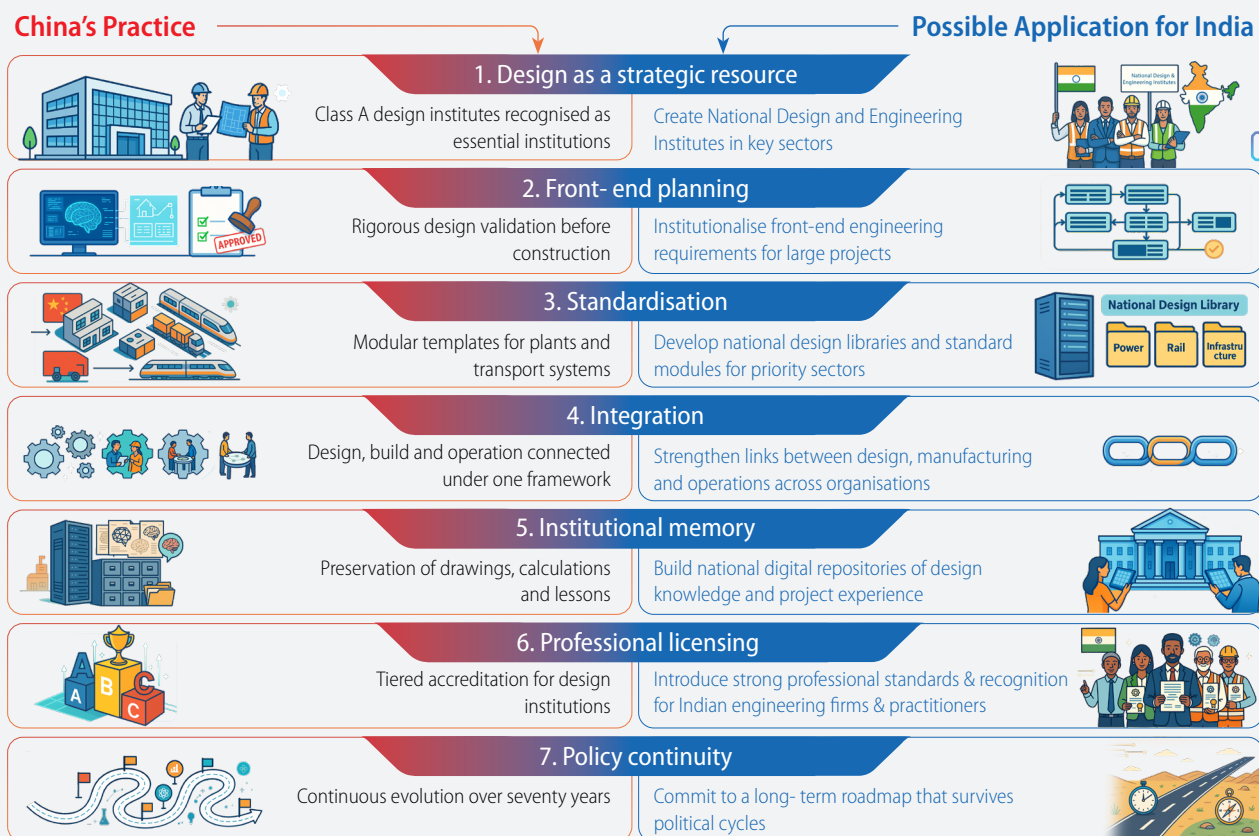
For example, a National Grid and Power Systems Design Institute could develop standard modules for renewable hybrid projects, define control philosophies for stability, and certify complex designs prior to investment. Institutes focused on semiconductors or advanced materials could support cleanroom design, utility systems, and safety standards, anchored in Indian conditions yet aligned with global norms.

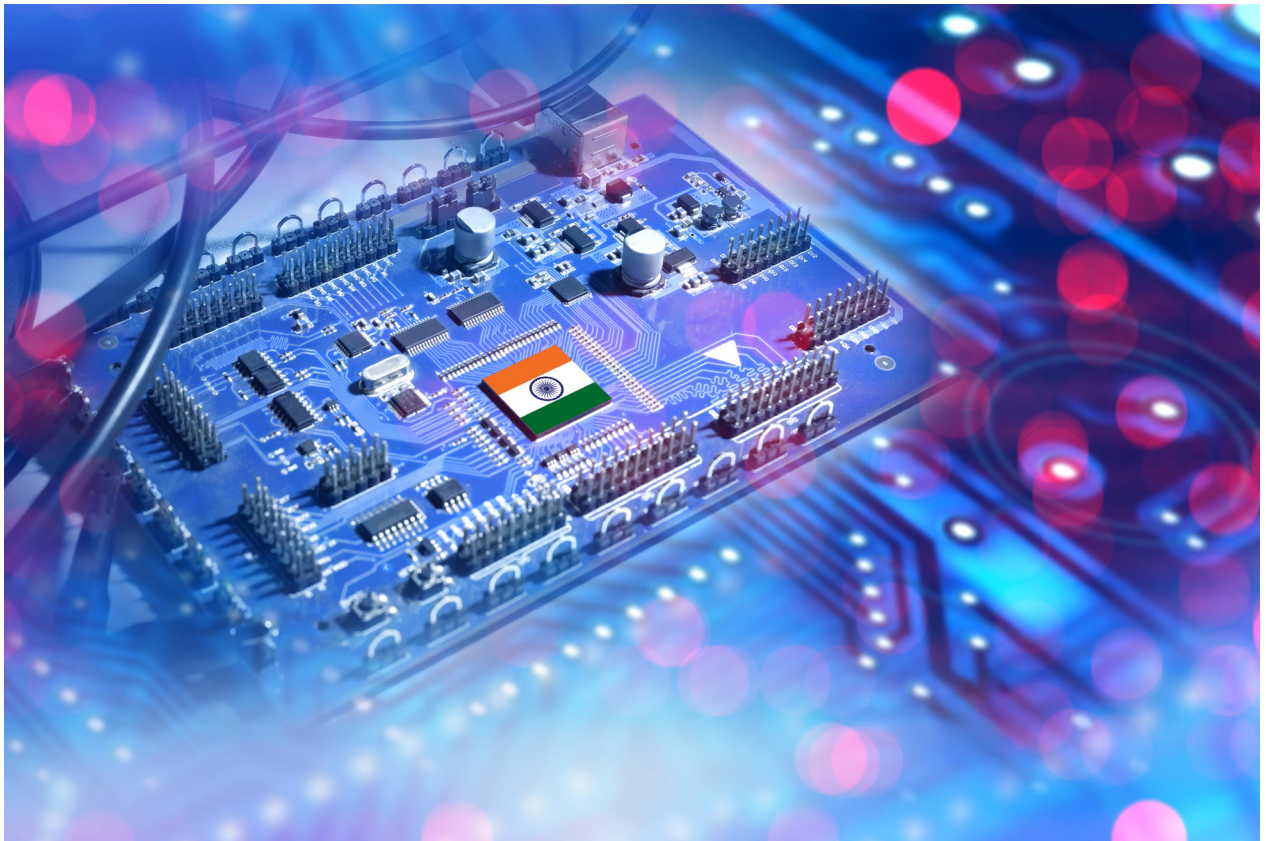
Such bodies would ensure design rigour, safety and long-term knowledge retention. They would also provide a home for multidisciplinary teams that work across project cycles and beyond political terms. This framework would represent a next step in self-reliance as design independence supported by international collaboration. When India owns its design codes and standards, it not only builds more efficiently, but it also shapes how future projects are replicated and improved.

4.7 Lessons for Policy Design

China's experience offers clear lessons that India can adapt to its own needs and values. These lessons are prompts for India to design its own structures that respect federalism, private initiative, and open markets, while ensuring that knowledge from publicly funded projects remains accessible to future generations.

Strengthening India's Engineering & Planning: Lessons From China's Practice





4.8 India's Moment for Design Sovereignty

China's journey from dependence to design mastery shows that lasting industrial power is built through ownership and organisation of design knowledge. Its institutes turned engineering into a source of national strength and continuity. India now stands at a different but equally significant juncture.

The success of India's energy transition, infrastructure expansion and digital transformation will depend on who designs the systems and where that knowledge resides. The same institutional discipline that shaped India's achievements in complex programmes can now be extended to civil and industrial sectors such as hydrogen and ammonia value chains, semiconductor fabrication, power grid modernisation, urban mobility and next generation materials.

By linking academic research with industry execution, codifying experience into standards and building professional pathways that recognise design excellence, India can create a self-sustaining ecosystem of design capability. Each project would then add both physical infrastructure and institutional intelligence.

Such institutions would serve as repositories of knowledge, ensuring that lessons from one generation of engineers pass to the next. They would represent continuity between policy, practice and progress. Once a robust design framework is established, sovereignty becomes more resilient. India can move from primarily executing to increasingly originating, from importing blueprints to sharing knowledge, and from episodic innovation to enduring design capability.

The factories and infrastructure of today will eventually age. The institutions that make design possible, if built with care and patience, will endure as quiet but decisive architects of modern India. Design capability is the invisible foundation of sovereignty. When nations treat design as a strategic resource, they gain not only infrastructure but institutional intelligence. For India, the challenge is adaptation. It must create frameworks that link research, industry and policy, ensuring that every project adds to a cumulative national knowledge base. This is the path from dependence to design independence and ultimately to global leadership.

Chapter 5: Indian Innovation and Resilience

India's growing confidence in its own ideas is supported by clear evidence. Although the country is sometimes described as dependent on external systems and technologies, its history and current achievements show a far more encouraging reality. Across many fields, India has shown originality, creativity and strong problem solving skills. These successes demonstrate that Indian institutions and engineers are fully capable of creating and delivering their own solutions when they are trusted with responsibility, supported with resources and encouraged to work with partners both within the country and around the world.



This chapter shares examples that show how Indian creativity thrives when public purpose, private commitment and academic expertise come together. Each example, from emergency response to advanced research, highlights the same message. India already possesses strong design capability. With thoughtful policies, the right incentives and meaningful partnerships, these strengths can grow and become central to the country's progress towards self reliance and design leadership while staying open to global cooperation.

5.1 CSR and the Pathway to Innovation

India's Corporate Social Responsibility law offers a valuable and often under used opportunity to support innovation and research. Schedule VII of the Companies Act 2013 allows companies to invest CSR funds in research and development activities. These include contributions to public universities, Indian Institutes of Technology, national laboratories and technology incubators in science, technology, engineering and medicine.

This framework provides Indian industry with a clear and formal way to strengthen the national research landscape. It enables private investment to support long term partnerships with knowledge institutions. CSR funding can also help create projects that include international partners so that Indian teams can learn from global experience while keeping design and adaptation rooted in the country.

There are some present limitations. Although companies may fund academic research through CSR, the ownership of any new intellectual property is not directly granted to them. CSR funds are meant for public benefit and non commercial objectives. As a result, using CSR funded outcomes for commercial purposes may seem to go against the spirit of the law. This means that intellectual property created through CSR projects usually remains with the academic or public institution. Companies may arrange licensing or shared ownership, but these agreements can be difficult and may draw scrutiny during compliance checks.

These restrictions sometimes prevent companies from investing in research that could lead to commercial products. This reduces the ability of Indian firms to generate patentable technology and limits the creation of intellectual property that can be exported. Other countries have clearer structures that support joint innovation and therefore benefit more in this area. This challenge also presents a promising opportunity. With an approach similar to the Bayh Dole framework, India could enable private companies to share or license intellectual property from CSR funded research under transparent and fair conditions.

Such reform would encourage more companies to invest in innovation, help research results reach the market more quickly and further strengthen the country's technological independence.

The comparison in [Table 5.1](#) below suggests that improving India's CSR framework can create a strong and reliable path for collaborative innovation. It can help India generate more home grown intellectual property and support meaningful cooperation with both domestic and international partners.

5.2 Industry and Academia Collaboration through CSR

In recent years, several Indian engineering and technology companies have begun to use corporate social responsibility in a more purposeful and forward looking manner. Instead of limiting CSR to charity or regulatory compliance, these organisations are building long term research partnerships with leading academic and scientific institutions. Such programmes demonstrate how CSR can become a powerful enabler of structured innovation, capability building and national impact.

One such initiative is an industry and academia collaboration programme that brings together an engineering company and premier research institutions, including a leading institute of technology, a major science university, a national chemical laboratory and an institute for advanced studies. These partnerships focus on technologies that are central to the future of industry, such as energy transition, industrial decarbonisation and sustainable manufacturing.

Aspect	Current CSR Law	Bayh–Dole–Style Potential
Intellectual property ownership	Not clearly allowed for private entities	Permitted through structured and transparent agreements
CSR use for research and development	Mainly allowed for public institutions	Broader use through organised partnerships between industry and academia
Commercialisation	Limited due to the non profit nature of CSR	Allowed with safeguards that ensure fairness and public benefit
Academia industry collaboration	Encouraged but not strongly defined	Strengthened with clear incentives, shared development and shared intellectual property

Table 5.1: Comparison of the Current CSR Law and a Bayh Dole Style Framework

Many of the research themes are aligned with global sustainability goals as well as India's national net zero ambitions, ensuring strong relevance to both domestic and international priorities. Most of the projects are positioned between technology readiness levels three to five, which is a critical phase where academic research is translated into working prototypes and validated for real world application. At this stage, the risk is often high and funding is scarce. The industry partner plays a vital role by providing not only financial support but also practical engineering insight, system level thinking and exposure to real operating constraints. The academic institutions contribute deep scientific knowledge, advanced laboratory infrastructure and research talent. Together, the partners co design problem statements, share data and co supervise students, creating a genuine model of co development rather than a traditional sponsor recipient relationship.

The collaboration portfolio spans a wide range of future facing technologies as an example, TCE is funding CSR projects in green hydrogen, sustainable fuels, carbon dioxide utilisation, 3D printed construction materials and advanced power cycle research. These efforts have delivered measurable outcomes in the form of functional prototypes, patents and peer reviewed publications. Several projects have received recognition at national forums for excellence in industry and academia collaboration. Research teams also participate in international conferences and global networks, ensuring that Indian work is benchmarked against leading global science while also contributing original knowledge to the international community. A few representative projects where TCE has collaborated through CSR support help illustrate the strength and depth of this collaborative model, as discussed in Chapter 11.

5.3 National Examples of Design and Leadership

Alongside formal industry and academia programmes, India's broader national experience offers strong and credible examples of design leadership, resilience and collective problem solving. Across health care, digital infrastructure, space science and finance, Indian engineers, designers and institutions have demonstrated the ability to respond to complex challenges with speed, ingenuity and scale.

Digital Public Health Systems

India's vaccination programme was supported by a large scale digital platform that managed registrations, appointments, vaccine supply and certification for a population of unprecedented size. The system handled hundreds of millions of registrations, coordinated inventory across thousands of vaccination centres and generated secure and verifiable digital certificates.

The platform was architected in India, drawing on global best practice in digital identity, consent management and scalable system design. Importantly, it was conceived as a reusable and adaptable framework rather than a one time solution. The system was later shared as an open reference model that other countries could study and adapt to their own public health needs. This experience demonstrated India's ability to design and operate digital systems at population scale while actively contributing to global knowledge exchange in public health infrastructure.

Planetary Exploration and Space Science

India's space programme provides a long standing and widely recognised example of national design capability. Missions such as the Mars Orbiter Mission and successive lunar projects have shown that Indian scientists and engineers can design, build and operate complex interplanetary systems with high reliability and at relatively low cost.

These missions relied on indigenous propulsion, navigation and communication technologies, supported by selective and well structured international collaboration in areas such as tracking, science instrumentation and mission safety. Their success is not merely symbolic. It reflects decades of institutional development, disciplined project management and an engineering culture that embraces careful risk taking and continuous learning. Each mission has strengthened confidence in India's ability to undertake increasingly ambitious scientific and technological endeavours.

Digital Payments and Financial Inclusion

The Unified Payments Interface has transformed India's retail payments ecosystem and stands as a notable example of thoughtful digital design. Conceived as an open and interoperable digital public infrastructure, it is governed by Indian institutions and regulated by the central bank.

By enabling instant and low cost transactions between individuals, businesses and government entities, it has expanded financial inclusion and reduced friction across the economy. UPI has also created a fertile platform for private sector innovation, enabling a wide range of payment applications and services. Its success has led to bilateral linkages with other countries and growing international interest in similar models of digital public infrastructure. This illustrates how a system designed for domestic needs can also shape global conversations on inclusive and efficient finance.

Frugal Innovation in Health Care

India has a long tradition of frugal innovation in health care, where clinical excellence is combined with process and system level design to deliver high quality outcomes at low cost. Models of eye care and cardiac care developed in India have achieved results comparable to leading global institutions while remaining accessible to large sections of the population.

These organisations have often collaborated with international partners on training, research and clinical protocols, even as they continue to refine models that respond to the realities of low and middle income settings. Their experience shows how thoughtful design, effective use of data and a strong sense of social purpose can produce solutions that are both locally relevant and globally instructive. Taken together, these national examples highlight India's growing confidence and capability in design and leadership. They show how institutions, engineers and designers can respond to pressure with creativity, build systems that operate at scale and contribute meaningfully to global knowledge while remaining rooted in Indian conditions and priorities.



5.4 The Indian Nuclear Programme Resilience under Constraint

India's nuclear programme stands as one of the clearest examples of national resilience, long term thinking and indigenous innovation in the modern era. Conceived in the early years after Independence, the programme took shape at a time when the country faced deep economic constraints, limited technological capability and a challenging geopolitical environment. Yet, from the outset, it was guided by a clear scientific vision and a strong belief in self reliance.

Under early scientific leadership, India laid the foundations of a comprehensive nuclear programme that would gradually build capability across the nuclear fuel cycle. Over time, this effort enabled the country to develop expertise in uranium exploration, reactor design, fuel fabrication, reprocessing and fast reactor technology. Very few nations have achieved such breadth, and India did so despite prolonged restrictions on access to global technology and materials.

The programme evolved largely under conditions of embargo and limited international cooperation. Following nuclear tests in the 1970s, India faced sanctions that constrained imports of specialised equipment, materials and technical know how. Rather than accepting long term dependence, Indian laboratories and public sector enterprises responded by strengthening indigenous research, design and manufacturing capability. Reactor designs such as the pressurised heavy water reactor were developed and refined to suit Indian conditions. Facilities for heavy water production and zirconium component fabrication were established domestically. Fuel cycle research progressed steadily, even in the face of limited external support.

A defining feature of the programme has been its long term architectural coherence. The three stage nuclear power plan, based on the sequential use of natural uranium, plutonium and thorium, was explicitly designed around India's resource endowment and energy security needs. While the timeline for this plan has extended beyond early expectations, it reflects a rare alignment of scientific vision, policy continuity and institutional patience over several decades.

Such consistency is difficult to sustain, yet it has allowed the programme to mature steadily rather than react to short term pressures. At the same time, the nuclear journey has not been one of isolation. Even during periods of restriction, India maintained engagement with the international community in areas such as safety research, materials science and regulatory learning. The civil nuclear agreements of the 2000s marked a significant turning point, recognising India's responsible track record and opening space for cooperation in fuel supply, reactor technology and safety practices. This phase strengthened confidence and enabled more open collaboration while preserving core indigenous capabilities.

Today, the programme continues to evolve in response to new energy and climate priorities. Concepts such as small modular reactors and designs tailored specifically to Indian operating conditions, sometimes described as Bharat Small Reactor concepts, are being explored as part of a broader technology portfolio. These efforts aim to support reliable and low carbon electricity generation while enhancing energy security and grid resilience.

The Indian nuclear story reveals several enduring characteristics of national innovation. It demonstrates confidence under constraint, systems thinking across science, engineering and policy, and an understanding that technological sovereignty is built through sustained design effort rather than short term acquisition. It also shows that openness and partnership need not be at odds with self reliance. Even while developing core capabilities domestically, India has worked with international agencies on safety standards, regulatory practice and non proliferation, contributing constructively to global norms while safeguarding national interests.

This same combination of resilience, patience and selective partnership will be increasingly important as India builds capability in new strategic domains such as semiconductors, artificial intelligence and quantum technologies. The nuclear experience offers not just a technological lesson, but a broader model of how nations can design for the long term under conditions of uncertainty and constraint.

5.5 Recognition, Legacy and the Road Ahead

The examples presented in this chapter, spanning research collaboration, crisis response, space exploration, digital public infrastructure and long term strategic programmes, together demonstrate that India possesses strong intellectual depth and institutional capability for self reliant innovation. They also reveal a consistent pattern. Progress has been most effective when three conditions come together, namely a clear public purpose, patient institution building and constructive engagement with global knowledge and practice.

Corporate philanthropy and industrial leadership have played an important role in shaping this journey. From early support to institutions focused on science and fundamental research to more recent investments in advanced laboratories, technology incubators and collaborative research platforms, private sector participation has helped strengthen India's innovation ecosystem. These efforts underline an important lesson, that private capital, when aligned with national priorities and public purpose, can accelerate discovery, de risk emerging technologies and deepen the research base.

Looking ahead, the central challenge lies in scaling these successes and embedding them within stable and long term policy frameworks. Individual initiatives and case studies now need to be supported by systems that encourage continuity, accountability and excellence across the engineering and research landscape. Mechanisms such as a stronger chartered engineer framework and professional accreditation can play a valuable role in raising design standards, reinforcing ethical responsibility and building confidence in Indian engineering services, both domestically and internationally.

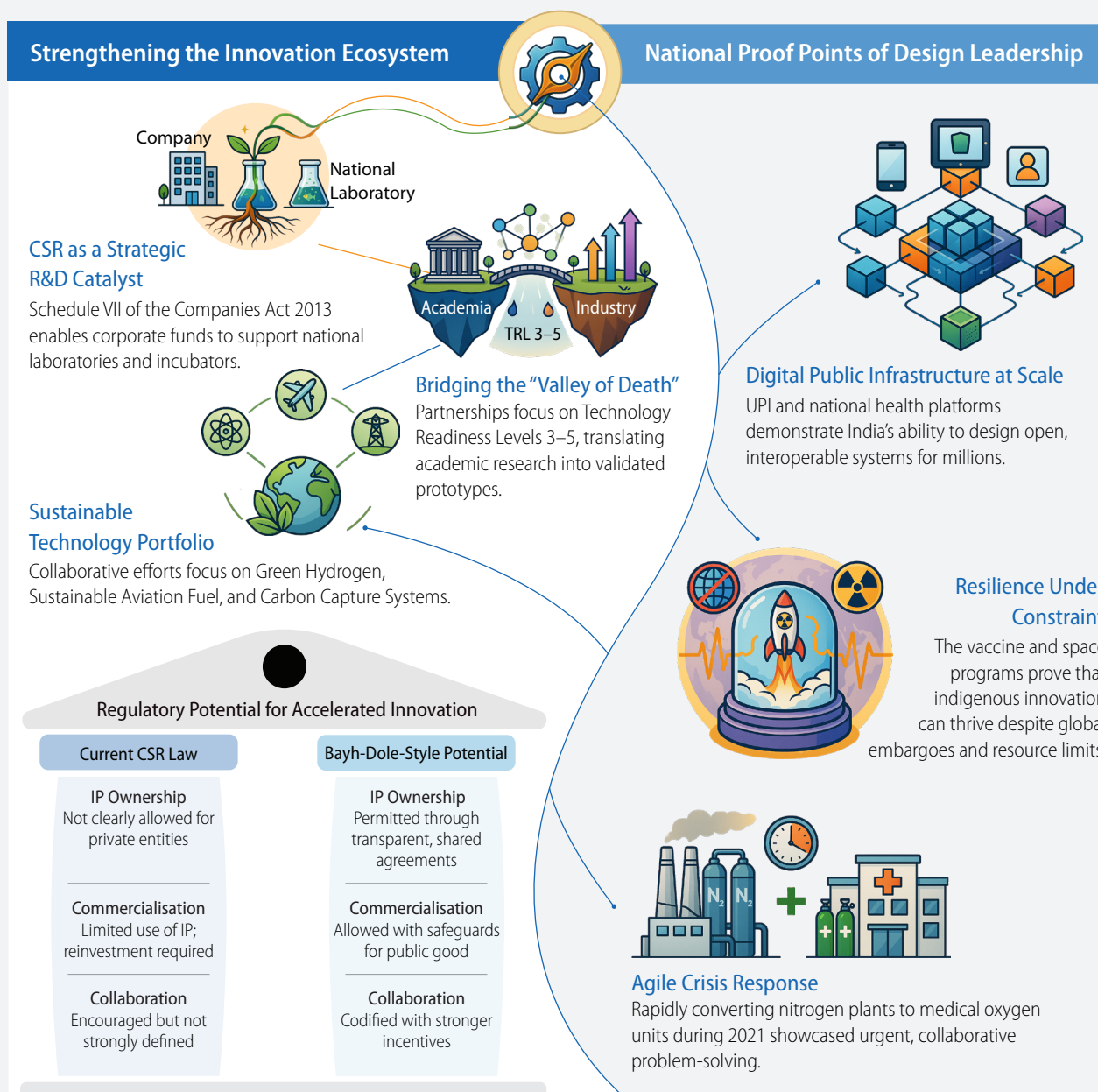
There is also scope to refine policies related to corporate social responsibility and intellectual property so that corporate funding, academic capability and industrial application are more closely connected. Clearer pathways for shared ownership, licensing and commercialisation can ensure that research outcomes move beyond laboratories into real world deployment, while still rewarding innovation and protecting national interests.

By consciously combining public funding, CSR investments, international collaboration and a growing pool of domestic talent, India has the opportunity to build a resilient and self reinforcing ecosystem of research, design and invention. Such an ecosystem can support the country's broader ambition of becoming a developed, confident and technologically capable nation.

Taken together, the case studies in this chapter show that India is not confined to a role of dependence or passive adoption. In moments of crisis, in ambitious national missions and in strategically important sectors, Indian institutions have already demonstrated the ability to design, adapt and lead, rather than merely execute imported solutions. This legacy provides a strong foundation for the future. The next chapter turns to the question of how domestic firms can be nurtured into enduring champions. These champions can carry forward India's design and innovation capabilities within the country and onto the global stage, working in partnership with peers around the world while remaining rooted in Indian strengths and values.

India's Innovation Blueprint: From Resilience to Design Leadership

India is transitioning from a passive adopter of technology to a global leader in original design, by leveraging Corporate Social Responsibility (CSR) for R&D and fostering deep partnerships between industry and academia, that focus on solving complex challenges in energy, health, and digital infrastructure.



Chapter 6: AI and Design Sovereignty

India's journey towards self reliance is now shaped not only by what the nation builds, but by how intelligently it designs. The next phase of development demands systems that do more than deliver projects on time. They must be able to learn from experience, adapt to changing conditions and improve with every cycle. In this context, Artificial Intelligence has emerged as a decisive force. It offers the ability to convert accumulated experience into foresight and to transform design from a static activity into a continuously evolving process. AI makes it possible to treat infrastructure and industrial systems as living entities. Each project becomes a source of data, insight and learning.



Design decisions made for one airport, metro corridor or power plant can be analysed, refined and fed forward into the next. Over time, this creates a compounding effect, where performance improves not only because of better materials or equipment, but because the design intelligence itself becomes sharper and more informed.

A modern and confident India cannot afford to lose institutional memory between generations of projects or professionals. This is the central idea behind the Vikasit Bharat Aadharit Samaadhan (VIBHAS) framework.

The framework envisions a national design ecosystem in which knowledge from completed projects is systematically captured and reused. Lessons are embedded into structured data sets, simulation models and intelligent design tools, ensuring that past experience actively shapes future outcomes.

Under this approach, designing is no longer carried out afresh for each project. Instead, it becomes a process of continuous intelligence.

Performance data from construction, operations and maintenance feeds back into design assumptions. Risk models improve with real evidence. Cost and schedule forecasts become more reliable. Sustainability outcomes are refined through measured results rather than aspiration alone. This shift has the potential to raise the quality, resilience and efficiency of Indian infrastructure at scale.

At the heart of this vision lies the need for strong national institutions that combine Artificial Intelligence with human judgement and clear accountability. One element of this institutional architecture could be a National Design and Innovation Council that provides strategic direction, aligns policy and ensures that long term national priorities are reflected in design standards and practices. Such a body can help balance innovation with safety, speed with responsibility and ambition with realism.

Alongside this, a network of AI driven design institutes can play a critical role in building capability. These institutes can act as centres of excellence where engineers, designers and researchers work with advanced tools, real project data and industry partners. They can support training, applied research and the development of reference models that are relevant to Indian conditions while meeting global benchmarks.

A supporting digital design grid can serve as the backbone of this ecosystem. By securely storing, refining and sharing design intelligence, it can enable collaboration across institutions, regions and sectors. With appropriate governance, such a grid can protect sensitive information while still encouraging learning and reuse. Over time, it can become a national asset that strengthens confidence in Indian design capability.

Together, these elements can help India cultivate a design culture that is evidence based, accountable and outward looking. Artificial Intelligence does not replace human expertise in this vision. Instead, it amplifies judgement, highlights patterns that may otherwise be missed and allows experience to accumulate at a national scale. Design sovereignty, in this sense. It is about having the capability to choose, adapt and lead with confidence in a rapidly changing world.

As India moves deeper into the age of intelligent systems, AI and design sovereignty will become central to economic strength, strategic autonomy and global relevance. By investing early in institutions, data and design intelligence, India can ensure that its future is not only built at scale, but designed with wisdom, continuity and purpose.

6.1 Designing India's Future through Intelligence and Trust

India has reached a stage of development where ambition must be matched by design capability. The challenge is no longer limited to the ability to construct infrastructure at scale. It now lies in the ability to design systems with foresight, safety and long term adaptability. Across the world, infrastructure is no longer viewed as static physical assets. It is increasingly understood as a dynamic system that generates data, experience and insight throughout its life cycle.

Every modern asset, whether a data centre, a transport hub or an energy installation, produces large volumes of information on energy use, safety performance, user behaviour and material degradation. When this information is systematically captured and processed through Artificial Intelligence, it becomes a powerful source of learning. AI can detect patterns that are difficult to identify through conventional analysis. It can simulate scenarios beyond historical experience and help decision makers evaluate design choices that reduce cost, improve resilience and manage risk more effectively.

In the Indian context, much of this potential remains underused. Valuable learning is often fragmented across projects and institutions. Technical reports are archived rather than analysed. Field level insights remain confined to individual teams. Lessons learned from one project say, city's metro system or industrial corridor do not consistently inform the next. This fragmentation slows delivery, increases uncertainty and weakens confidence in design outcomes. A nation that seeks design sovereignty must address this gap by building institutional memory and trust in shared knowledge systems.

Artificial Intelligence offers a practical means to bring coherence to this dispersed experience. By analysing decades of project data across sectors and regions, AI systems can compare outcomes, identify recurring challenges and generate early warnings for potential risks. Engineers can test design options before construction begins, refine standard templates and improve decision clarity across the project life cycle, from conceptual planning through commissioning and operation. Over time, this creates a cumulative effect where each new project starts from a higher benchmark than the last.

India has already demonstrated the value of this approach in the digital domain. Platforms such as the unified payments system showed how thoughtful design, strong governance and effective use of data can enable transformation at national scale.

The same principle can now be applied to the physical world through structured design intelligence. By embedding learning into design processes, India can move towards infrastructure systems that are not only larger and faster to build, but also smarter, safer and more reliable.

Designing India's future through intelligence therefore requires more than advanced tools. It requires trust in shared data, confidence in institutional processes and a willingness to learn collectively from success and failure. When intelligence and trust are combined, design becomes a strategic national capability rather than a project specific activity. This shift is essential if India is to sustain growth, manage complexity and assert design leadership in an increasingly uncertain global environment.

Stage	Collection	Interpretation	Prediction	Standardisation	Application
Data Source 	Sensor data, design drawings, operational logs from completed projects (e.g., metro stations, refineries, data centres)	Historical project records and simulation results	Real-time operational data from running assets	Validated insights from multiple projects and sectors	Approved modular templates and best-practice models
AI Analysis 	AI gathers and organises structured and unstructured data into a unified format	AI compares design variations and performance metrics	Predictive AI models simulate performance under future scenarios	AI clusters similar patterns to establish modular design norms	AI integrates insights into new project designs
Insight Generated 	Patterns of performance, reliability, and environmental impact are identified	Highlights design weaknesses, inefficiencies, and best-performing configurations	Early warnings for potential failures, energy inefficiencies, or cost overruns	Standardised design components and sector-specific benchmarks	Rapid adaptation to geography, climate, and usage needs
Applied Improvement 	Enables creation of digital twins and baseline models for future projects	Guides refinement of design templates and material choices	Supports preventive maintenance and redesign for improved lifecycle performance	Forms the basis for national design standards and codes	Reduces project timelines, costs, and external dependency
	1	2	3	4	5

6.2 The Case for an AI led Design Transformation

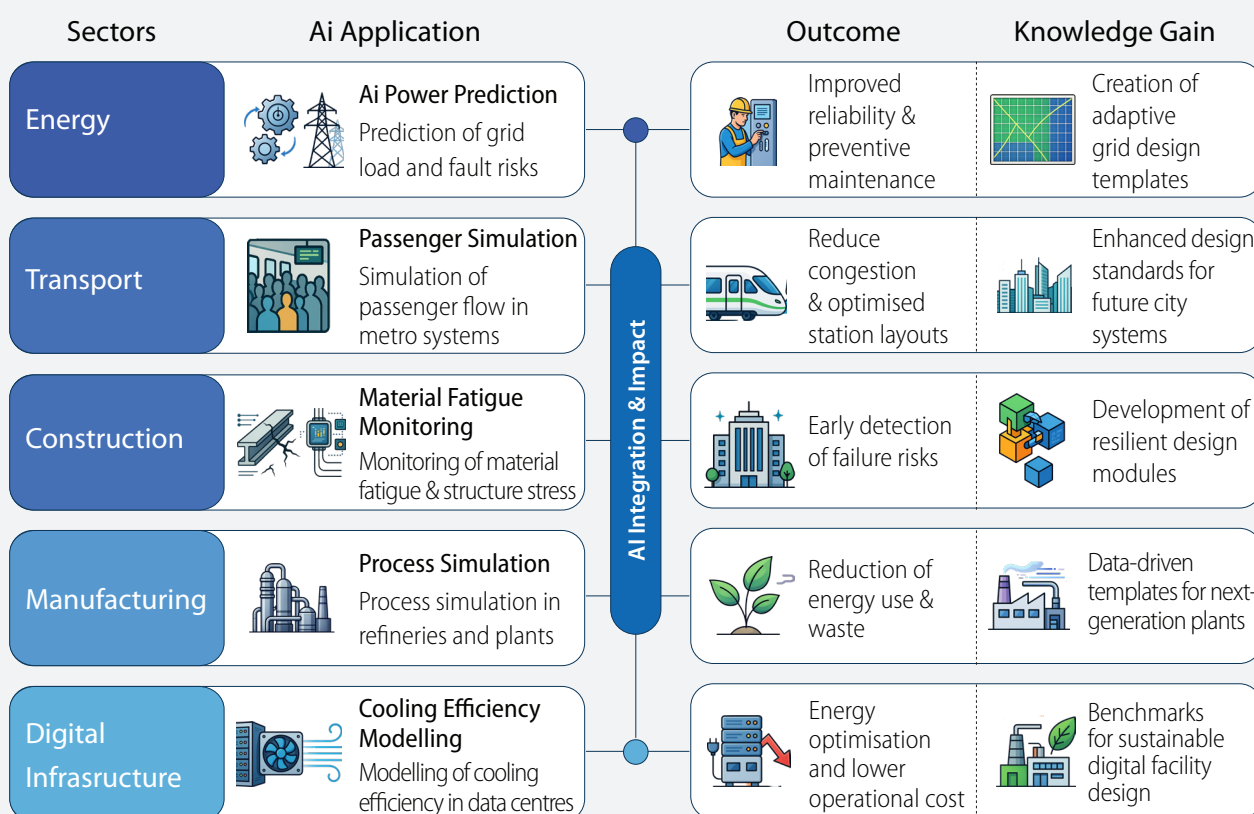
Artificial Intelligence has progressed from a supplementary analytical aid to a core element of modern engineering practice. Across sectors, it is being used to accelerate discovery, reduce material and energy waste and improve design quality. One of its most significant advantages lies in simulation. Thousands of design options can be tested virtually before physical construction begins. This allows engineers to explore alternatives, identify weaknesses early and make informed trade offs that would be difficult or time consuming using conventional methods alone.

For India, the case for an AI led design transformation is especially strong because of the scale and diversity of its infrastructure expansion. Every major project generates extensive information, including drawings, calculations, sensor data, operational logs and maintenance records. Over decades, this has created large archives of knowledge on performance, reliability, climate exposure and user behaviour. However, much of this information remains under used because it is dispersed across organisations, stored in incompatible formats or not analysed beyond immediate project needs.

Artificial Intelligence offers a way to unify this fragmented data and convert it into usable design intelligence. By integrating information across projects and sectors, AI systems can compare design alternatives, predict material behaviour under different conditions, identify energy inefficiencies and model passenger flow or traffic movement with greater accuracy. When applied responsibly, AI acts as a partner to engineers. It does not replace professional judgement, but broadens the range of options that designers can consider and improves the evidence base on which decisions are made.

International experience shows that AI is already being applied in several areas such as power grid stability analysis, structural optimisation, predictive maintenance, aerodynamics and advanced manufacturing. India has the opportunity to apply similar techniques across many sectors such as semiconductors, minerals, energy, transport, construction and digital infrastructure sectors. Doing so at national scale requires more than isolated pilots. It calls for a shared system in which learning from one project is available to others, reducing duplication of effort and raising overall design quality.

Ai Applications In Industry: Sectors, Outcomes & Knowledge Gain



An AI led approach also helps address long standing challenges in Indian infrastructure delivery. Variations in standards, inconsistent data quality and delays caused by unforeseen site or operational issues remain common. Intelligent design templates, generated and refined using past experience, can support greater consistency, improve predictability of timelines and reduce avoidable rework. Over time, this can strengthen trust in project outcomes among investors, regulators and the public.

The case for AI led design transformation is therefore not primarily about technology adoption. It is about changing how knowledge is captured, shared and applied. By embedding learning into design processes, India can move towards an infrastructure system that improves with each project, rather than repeatedly relearning the same lessons. This shift is essential if India is to manage complexity, control cost and deliver resilient assets at the pace and scale that national development demands.

6.3 The VIBHAS Vision

The Vikasit Bharat Aadharit Samaadhan framework sets out a vision in which design intelligence is treated as a national asset rather than a project level by product. It proposes an ecosystem where every infrastructure and industrial project, regardless of scale or geography, contributes to a shared and cumulative body of knowledge. By combining Artificial Intelligence, engineering expertise and institutional governance, VIBHAS seeks to create a design system that improves in quality, reliability and insight with each generation of projects.

At its core, the framework recognises that national capability is strengthened when learning is not lost between projects or institutions. Instead of isolated design efforts, VIBHAS promotes continuity, where experience from completed assets informs new ones in a structured and trusted manner. This approach allows design standards to evolve based on evidence rather than repetition and enables the country to respond more effectively to complexity, uncertainty and change.

The VIBHAS vision rests on three complementary pillars.

1. **The first pillar is the National Design and Innovation Council (NDIC).** This body would provide strategic direction and define long term goals for design capability across sectors. It would set ethical principles for the use of Artificial Intelligence in engineering, align ministries, public agencies, academic institutions and private firms around shared design priorities and ensure that innovation is pursued with responsibility, safety and public interest at its centre. By offering continuity beyond electoral or project cycles, the council would help anchor design policy in long term national objectives.
2. **The second pillar is a Network of AI Driven Design Institutes (AIDI).** These institutes would function as centres of applied research and capability building. They would collect and curate project data, develop simulation models, generate modular design templates and support training in computational and data informed design methods. Each institute would specialise in a defined domain such as energy systems, urban transport, digital infrastructure, industrial processes or ecological engineering. This sectoral focus would allow depth of expertise while still contributing to a shared national knowledge base.
3. **The third pillar is the Design Intelligence Grid (DIG).** This would serve as a secure digital framework linking organisations across the country. The grid would store anonymised project data, validated models and performance insights derived from completed assets. With appropriate governance, access controls and quality assurance, this information would be made available to support future design work. Over time, the grid would evolve into a living repository of national engineering wisdom, strengthening consistency, reducing avoidable risk and supporting evidence based decision making.

Pillar	Primary Role	Outcome	Institutional Benefit
NDIC	Sets ethical standards, policy direction and national design strategy	Aligns ministries, academia and industry under a unified mission	Provides long-term governance and accountability
AIDIs	Conduct applied AI research and generate modular templates for design	Develop India-specific models across energy, transport, and manufacturing	Build technical capacity and skill ecosystems
DIG	Collects and analyses project data from across sectors	Creates an evolving digital knowledge base	Ensures that learning from every project remains accessible and reusable

Table 6.2: The Core Components of VIBHAS

Importantly, VIBHAS is not intended to replace human creativity or professional responsibility. Engineers and designers will continue to make final decisions and exercise judgement. Artificial Intelligence, within this framework, functions as an enabling tool that helps identify potential risks, evaluate material choices, test scenarios and explore alternatives that may not be immediately apparent. To reinforce accountability, a professional certification for AI assisted engineering practice could be introduced, creating a recognised cadre of practitioners trained to use these tools responsibly and transparently.

The vision also acknowledges that knowledge grows through collaboration. India's engagement with global partners in areas such as advanced materials, hydrogen systems, semiconductor design, nuclear safety and clean energy will continue. Under VIBHAS, such collaboration is guided by domestic standards and a clear principle. International partnerships should strengthen national capability, deepen learning and enhance resilience, rather than substitute for indigenous design effort.

Taken together, the VIBHAS framework offers a structured path towards design sovereignty. It combines intelligence with governance, innovation with accountability and national purpose with global engagement. By institutionalising learning and trust, it provides a foundation for India to design at scale, with confidence, continuity and long term strategic intent.

6.4 Institutional and Governance Architecture

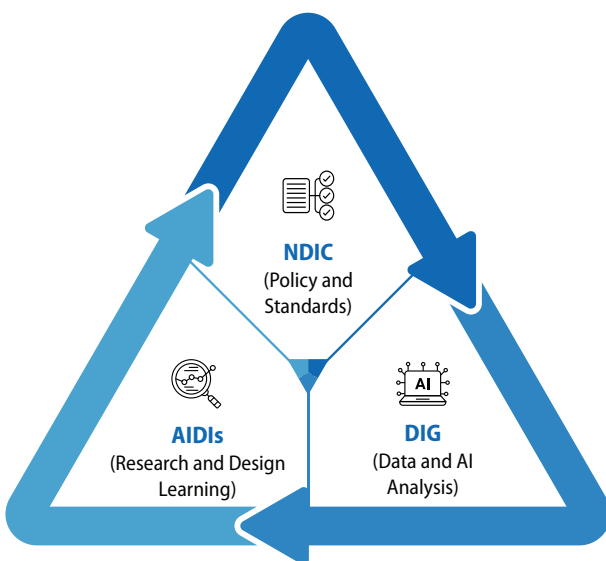
The success of VIBHAS will depend on how effectively design intelligence is translated into enduring institutional strength. Technology alone cannot guarantee progress. It is institutions that convert ideas into sustained national capability by providing continuity, accountability and trust. The institutional and governance architecture of VIBHAS is therefore conceived as the backbone of India's design sovereignty. It brings together public purpose, private creativity and technological discipline within a coherent national system.

At the centre of this architecture is a National Network of AI Driven Design Institutes. These institutes are envisioned as living laboratories that connect government agencies, private enterprises, academic institutions and professional bodies. Their role is essentially, collaborative problem solving, where real world project data informs applied research and design practice.

Under this framework, every significant project, whether a metro system, airport, refinery or industrial facility, contributes design and performance information to the network. This ensures that knowledge gained through experience is not lost and that each new project begins with a higher level of design intelligence than the last. Learning becomes cumulative rather than episodic.

To guide and integrate these efforts, a National Design and Innovation Council will serve as the apex institutional body. Anchored within the central governance framework of the State, the council will define long term design standards, oversee the evolution of the design institutes and ensure that Artificial Intelligence is applied ethically, transparently and in the public interest. It will act as a bridge between national development priorities and the design ecosystem, ensuring that public investment in infrastructure produces not only physical assets but also lasting knowledge.

Each design institute within the network will specialise in a specific domain such as energy systems, transport infrastructure, digital platforms or advanced manufacturing. Together, they will operate as an interlinked system guided by shared data standards, ethical norms and governance principles. Their work will span the full lifecycle of engineering, from feasibility and conceptual design to simulation, validation and post commissioning evaluation. Over time, the network will develop a national repository of modular design templates, validated simulation models and predictive tools that reflect contemporary Indian design capability. To strengthen professional accountability, a formal certification for AI assisted engineering practice can be introduced. This would establish a recognised cadre of engineers trained to interpret AI outputs, exercise judgement and validate outcomes responsibly. Such certification would clarify accountability between human expertise and technological assistance, while aligning Indian engineering practice with international expectations.



The VIBHAS Institutional Triad

The institutional framework of VIBHAS follows a distributed and federal model, similar to India's established scientific and technical networks. Just as national institutions have shaped higher education and space research over decades, the design institutes can nurture long term design intelligence. Each institute would operate autonomously while remaining connected through the Design Intelligence Grid, a secure digital framework linking ministries, public enterprises, private firms and academic institutions through common data protocols.

The grid would host validated design models, anonymised performance data and analytical insights, enabling AI systems to learn continuously from actual project experience. Its purpose is to support learning and improvement rather than comparison or ranking between organisations, thereby encouraging trust and participation.

Governance of this ecosystem rests on three core principles.

1. **Sovereignty of data.** Design and project information generated within India should remain under national oversight, with clear rules governing access and use.
2. **Integrity of standards.** All designs informed by Artificial Intelligence must comply with established safety, environmental and performance requirements, with clear professional responsibility for outcomes.
3. **Inclusivity of participation.** Public sector enterprises, private firms, start ups and universities should all be able to contribute to and benefit from shared design intelligence under common governance norms.

International collaboration will continue to play an important role within this framework. India will engage with global partners in areas such as semiconductors, hydrogen systems, advanced materials and clean energy technologies. These partnerships will operate within Indian institutional structures, ensuring that data governance and final design authority remain domestic. External expertise will therefore complement national capability.

Funding for VIBHAS institutions will reflect a partnership between public vision and private dynamism. Initial support may come from national infrastructure and innovation programmes, while long term sustainability can be strengthened through project linked contributions and performance based incentives. Over time, shared design intelligence itself becomes a source of economic and strategic value.

Ethical governance remains central to the architecture. AI systems used within the VIBHAS framework must be transparent, explainable and subject to periodic human review. Algorithms should be auditable, and all AI informed decisions must pass through professional validation. This ensures that technology remains accountable to human judgement, preserving safety, trust and legitimacy across the design ecosystem.

6.5 A New Model of Collaboration

India's transition towards a design led and innovation driven economy cannot occur in isolation. In a world where knowledge, technology and capital move across borders, collaboration is essential. However, the nature of collaboration must evolve. It must be based on equality, trust and shared value creation. The approach envisioned under VIBHAS is captured in the principle of India Led, World Linked.

Historically, many international collaborations in infrastructure and industry were structured around foreign entities that controlled design, decision making and intellectual outcomes. While such arrangements enabled access to technology, they often limited domestic ownership of knowledge. Design data, models and operational learning generated through these projects frequently remained outside Indian institutions. Over time, this reduced the accumulation of national design capability and reinforced cycles of dependence.

The VIBHAS framework seeks to reverse this pattern by placing Indian engineers, institutions and knowledge systems at the centre of collaboration. Under this model, Indian organisations lead on problem definition, feasibility assessment, system architecture and design governance. Global partners participate as contributors in specialised areas such as advanced materials, simulation tools, component technologies or frontier research. This ensures that every collaboration strengthens domestic expertise and adds to the national knowledge base.

Collaboration Models: Earlier Approach Vs. VIBHAS Model

Aspect	Earlier Approach	VIBHAS Collaboration Model	Resulting Benefit
Leadership	 Driven by foreign firms	 Guided by Indian institutions with global support	 Local ownership and accountability
Knowledge Flow	 One-way transfer of designs and data	 Two-way exchange through joint research and shared standards	 Mutual learning and co-creation
Decision Authority	 External consultants and licensor's	 National councils and certified professionals	 Strategic autonomy and transparency
Intellectual Property	 Retained abroad	 Held within Indian jurisdiction	 Builds domestic knowledge capital
Outcome Of Partnership	 Execution support	 Long-term capability & innovation building	 Sustainable growth and shared progress

India has already demonstrated the effectiveness of leadership through ownership in the digital domain. Platforms such as Aadhaar, the unified payments system and other digital public infrastructures have shown that when design authority and governance reside with Indian institutions, outcomes can achieve both national scale and global recognition. The same principle can now guide engineering and industrial partnerships. India defines the objectives, standards and institutional frameworks, while international expertise supports these goals through joint research, adaptation and skills development.

In practical terms, this means that Indian consulting firms, public enterprises and research organisations lead feasibility studies, master planning and system design. International firms participate within Indian regulatory and institutional frameworks, contributing through technology sharing, collaborative research and professional training. This creates relationships based on reciprocity rather than hierarchy, where each partner contributes from a position of strength.

AI enabled design systems under VIBHAS further enhance this model. By embedding learning into digital models and modular design frameworks, India can offer globally relevant solutions that are adaptable to diverse contexts. For developing regions in Asia, Africa and Latin America, these solutions may provide scalable and affordable approaches grounded in real world operating conditions. For advanced economies, India can act as a co innovator in areas such as new materials, clean energy systems, intelligent infrastructure and safety frameworks.

The principle of India Led, World Linked also introduces greater transparency and balance into international engagements. Partnerships are shaped by design excellence and problem solving capability rather than financial dominance. Design intelligence is treated as a national asset, particularly in strategic sectors such as semiconductors, hydrogen, data centres, renewable energy and advanced manufacturing. India participates not as a downstream service provider but as a knowledge partner.

Institutional mechanisms under VIBHAS make this approach operational. The National Design and Innovation Council and the network of AI Driven Design Institutes establish clear norms for data sharing, joint research and validation of co created designs. Intellectual property generated within India remains under national jurisdiction, while professional accountability rests with certified Indian engineers trained in AI assisted design practice. This provides clarity and confidence to global partners while safeguarding India's design sovereignty.

Over time, this model of collaboration reshapes India's role in the global economy. Just as the country combined scale, quality and affordability to become a global leader in pharmaceuticals, it can now combine intelligence, inclusivity and trust to emerge as a global centre for design. By exporting design standards, digital frameworks and institutional practices rather than only physical assets, India creates a new form of knowledge based engagement rooted in shared progress. The India Led, World Linked approach demonstrates that self reliance and collaboration are not opposing ideas. When guided by strong institutions, ethical governance and mutual respect, they reinforce each other. Through this balance, India can contribute meaningfully to global development while steadily strengthening its own design capability and strategic autonomy.

6.6 Implementation Roadmap and Policy Enablers

Realising the VIBHAS vision requires more than technological readiness. It calls for a carefully sequenced implementation roadmap that connects national ambition with practical execution. The objective is not to create another time bound initiative, but to establish a long lasting national capability that endures beyond political cycles and economic conditions. This can only be achieved through clear policy anchoring, coordinated institutional action and sustained trust in India's engineering and design ecosystem.

- 1. The first requirement is policy recognition.** Design and engineering intelligence must be acknowledged as a strategic national capability, comparable in importance to energy security or digital infrastructure.

This recognition should take the form of a formal national mission led by the National Design and Innovation Council. With statutory backing, the council would coordinate across ministries, state governments and industry bodies to establish standards for AI assisted design, data governance and professional accountability.

A key outcome at this stage is the requirement that major public projects systematically contribute design and operational data to a shared national repository, creating a permanent and growing design memory for the country.

2. The second step is institutional activation.

The Network of AI Driven Design Institutes provides the operational foundation of VIBHAS. Each institute will focus on a priority sector such as transport, energy systems, advanced manufacturing or digital infrastructure. Their role extends beyond research to include continuous engagement with field execution. By collecting project data, training AI models and developing modular design templates, the institutes ensure that every new asset also becomes a source of learning. Infrastructure investment thus produces both physical outcomes and cumulative intelligence.

3. The third step is digital integration through the Design Intelligence Grid.

This secure but open platform will connect government agencies, public enterprises, private engineering firms and academic institutions. It will host structured data, simulation models and performance analytics from projects across the country.

By enabling near real time feedback, the grid allows lessons from one location or sector to immediately inform another. Over time, this feedback loop turns infrastructure into a living learning system rather than a collection of isolated assets.

4. Human capability forms the fourth pillar of implementation.

The introduction of a Professional Engineer for AI certification will ensure that engineers are trained to use Artificial Intelligence responsibly and remain accountable for its application. Universities and technical institutions should integrate AI enabled design into engineering curricula, combining fundamentals with computational methods. National training programmes led jointly by the council and the design institutes can upgrade the skills of the existing workforce, ensuring continuity as tools and practices evolve.

Phase	Time Frame	Key Actions	Lead Institutions	Expected Outcomes
Phase 1: Policy Foundation	2025–2027	Establish NDIC; create statutory framework; set design data standards	NDIC, NITI Aayog, MeitY	National policy recognition of design sovereignty
Phase 2: Institutional Setup	2027–2029	Launch pilot AIDIs; identify sectoral focus; initiate data collection	NDIC, AIDIs, DST	Operational design research hubs in key sectors
Phase 3: Digital Integration	2029–2032	Build and test the Design Intelligence Grid; integrate pilot projects	NDIC, NIC, AIDIs	Interconnected design knowledge repository
Phase 4: Skill and Certification Development	2032–2034	Introduce Professional Engineer for AI certification; update academic curriculum	AICTE, NDIC, IITs	Skilled engineering workforce with AI expertise
Phase 5: National Roll-out	2034–2037	Expand AIDI network; link all infrastructure projects to DIG	NDIC, State Governments	Nationwide adoption of AI-enabled design
Phase 6: Global Collaboration and Continuous Learning	2038–2040	Launch international design partnerships; upgrade AI models and ethics framework	NDIC, MEA, AIDIs	India positioned as a global design leader with continuous improvement systems

Table 6.2: Implementation Roadmap

Sustainable financing is essential to support this ecosystem. Initial endowments may be drawn from national infrastructure and research programmes, while long term growth should be supported through public private partnerships. Firms that contribute design data, validated models or AI tools to the VIBHAS ecosystem can be recognised through incentives such as tax benefits or preferential consideration in public procurement. Procurement frameworks themselves must evolve from a narrow focus on lowest cost towards models that reward quality, learning and knowledge sharing.

Ethics and governance remain central throughout implementation. All AI systems used in design must be transparent, explainable and subject to regular human review. A National Code of AI Engineering Practice should define norms for data usage, algorithmic fairness and professional responsibility. This framework ensures that technology remains accountable to human judgement and maintains public trust.

Implementation should proceed in phases to allow testing, learning and adaptation. Early pilots can focus on sectors with high replication potential such as metro systems, airports, renewable energy parks and industrial clusters. These pilots will demonstrate lifecycle cost savings, validate AI based design processes and refine protocols for data sharing before national expansion.

6.7 From Self Reliance to Shared Leadership

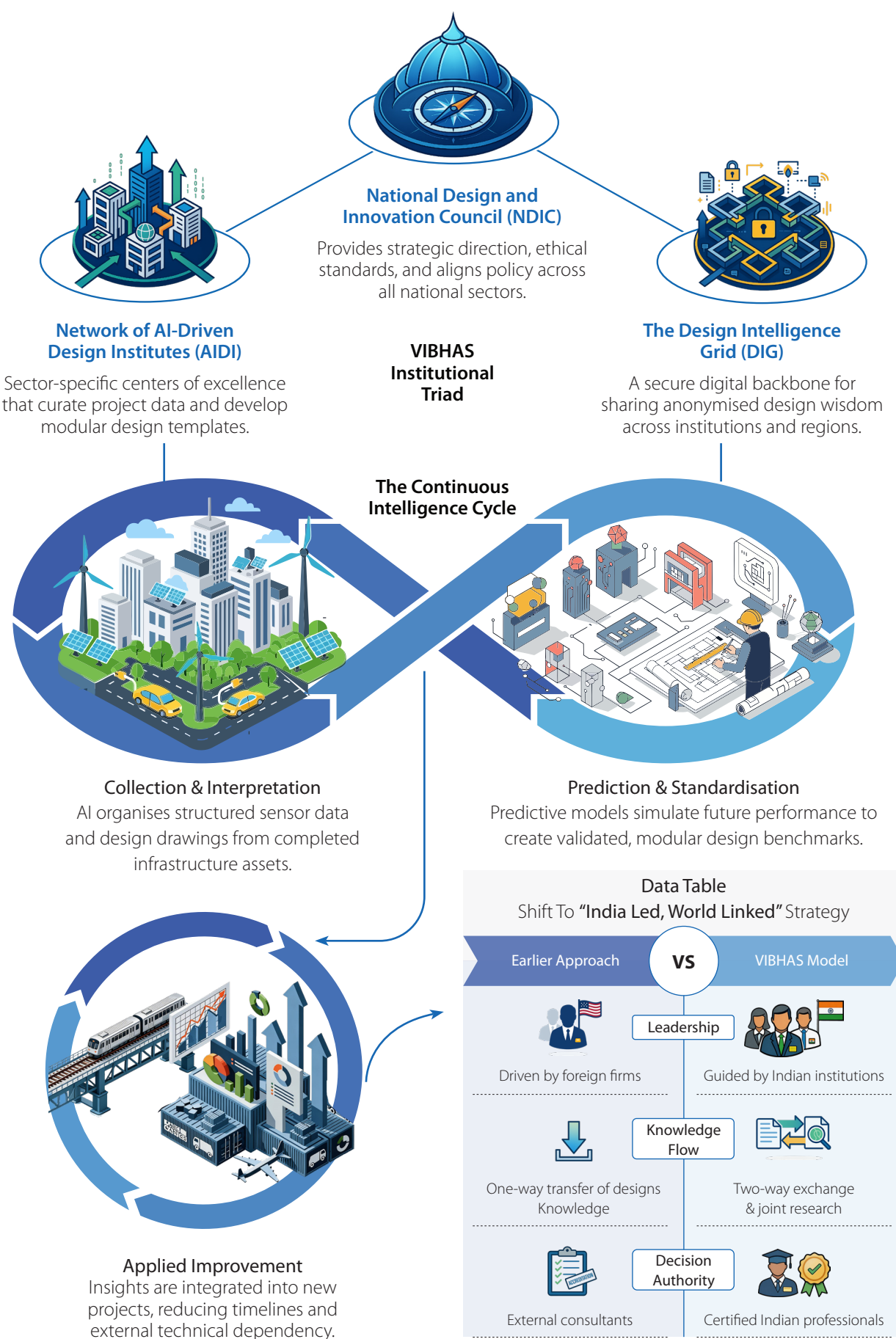
The coming decades will not reward nations merely for the size of their workforce or the speed of their construction. They will reward those that can convert knowledge into intelligence and intelligence into systems that endure and improve with time. For India, the journey from self reliance to shared leadership will depend on how effectively it builds institutions that learn, adapt and innovate across generations. The VIBHAS framework represents more than an engineering or technology initiative. It articulates a broader national philosophy in which development is understood as authorship rather than imitation, collaboration as partnership rather than dependence and sovereignty as confidence in one's own capacity to think, design and create. It signals the emergence of a new design culture in which learning is continuous, responsibility is shared and innovation is collective.

Historically, nations have pursued leadership through centralised control of design expertise or through scale driven industrialisation. India's opportunity lies in a different path. By democratising design intelligence through trusted institutions and AI enabled systems, the country can ensure that learning is distributed, cumulative and resilient. Under this model, every project contributes to a shared national memory. Each power plant, transport corridor or data centre becomes not only a physical asset but also a source of insight for those that follow. By 2047, as India marks a century of independence, the true measure of progress will lie not only in the number of assets created, but in the depth of knowledge embedded within them. A developed India will be one that designs with foresight, learns from experience and applies intelligence systematically. Such a nation will inspire through ideas as much as through scale and will collaborate with confidence as well as humility.

VIBHAS offers a pathway towards this future. It shows how Artificial Intelligence, guided by human judgement and ethical governance, can elevate engineering from execution to continuous improvement. It outlines a model for institutions that think, systems that learn and partnerships that empower. It invites the world to collaborate on equal terms, sharing ideas while retaining identity and purpose. The promise of VIBHAS is therefore the promise of a confident and capable India. A nation that leads with knowledge, builds with conscience and learns as it grows. It is an India that understands progress not only through what it creates, but through what it accumulates, refines and shares with others.

This vision, however, is only the beginning. Design intelligence can empower a nation, but it must be carried into practice by enterprises that apply, scale and export this collective capability. The next stage in India's pursuit of self reliance lies in nurturing domestic engineering champions that translate institutional intelligence into industrial strength. As the following chapter explores, building domestic champions is about converting design knowledge into economic and strategic power. Where VIBHAS provides the brain of national design capability, these enterprises provide the hands that build, sustain and extend India's leadership in a world increasingly shaped by intelligence, collaboration and trust.

VIBHAS: Building India's Future through AI-Driven Design Sovereignty



Chapter 7: Bridging the Capex and Opex Divide

Achieving technological sovereignty by 2047 will depend not only on what India builds, but on how well it maintains and improves what it creates. Over recent decades, the country has gained confidence in its ability to design and deliver complex assets. However, true progress is not defined by the day an asset is commissioned, but by many years of safe, reliable and efficient operation. Design excellence must therefore be supported by strong operational discipline and a commitment to continuous learning and improvement.



Every large scale engineering system passes through two closely linked phases. The first is capital expenditure, where designing, planning and investment come together to create new assets. This is the phase of conceptual thinking, design integration and construction. The second is operational expenditure, where those assets are run, maintained and refined over their useful life. This phase is defined by reliability, efficiency and incremental improvement. Although these phases differ in rhythm, incentives and culture, they are fundamentally interdependent. One creates the system, the other ensures that it delivers value over time.

These phases also correspond to two distinct professional communities. On one side are the design and project engineers who work with models, assumptions and long term intent. On the other side are the operations and manufacturing engineers who manage real world variability, wear, safety and human interaction. Each group brings specialised knowledge that cannot be substituted by the other. The most experienced plant operator cannot design a new industrial facility from first principles. Equally, the most capable design engineer cannot guarantee stable daily production without deep operational understanding.

Complex systems across sectors demonstrate this separation clearly. Clinical expertise does not replace the skills required to design and build a hospital. Process knowledge in semiconductor fabrication does not alone ensure that a wafer manufacturing facility meets exacting standards of vibration control, contamination and temperature stability. Airlines with highly trained crews do not design aircraft independently of dedicated engineering teams. In each case, the creation of an asset and its sustained operation require different skills, mindsets and responsibilities.

The challenge arises when the boundary between these two domains is either ignored or poorly governed. When design decisions are made without operational feedback, assets often suffer from inefficiencies that persist for decades. Conversely, when operational constraints dominate early design without structured translation, innovation is constrained and long term performance suffers. Effective leadership in complex projects therefore requires clarity and humility. Each domain must be empowered to contribute at the appropriate stage, with defined interfaces for feedback and learning.

The relationship between capital expenditure and operational expenditure can be compared to that between information technology systems and operational technology systems. Both must exchange data and insights through controlled interfaces. Neither should override the authority of the other. When structured design is blurred with real time operational decision making, outcomes often include delay, cost escalation or under performance. Clear separation combined with disciplined collaboration is therefore essential.

This chapter examines how the capex and opex domains can function in harmony. It clarifies their distinct roles and mindsets, explains why separation and collaboration must coexist, and reviews global practices where design and operations reinforce each other over the full asset lifecycle. It also explores digital and policy tools that help bridge this divide and offers recommendations for nurturing both the creators and custodians of India's technological future.

7.1 Distinct Roles, Equal Importance

India's progress towards technological sovereignty will depend on how effectively it cultivates and harmonises two vital streams of engineering capability. On one side are the design, project, planning and construction engineers who conceptualise, design and build new systems.

On the other side are the manufacturing, operations and industrial engineers who run, maintain and steadily refine those systems once they are created. The first group operates in the realm of ideas, innovation and structured creativity. The second works in the domain of performance, reliability and optimisation.

Together, these two communities form the full continuum of creation and sustenance that defines any advanced industrial ecosystem. Each brings a distinct way of thinking. The design focused engineer begins with a blank canvas and asks what is possible. They model systems, explore materials and balance design ideas with discipline to shape something that does not yet exist.

The operations focused engineer starts with a working system and asks how it can be made safer, more efficient and more productive. They observe behaviour, measure performance and refine processes over time. Both roles demand intelligence, precision and accountability, but they function under different pressures and time horizons. Designers work amid uncertainty and must balance ambition with feasibility. Operators work amid continuity and must balance stability with adaptation.

Industrial maturity emerges when these two perspectives are recognised as complementary. The designer and the operator are partners in a shared mission. One conceives and builds, while the other ensures that what has been built delivers value reliably over many decades. Neither role is complete on its own. In successful systems, these perspectives work together in a continuous cycle. An idea becomes a true asset only when operations teams take ownership and refine it in real conditions.

In turn, the data and experience generated through daily operation shape the next generation of design. This cycle of learning underpins the success of advanced industrial economies, where respect for both creators and operators is deeply embedded in institutions and culture.

Leadership therefore requires a clear appreciation of this duality. Visionary design alone is insufficient if execution and operation falter. Equally, operational excellence cannot compensate for outdated or poorly conceived design. A large share of lifetime cost, safety and quality is determined at the design stage. The realisation of that value depends on disciplined implementation, reliable operation and structured feedback from the field.

For India, this balance must become a matter of policy, education and professional culture. Design engineers need environments that reward innovation, support experimentation and expose them to global best practice. Operations engineers need systems that recognise discipline, consistency and problem solving under real conditions.

Both must be seen as equally prestigious contributors to national capability. A refinery, power plant, data centre or metro system succeeds not only because it is well designed, but also because it is well operated year after year. The professionals who create the blueprint and those who sustain performance together form the backbone of an advanced economy. Respecting their distinct roles, while ensuring constant communication between them, will determine how effectively India converts ideas into enduring achievement.

Collaborative, Not Interchangeable

Design teams and operations teams must work in close partnership, but collaboration does not imply interchangeability. Each group brings a mindset that cannot simply be swapped or absorbed by the other. The designer's world is shaped by systems thinking, integration and structured creativity. The operator's world is shaped by discipline, consistency and decision making in real conditions. Their partnership is strongest when difference is recognised.

A Comparative Framework: Design & Project Creation Vs. Operations & Sustenance

Design and Project Creation Imagine, Design & Build		Operations and Sustenance Sustain, Optimise & Renew	
 To imagine, design and build new systems that expand national capability	Purpose	To sustain, optimise and renew systems over their operating life	
 What should be created to serve long-term national needs?	Primary question	How can existing systems deliver consistent value?	
 Conceptual and time-bound, focused on integration and innovation	Nature of work	Continuous and cyclical, focused on reliability and improvement	
 Systems design, engineering analysis, project delivery and foresight	Core skills	Maintenance engineering, process control, troubleshooting and assurance	
 Exploratory, future-focused and comfortable with uncertainty	Typical mindset	Practical, consistent and guided by experience	
 Quality of design, delivery discipline and scalability	Measures of success	Efficiency, uptime, safety and asset longevity	
 Creates new assets and technological knowledge	Contribution to national capability	Preserves and strengthens national infrastructure resilience	
 Establishes new knowledge, technologies and assets that symbolise progress	Contribution (symbolic)	Protects and extends the life of national assets and ensures resilience of the economy	

A highly capable designer may not be equipped to manage daily production pressures, just as an exceptional plant manager may not have the skills to conceptualise and design a complex system from first principles. When organisations confuse these roles, they invite inefficiency, risk and failure. History offers many examples where unclear boundaries between design and operation led to costly outcomes. Clinical expertise does not equate to the ability to design and construct a hospital. Pilots, however skilled, do not engineer aircraft. Their excellence depends on the quality of systems created by specialised design professionals.

Effective collaboration therefore occurs at defined interfaces. These include requirement definition, design review, testing, commissioning and structured handover. Design engineers must actively listen to operational feedback so that systems are practical, maintainable and safe. Operations teams must, in turn, respect design intent and specifications, recognising that every tolerance and standard exists to protect quality and safety. When boundaries are clear and communication is disciplined, excellence follows naturally.

When organisations embed this dialogue within governance and culture, rather than leaving it to chance, both design and operations mature together. Collaboration is about alignment. Designers define what is possible in the future, while operators bring those possibilities to life and sustain them in practice. Mutual understanding between the two is the foundation of technological maturity. The balance between design and operation, between creation and performance, will shape sustainable innovation for a nation that aspires to leadership in engineering and design.

7.2 Defining CAPEX and OPEX Mindsets

In engineering, economics and public infrastructure, two distinct forms of effort shape the rhythm of national growth. Capital expenditure represents the realm of creation. It involves investment in conceiving, designing and building long term assets and major transformations. Operational expenditure represents the realm of stewardship. It covers the continuous discipline required to run, maintain and improve those assets once they exist.

In financial terms, capital investments are capitalised and depreciated over time, while operational costs recur annually. In practice, these distinctions run much deeper than accounting. Beyond finance, CAPEX and OPEX represent fundamentally different philosophies of work and leadership. The capital mindset thrives on imagination, initiative and structured risk taking. It belongs to those who design and construct new systems. The operational mindset thrives on precision, consistency and dependability. It belongs to those who sustain performance and reliability. Both are indispensable. Without capital creation there is nothing to operate. Without operational excellence even the most advanced designs steadily lose value.

A capital project mindset is oriented towards building something new or delivering a major transformation. It operates within a defined project window with a clear scope, schedule and budget. Its purpose is to design, plan and execute a system that does not yet exist, while managing integration across disciplines and anticipating future needs. An operational mindset is oriented towards running existing systems safely and efficiently. It is continuous rather than time bound. Its purpose is to maintain stability, manage risk and drive incremental improvement through data, procedures and experience. This distinction aligns with established thinking in project and operations management. Projects are temporary endeavours that produce unique outputs. Operations are ongoing activities that sustain and enhance those outputs. Nations that master both are able to convert episodic achievements into lasting capability.

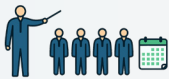
Both mindsets demand leadership and technical excellence. The engineer who designs and delivers, say a power station and the professional who operates it share the same overarching purpose, even though their daily realities differ. One manages design complexity and delivery risk. The other manages reliability, safety and performance risk. Progress depends on bringing these perspectives together with mutual respect, shared standards and a common sense of purpose. Projects and operations together form a lifecycle. Every asset begins as a project that is conceived, designed and built.

It then transitions into operations, where it is run, maintained and optimised over time. Expansions and upgrades restart the cycle. To preserve continuity, commissioning and structured handover must be rigorous. Documentation, training and acceptance testing ensure that operational teams inherit full design intent and capability. Once operations begin, authority must rest with those responsible for performance, supported by clear change control that routes modifications back through design validation.

These mindsets also shape talent development. Engineers who prefer conceptual thinking, system integration and analytical creativity often thrive in project roles. Those who excel in real time decision making, troubleshooting and process discipline find their strength in operations.

Both paths are equally valuable and should be recognised as such. Effective leadership identifies aptitude early, encourages exposure across interfaces and ensures that each community understands the constraints and contributions of the other. In the Indian context, institutional recognition of this duality is essential. Project teams must plan for operational readiness from the earliest design stages. Operational teams must provide structured feedback that informs future projects. When policy makers, educators and industry leaders align these mindsets through governance, curriculum and professional norms, the nation moves from isolated excellence to sustained capability. A country that can both create and sustain complex systems with confidence has already crossed a critical threshold of technological sovereignty.

A Comparative Framework: Capex Mindset Vs. Opex Mindset

CAPEX Mindset: Creation and Design			OPEX Mindset: Operation and Optimisation	
	Creation of new assets and systems through design and project execution	Core Focus	Sustaining and improving assets through operation and maintenance	
	Temporary endeavour with a defined end	Nature & Timeframe	Continuous activity with no defined end	
	Deliver the right system aligned with long term intent	Primary Objective	Ensure consistent performance and long asset life	
	Long term and project based	Time Orientation	Daily and cyclical	
	Accepts uncertainty through analysis and simulation	Approach To Risk	Controls risk through procedures and monitoring	
	Exploratory and conceptual	Decision Style	Analytical and data driven	
	Engineering Design Integration Project Delivery	Knowledge Base	Process Control Reliability Operational Safety	
	Visionary and comfortable with ambiguity	Leadership Traits	Disciplined and focused on execution	
	Architect's office	Typical Environment		
	Design Quality Delivery Discipline Scalability	Measures of Success		
	Cost escalation, delay or overdesign	Common Failure Mode	Declining efficiency or maintenance backlog	
	Expands capacity and introduces new capability	Contribution To National Development	Protects assets and sustains economic confidence	

7.3 The CAPEX and OPEX Divide in Practice

The distinction between CAPEX and OPEX becomes most evident when viewed through real sector experience. Across industries, the interaction between creation and operation reveals how innovation and reliability reinforce each other when roles are clearly defined and deliberately connected. Design and operation are not competing functions. They are complementary domains with different responsibilities and time horizons.

Where design professionals and operational experts engage through structured boundaries, systems achieve both excellence and longevity. Design establishes intent, limits and capability. Operations translate that intent into sustained performance over decades. Where these boundaries are unclear or authority is blurred, opportunities for efficiency, quality and learning are often diluted. Industrial maturity emerges not from overlap, but from disciplined collaboration.

Semiconductors Precision Built on Partnership

Semiconductor manufacturing demonstrates collaboration at one of the highest levels of industrial maturity. The creation of a semiconductor fabrication facility is among the most demanding capital endeavours in modern industry. Civil, mechanical, electrical, chemical and automation specialists work together to establish exacting standards for air purity, vibration isolation, chemical handling, spatial layout and uninterrupted power supply. Cleanrooms, ultra pure water systems and precision utilities are designed with little tolerance for deviation. This CAPEX phase relies on rigorous design discipline, deep integration across specialisms and absolute precision in execution.

Once construction is complete and fabrication begins, responsibility shifts decisively to a highly specialised operational ecosystem. Process engineers and equipment specialists focus on yield, uptime and process stability under tightly controlled conditions. Operational excellence is not improvised but built on disciplined adherence to defined parameters. Information flows continuously between design and operation, yet authority remains clearly defined.

Designers retain responsibility for design intent, while operators are accountable for performance within those limits.

Any alteration to utilities, layouts or process conditions is routed through formal design review, validation and change control. These controls do not restrict innovation. Instead, they enable designers to innovate with confidence and operators to perform with assurance. Precision is maintained because boundaries are respected, interfaces are disciplined and feedback is structured. Where this partnership is upheld, semiconductor facilities achieve world class reliability, yield and longevity. The lesson is clear. Sustained success depends on preserving the integrity of both domains while connecting them through rigorous governance.

Aviation Safety Through Separation and Feedback

Aviation offers a mature example of how design and operation coexist through clear separation, accountability and continuous learning. Aircraft manufacturers are responsible for design integrity, testing and certification under stringent regulatory standards. Airlines, maintenance organisations and flight crews then operate these systems safely and reliably over decades.

The two ecosystems are connected through formal documentation, regulatory oversight, performance reporting and structured incident analysis. Each party is accountable within its own domain. Manufacturers are responsible for certified design intent. Operators are responsible for disciplined execution in real world conditions.

Operational experience strengthens future design decisions through structured feedback. At the same time, operational practices remain aligned with certified design intent rather than informal modification. Safety emerges not from shared authority, but from transparency, learning and mutual respect. This disciplined separation has enabled aviation to become one of the safest and most reliable modes of transport globally.

Healthcare Infrastructure Collaboration Without Substitution

Hospitals are among the most complex public assets, requiring the integration of architecture, structural engineering, biomedical systems, infection control and digital platforms. During the CAPEX phase, specialised design expertise brings these elements together to support safety, resilience, accessibility and energy efficiency.

After commissioning, clinical administrators, medical professionals and facility teams assume responsibility for daily operation. Mature healthcare systems recognise that adaptation is inevitable, but substitution of design authority is not. Best practice emerges where operational insight informs future design improvements through structured review rather than informal change.

Facility management teams work closely with design professionals to ensure that modifications respond to evolving clinical needs without compromising system integrity. Digital models that connect design intent with operational data allow hospitals to evolve while preserving safety, functionality and long term performance. Clear role definition enables healthcare infrastructure to adapt without eroding design discipline.

Infrastructure and Industrial Projects Clear Roles Clear Results

Large infrastructure and industrial assets such as highways, refineries, metro systems, data centres and industrial plants consistently demonstrate the value of disciplined handover and clear authority. Projects that respect design completeness before construction benefit from smoother execution, fewer disruptions and predictable outcomes.

Once assets enter operation, structured commissioning and formal change processes ensure that performance improvements do not introduce unintended risk. Design authority remains a continuing reference point rather than a one time activity. This allows operational teams to adapt assets responsibly while preserving safety, reliability and compliance. Clear roles produce clear results, strengthening resilience and protecting long term value.

Steel Tradition Meeting Digital Practice

Modern steel plants illustrate how digital tools can reinforce the relationship between CAPEX and OPEX without blurring responsibility. Facilities are designed using detailed three dimensional models that simulate structures, equipment and material flows before construction begins. This enables design decisions to be tested, optimised and validated early.

During operation, sensor data, analytics and predictive maintenance support continuous optimisation of yield, energy efficiency and safety. Design excellence establishes the foundation. Operational excellence sustains and enhances it. Digital continuity allows learning to flow in both directions, converting operational experience into design intelligence for future facilities. Discipline, not improvisation, enables improvement.

Power Designing for Longevity

Power generation highlights the importance of aligning design intent with decades of operation. The CAPEX phase delivers complex systems such as turbines, boilers, substations and grid connections. The OPEX phase then extends across long asset lives through preventive maintenance, condition monitoring and performance optimisation.

Digital twins now provide real time representations of plant behaviour, supporting informed decision making and reducing unplanned outages. When operational realities are considered during design, maintainability improves. When design intent guides operations, safety and efficiency are preserved. Longevity is achieved through disciplined alignment between creation and performance.

Across sectors, the lesson is consistent. Technological maturity is not achieved by collapsing the distinction between design and operation, but by strengthening the interface between them. Clear responsibility, structured feedback and mutual respect allow innovation to endure beyond commissioning.

Where creators and operators are connected through discipline rather than convenience, assets deliver value throughout their full life cycle. This balance between design authority and operational excellence defines sustainable innovation for nations and institutions that aspire to long term leadership in engineering and industry.

Sector	CAPEX focus: design and build	OPEX focus: operate and maintain	Key learning for India
Semiconductors	Cleanroom design, precision construction, tool installation and systems integration	Process optimisation, yield improvement, equipment reliability and continuous monitoring	Keep design and operations frameworks distinct with clear technical interfaces and feedback
Aviation	Aircraft design, manufacturing and certification	Fleet maintenance, safety compliance, performance monitoring	Maintain a strict boundary between design authority and operational authority with transparent communication
Steel	Plant layout, furnace and rolling mill design, automation and environmental controls with 3D modelling	Process control, predictive maintenance and real time optimisation using analytics	Link design data with operational feedback through digital systems for continuous improvement
Power	Generation units, turbines, substations and grid infrastructure design and construction	Long term operation, preventive maintenance, energy efficiency management	Embed design maturity and digital handover to support life long reliability
Healthcare	Hospital planning, building services, critical power, HVAC and infection control design	Clinical operations, facility management, safe reconfiguration of spaces	Use structured change control so operational needs do not erode design integrity
Infrastructure	Detailed engineering, procurement and construction management	Asset operations, maintenance and upgrades	Do not start construction without design maturity and keep formal change approval during operation

Table 7.3 Illustrating the CAPEX and OPEX Divide Across Sectors

7.4 Collaboration of Teams Why Clear Roles Enable Strong Outcomes

Collaboration between teams is not about hierarchy or distance. It is about clarity of roles, defined communication and long term performance. When design teams and operations teams are clearly defined yet deliberately aligned, both progress with confidence. When responsibilities become blurred, decision making loses clarity and accountability weakens. Experience across sectors shows that systems perform best when design authority and operational authority remain distinct, while being connected through structured communication, shared data and disciplined processes.

Collaboration of teams works most effectively when each function contributes its expertise through clearly defined interfaces. Design provides intent, limits and technical logic. Operations deliver sustained performance within those limits. Defined communication enables the sharing of respective inputs without dilution of responsibility.

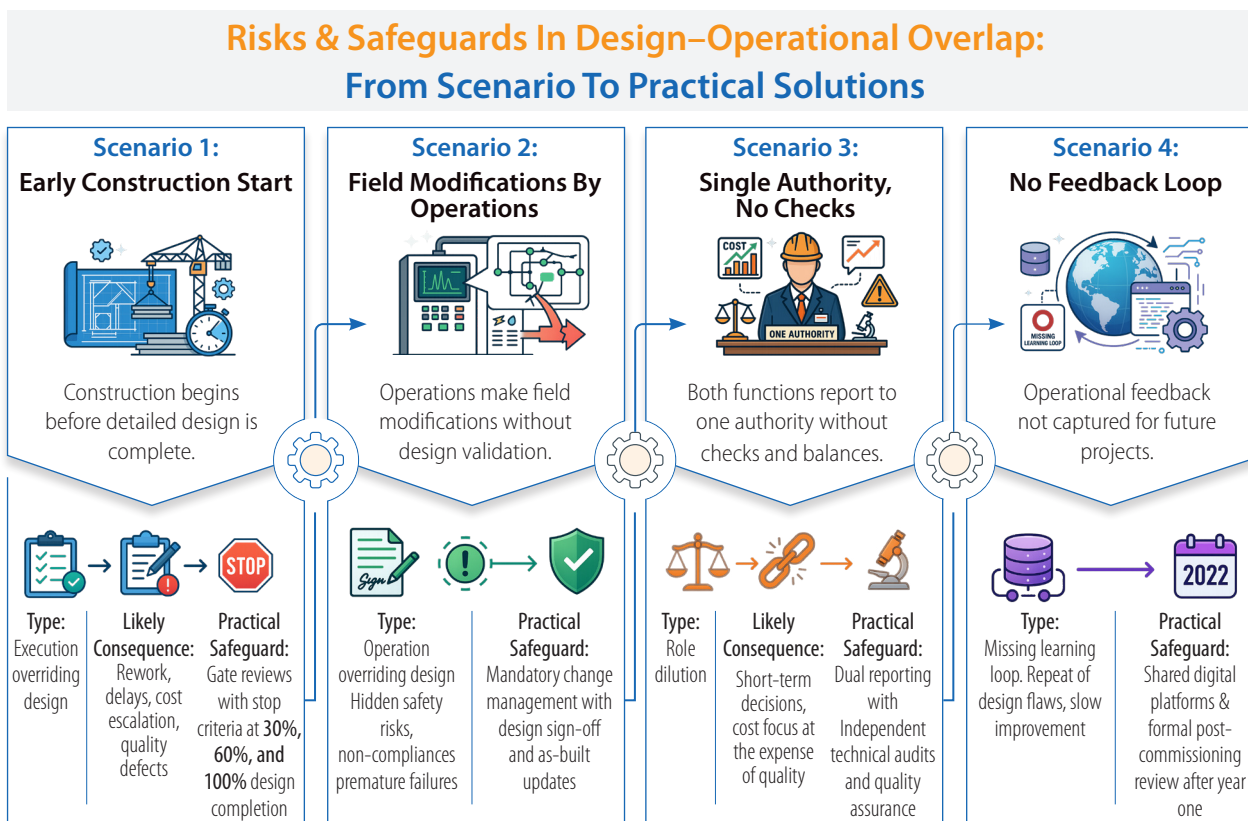
Learning from Practice When Roles Are Not Clearly Defined

Experience across sectors also highlights the value of role clarity through contrast. Situations where construction begins before design maturity, or where field changes are introduced without formal design validation, demonstrate the importance of explicit coordination mechanisms. In such situations, knowledge is often lost rather than captured, and short term decisions can introduce long term risk.

Safeguards such as gate reviews, structured change management, independent audits and shared digital platforms help ensure that learning strengthens future outcomes rather than remaining informal. These mechanisms do not restrict collaboration. They enable teams to exchange inputs confidently while preserving accountability and design integrity.

Typical Overlap Scenarios and Practical Safeguards

The figure below summarises common situations where the absence of clear role definition affects outcomes, along with safeguards that support effective collaboration of teams.



Why Defined Roles Strengthen Long Term Value

When design and operations are treated as interchangeable rather than complementary, two predictable patterns emerge. Design drift occurs when technical intent is gradually diluted under short term pressures. Operational erosion occurs when assets diverge from their original logic through unstructured modification. Both reduce value and weaken system coherence.

By contrast, organisations that preserve role clarity while encouraging defined communication achieve consistency, reliability and resilience. Design authority remains a stable reference point. Operational authority delivers performance within validated boundaries. Learning flows through structured feedback, review and data rather than informal adjustment. This balance allows systems to evolve while retaining integrity.

The Indian Context Building Institutional Clarity

In India, role overlap sometimes arises from urgency or constrained resources. Project teams may be required to support operations before formal transfer, or operational teams may introduce informal changes to meet immediate needs. While practical in the short term, these approaches can weaken accountability and limit learning over time.

Institutionalising clear role definition enables collaboration without confusion. Clear design ownership, structured handovers, professional certification and transparent feedback mechanisms allow teams to share inputs effectively while preserving responsibility. This approach supports the development of an engineering culture where assets perform as designed and endure as intended.

The Enduring Lesson

Across sectors, the message is consistent and positive. Systems achieve excellence when design and operations remain distinct in authority yet connected through defined communication, governance and shared accountability. This balance enables innovation without fragility and reliability without rigidity.

For India, embedding this principle across education, policy, procurement and governance offers a strong foundation for long term capability. Design can lead with imagination and foresight. Operations can follow with mastery and discipline. Together, through collaboration of teams, they form a virtuous cycle that sustains technological progress over decades.

7.5 Global Best Practices and Models of CAPEX and OPEX Integration

Across the world, countries that have achieved technological maturity offer a consistent and encouraging lesson. They have not blurred the boundaries between design and operation. Instead, they have strengthened both by defining clear roles, supported by structured collaboration and disciplined feedback. These models show that when separation is paired with coordination, organisations achieve higher safety, stronger accountability and sustained excellence over time.

This approach creates confidence as designers are empowered to focus on intent, integrity and long term performance, while operators are trusted to execute, observe and improve within a well governed system. The result is progress that is reliable, repeatable and resilient.

Japan The Discipline of Monozukuri

In Japan, engineering is viewed not only as a profession but as a cultural practice. The philosophy of monozukuri, meaning the art of making things, reflects a deep respect for precision, craftsmanship and continuous improvement. Japanese industries demonstrate how creativity in design can coexist with rigour in execution when both are grounded in mutual respect. Design engineers work closely with production teams, yet accountability remains clearly defined. Operators are encouraged to observe, question and suggest improvements through the practice of kaizen.

Every improvement, however small, follows a structured path of documentation, validation and approval by the design authority. This ensures that operational learning strengthens design quality without compromising responsibility or safety.

Many large Japanese organisations reinforce this balance through planned job rotations. Early career engineers spend time in design offices and on the factory floor, gaining insight into how ideas are transformed into physical reality. As they progress into leadership roles, they carry a holistic understanding of performance, reliability and lifecycle value. This shared understanding builds an industrial culture where quality is designed, built and sustained over decades.

Germany Dual Education and Vocational Excellence

Germany's manufacturing strength is rooted in its dual education system, which integrates academic learning with long term industrial apprenticeship. Students divide their time between vocational institutions and real workplaces, developing strong theoretical foundations alongside practical mastery. This system creates two complementary and equally respected professional paths. The design engineer focuses on concept, analysis and system integration, while the skilled operator brings depth of execution and process knowledge. The Meister or master craftsman holds professional status comparable to an engineer, reflecting a national respect for applied expertise.

Leading companies such as Siemens, Bosch and BMW actively support this ecosystem through in house training aligned with future technologies. Professional chambers ensure that certified individuals alone carry design or operational responsibility. These arrangements build trust in engineering outcomes and reinforce ethical practice. As a result, innovation and precision reinforce each other. Designers understand manufacturability and operators respect design intent, leading to projects that are delivered efficiently, safely and to specification.

Finland and the Nordic Model Flexibility and Respect for Practice

Nordic countries such as Finland and Denmark demonstrate how flexibility can strengthen integration without eroding accountability. Their education systems allow professionals to move between design focused and operations focused roles over the course of a career. A machinist may become an engineer, and an engineer may choose hands on operational work at different stages of life. This permeability reduces hierarchy and builds shared respect between intellectual and practical excellence. Universities such as Aalto University and the Technical University of Denmark maintain close partnerships with industry, ensuring that education remains relevant and applied.

In everyday work, Nordic teams bring together designers, operators, sustainability specialists and digital experts in collaborative settings. Equality is a core social value and is reflected in professional behaviour. Collaboration is embedded as a habit. This openness ensures that design remains grounded in reality and that operations continue to evolve through informed innovation. It also enhances resilience, enabling projects to adapt smoothly to new technologies, materials and environmental expectations.

United States Professional Licensure and Institutional Accountability

The United States provides a strong example of how formal accountability supports both innovation and public safety. Engineers whose work affects life and property are required to hold a Professional Engineer licence. This credential carries legal and ethical responsibility. A licensed engineer's signature on a drawing or report confirms compliance with recognised safety and quality standards. This system protects design integrity. Field level changes cannot be made based on individual judgement alone. Any modification must be reviewed and approved by a qualified design authority.

This clear separation of responsibility ensures that innovation proceeds within a framework that safeguards people and assets. Operational roles in safety critical sectors such as aviation, nuclear energy and process industries are similarly regulated. Operators must hold licences that are periodically renewed, supported by audits and documentation. Large national infrastructure and defence programmes follow structured design reviews and operational readiness assessments. Together, these practices create confidence that creativity and execution are aligned, disciplined and accountable.

Country / Region	Core Mechanism	Description	Key Outcome for Integration
Japan	Monozukuri and Kaizen	Continuous improvement culture linking shop-floor feedback to design review under formal documentation.	Balanced respect between designer and operator leading to durable products and a culture of quality learning.
Germany	Dual education and certification	Combination of classroom learning and industrial apprenticeship, with equal status for engineers and technicians.	Seamless translation of design into operation, producing a technically competent and motivated workforce.
Finland and Nordics	Flexible education and professional mobility	Ability to move between academic and vocational tracks ensures mutual understanding between theory and practice.	Blended teams with strong collaboration and high adaptability across roles.
United States	Professional licensure and independent technical oversight	Legal requirement for certified design sign-off and formal accountability for both design and operation.	Public trust in engineering, institutional clarity and consistent quality across projects.
Singapore	Integrated national innovation agencies	Coordination among research, design and industrial development bodies such as A*STAR and JTC.	Rapid translation of design into scalable operations through structured collaboration and shared responsibility.

Table 7.5 (a): Summary of National Mechanisms for Integrating CAPEX and OPEX Excellence

Singapore Integrated Innovation and Rapid Scale Up

Singapore illustrates how coordinated institutions can support rapid industrial advancement. Public agencies such as A STAR, Jurong Town Corporation and the Economic Development Board work in close alignment to move ideas from research to real world application. Research, design and pilot operations are connected through shared programmes, while responsibilities remain clearly defined. Funding structures assign clear objectives and performance expectations to each phase, from concept development to full scale operation.

Public private partnerships accelerate this journey. Technologies developed in research laboratories are tested in pilot facilities and then transferred to industry for commercial deployment. Throughout this process, separation supported by collaboration remains central. This ensures that public investment delivers economic and social value without weakening design discipline or operational rigour. It also builds a strong talent pipeline, with professionals moving between research and industry and carrying learning across boundaries.

Key Lessons for India

These global experiences offer a positive and consistent message. Countries that treat design and operation as distinct but connected disciplines achieve higher levels of safety, quality and innovation. They educate, regulate and reward their professionals differently, yet unite them through transparency, respect and structured feedback. For India, technological sovereignty calls for a thoughtful synthesis. Japan offers discipline, Germany offers vocational strength, the Nordic countries offer equality, the United States offers accountability and Singapore offers institutional coordination.

Together, these principles provide a strong foundation for an Indian model that supports both ambitious capital investment and reliable long term operations.

7.6 Recommendations for India Building Dual Cadres and a Unified Vision

For India to move decisively from dependency towards design sovereignty, it must consciously strengthen two complementary pillars of capability. The first consists of those who conceive, innovate and engineer complex systems, representing the CAPEX mindset of design and creation. The second comprises those who execute, operate and sustain these systems at scale, representing the OPEX mindset of performance, reliability and continuity.

India's challenge lies in the absence of a structured framework that allows these two worlds to grow together, communicate consistently and reinforce one another. The task ahead is to build an ecosystem where design intelligence and operational wisdom coexist as equal and respected contributors to national capability. Achieving this requires coordinated action across education, industry practice, organisational culture and public policy.

Educational Reforms Two Pathways of Excellence

- **Strengthening engineering design and project education:** India's engineering education system has created a large and capable workforce, yet relatively few graduates are trained for design led and project oriented roles. Universities must now evolve from knowledge delivery centres into design and innovation ecosystems.

Engineering curricula should give equal importance to conceptual design, simulation, prototyping and project execution. Students should experience the full lifecycle of engineered systems, from initial idea through design, construction and operation. Capstone projects that integrate mechanical, electrical, civil and digital disciplines should become a standard requirement, reflecting the collaborative reality of modern engineering.

Institutions of national importance can introduce specialised postgraduate programmes in systems engineering, project design and integrated infrastructure management. These programmes should combine academic rigour with real world exposure through internships, mentorship by practising engineers and engagement with national missions such as renewable energy, semiconductor manufacturing and urban infrastructure.

Universities should also establish Centres of Excellence in design and systems engineering in partnership with industry and government. These centres can focus on frontier areas such as hydrogen systems, smart manufacturing, digital twins and circular economy design. Over time, they can become repositories of indigenous design knowledge accessible to both academia and industry. Encouraging research fellowships in areas such as design automation, reliability engineering and digital project management will help attract high quality talent. When students work on Indian engineering challenges, they build skill while generating intellectual property that strengthens national capability.

- **Modernising and elevating vocational and technical education:** Vocational and technical education must be recognised as an equal pillar of national competence rather than a secondary pathway. Industrial Training Institutes, polytechnics and skill universities should become engines of a technically skilled and digitally capable workforce.

Curricula should include robotics, automation, advanced maintenance, additive manufacturing and mechatronics alongside traditional trades. Apprenticeships should be expanded through structured collaboration with industry, ensuring that learners spend substantial time in factories, construction sites and energy facilities. The dual education model used in several advanced economies demonstrates the value of earning and learning simultaneously under certified mentors. India can adapt this approach through partnerships between industry, sector skill councils and educational boards.

Equally important is social recognition. Technicians, fitters and instrumentation specialists must be recognised as professional contributors to national growth. Clear career pathways should allow progression from technician to engineer and from engineer to manager. Government incentives and employer recognition schemes can reinforce this parity. Vocational training centres should also function as digital learning hubs, where workers learn to interpret sensor data, use immersive interfaces and perform predictive maintenance. This blend of craft and computation will define the workforce of the future.

Leadership and Management Development

India's future engineering leaders must understand both creation and continuity. Leadership development programmes should therefore integrate exposure to both project delivery and operational environments.

Business schools and technical universities can collaborate to offer executive education in lifecycle leadership, where participants spend time in design offices as well as operational facilities. A manager responsible for building a refinery should understand how corrosion, downtime and compliance are managed years later. Likewise, a plant manager should appreciate the design constraints and risks faced during construction.

Institutions offering advanced management education can incorporate structured cross domain immersion as part of leadership training. Graduates of such programmes will be better equipped to balance cost, quality, safety and longevity in complex decision making.

Industry Practices Building Structures for Collaboration

1. **Dual career ladders:** Organisations should formally recognise two streams of excellence, one focused on design innovation and project delivery, and the other on operational reliability and performance. Both streams deserve equal respect, visibility and reward. Roles such as chief design engineer, chief project architect, chief operations engineer and chief maintenance leader should operate at comparable organisational levels.

This dual track model ensures accountability for both build quality and long term performance, making design and operations joint custodians of value creation and value preservation.

2. **Structured stage gate reviews and operational handover:** Projects should pass through structured readiness reviews before moving from one phase to the next. Stage gate reviews ensure design maturity before construction and operational readiness before handover. Operations professionals should participate in design reviews to provide insight on maintainability, safety and usability. Project teams should remain engaged during early operations to understand real world performance.
A formal operational readiness phase, where both teams jointly run the facility, enables smooth commissioning and effective knowledge transfer.
3. **Cross pollination and mutual respect:** Engineering excellence grows when professionals experience each other's environments. Early career design engineers should spend time in operational settings, and operational engineers should gain exposure to design offices. Such rotations should be institutionalised within graduate and leadership programmes. Organisations should celebrate successful collaboration publicly, making teamwork a source of pride. Performance systems can include measures that reflect how operational feedback improved design quality or how design decisions enhanced operational efficiency.
4. **Strategic partnerships and ecosystem collaboration:** No single organisation can master every dimension of modern engineering. Strategic partnerships between design firms, construction entities, technology providers and operators can multiply national capability. Public policy should encourage joint ventures and knowledge partnerships that bring design and operational expertise together. The objective is collective self reliance across the national ecosystem.

Governance and Policy Creating an Enabling Framework

1. **Standards and professional licensure:** Professional certification should cover both design and operations roles, with clear accountability for safety, quality and compliance. Public projects should require certified professionals in key positions to raise national benchmarks of competence.
2. **Transparent and accountable project structuring:** Public and private projects should clearly separate design, construction and operation phases with defined accountability. Procurement frameworks should reward lifecycle performance rather than lowest initial cost. Practices such as independent design verification, two stage bidding and mandatory digital handover can strengthen outcomes.
3. **Skill development and knowledge exchange:** National skill programmes should integrate digital learning, apprenticeships and continuous upskilling. Centres of excellence across sectors can serve as hubs for training, research and shared learning. Regular forums that share success stories and lessons learned can accelerate collective improvement.
4. **Knowledge sharing and institutional memory:** Every major project should include a post implementation review that captures what worked well and what can be improved. Lessons should be anonymised and shared through professional or public platforms, creating a growing repository of engineering wisdom and reducing the repetition of avoidable mistakes.
5. **Fostering a culture of mutual respect:** Cultural change is as important as technical reform. Public discourse, education and recognition systems should celebrate both designers and operators as contributors to national progress. Awards and honours should reflect this dual contribution.

Breaking Silos through Institutional Collaboration

One of the most important shifts required for design sovereignty is the deliberate dismantling of functional silos. In many organisations, design, construction and operations continue to function as sequential or isolated units, interacting only at formal handover points. While this structure has delivered assets, it has limited the flow of learning and slowed improvement.

India must move towards institutionalised collaboration, where interaction between CAPEX and OPEX communities is continuous, structured and expected. This does not imply merging roles or diluting accountability. Instead, it requires creating formal interfaces where knowledge is exchanged without authority being overridden.

Professional bodies, industry associations and public agencies can play a catalytic role by hosting joint forums, workshops and review platforms where designers and operators analyse real projects together. Topics such as design for maintainability, operational feedback for future design and lifecycle risk management should become part of mainstream professional dialogue.

Within organisations, cross functional councils and lifecycle review boards can ensure that operational insights systematically inform design standards, and that design intent remains visible during operation. When collaboration is embedded institutionally rather than left to individual relationships, silos weaken naturally and trust strengthens.

Towards a Unified Vision

If India institutionalises these recommendations, it can create a self reinforcing ecosystem where innovation and reliability advance together. Designers will focus on conceptual excellence, while operators ensure sustained performance. Both will work towards a shared national purpose of competence and self reliance. This approach will also generate high quality employment across the engineering value chain, from research and design to construction and operations. It will enable Indian firms to compete globally on quality, dependability and trust, not only on cost. Ultimately, the strength of a nation's engineering identity lies in its ability to build what it imagines and sustain what it builds. By uniting creators and custodians under a common vision, India can make this balance the defining feature of its journey towards design sovereignty.

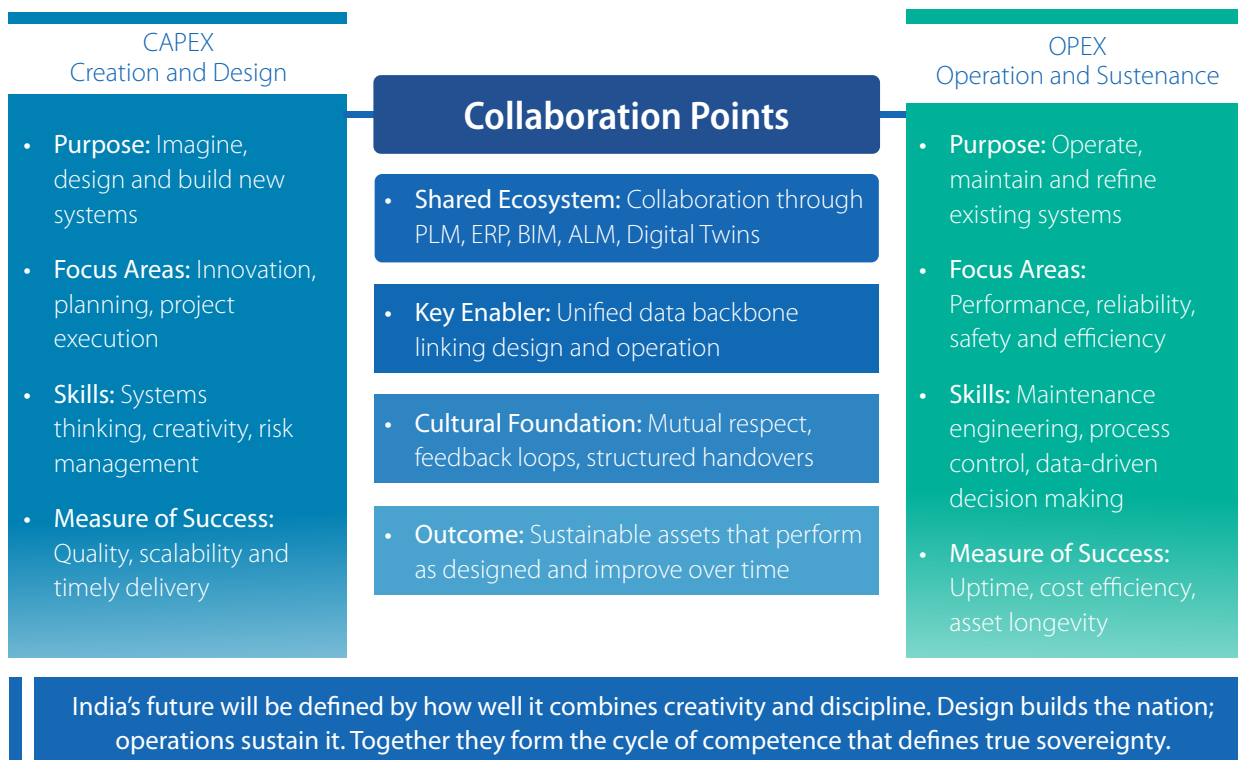
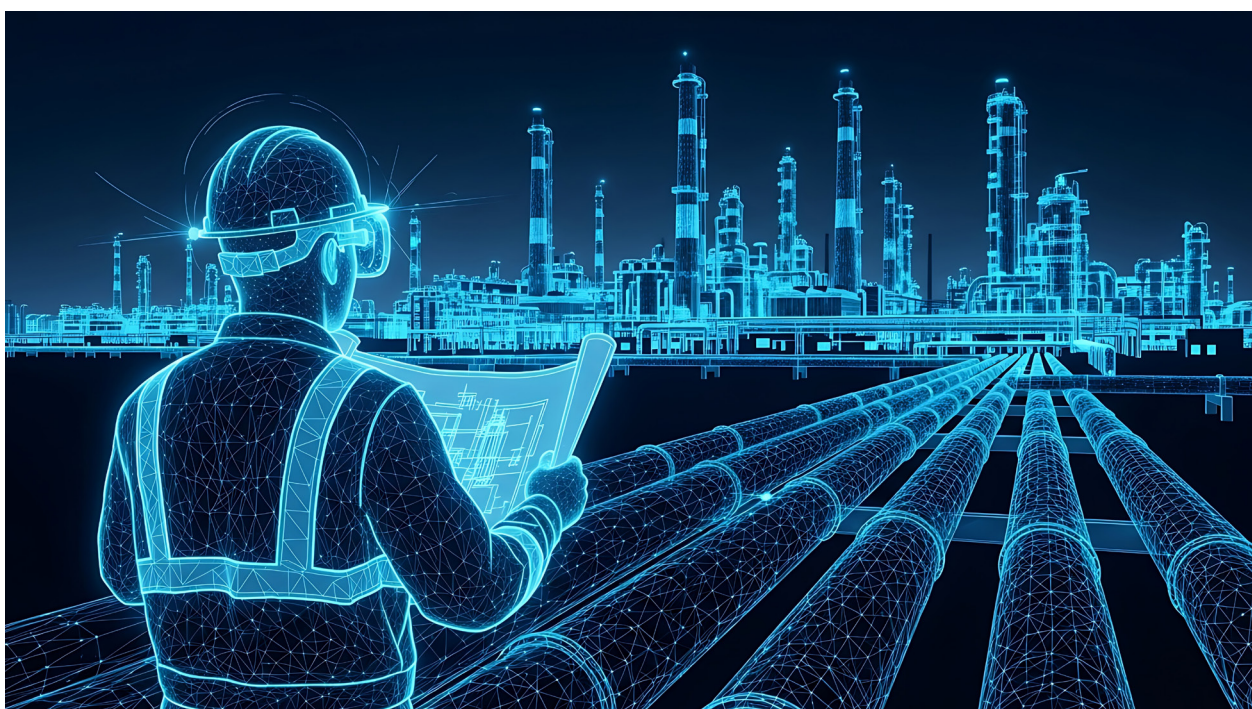


Figure 7.1: From Creation to Continuity – The Two Pillars of Technological Sovereignty

Chapter 8: Digital Frameworks Integrating Design and Operations

Modern enterprises increasingly rely on digital frameworks to strengthen the connection between design and operation across the asset lifecycle. These frameworks do not replace human judgement. Instead, they preserve design intent and operational knowledge as shared digital assets. Systems such as Product Lifecycle Management, Enterprise Resource Planning, Asset Lifecycle Management, Building Information Modelling and Collaborative Product Innovation create continuity from concept through construction, commissioning and operation.



They form a digital thread that links capital expenditure decisions with operational performance, learning and value creation over time. Used well, these frameworks reinforce accountability, enable informed collaboration and ensure that investments made during the CAPEX phase continue to deliver value throughout OPEX.

8.1 Digital System Applications

Product Lifecycle Management (PLM) systems govern every stage in the life of an asset or product, from early concept and design through manufacture, service and eventual retirement.

Their core value lies in establishing a single and trusted source of truth for all engineering data and design documentation, ensuring that every stakeholder works from the same verified information. This shared foundation reduces duplication, eliminates ambiguity and prevents error as ideas move from concept to physical reality. Designers, engineers, procurement teams and constructors remain aligned because design intent is preserved through controlled data, rather than fragmented documents or informal communication.

When PLM is integrated with Enterprise Resource Planning systems, this alignment extends seamlessly into execution. A design change approved within PLM automatically flows into procurement plans, construction schedules and cost estimates managed through ERP. This ensures that what is built always reflects the latest authorised design, strengthening predictability and cost control. In advanced sectors such as aerospace, power generation and complex infrastructure, PLM also enables structured digital handover at commissioning. The as built model is transferred electronically to the operator with complete drawings, specifications, maintenance manuals and configuration data. From the first day of operation, teams have clear visibility of design intent, enabling accurate maintenance, upgrades and informed life extension decisions.

Enterprise Resource Planning (ERP) platforms form the operational backbone of the organisation by integrating financial, procurement, supply chain and project management data into a unified system. During the CAPEX phase, ERP governs budgets, material flows, contracts and schedules, translating design decisions into executable plans. During the OPEX phase, the same system tracks inventory, workforce deployment, asset performance and operating cost, ensuring continuity between investment and operation rather than a handover gap. When ERP operates in close integration with PLM, design and execution become inherently connected. A change in equipment specification or material selection automatically updates purchase orders, delivery timelines and cost forecasts in real time. This reduces delay, avoids rework and strengthens financial discipline. ERP therefore ensures that capital decisions are grounded in operational reality and that operational performance remains traceable to original design choices.

Application or Asset Lifecycle Management (ALM): As digital systems increasingly define the behaviour of physical assets, software lifecycle management has become as critical as mechanical maintenance. Application or Asset Lifecycle Management systems track every change in automation logic, control software and digital configuration across the asset lifecycle.

In modern plants, a software update can affect safety, reliability and output as significantly as a physical modification.

ALM introduces discipline into this digital complexity by ensuring that every change is tested, approved and documented before release. When integrated with PLM and ERP, ALM maintains alignment between physical configuration, digital behaviour and operational intent. Design assumptions, software logic and field performance evolve together, supporting safe and stable operation in highly automated environments.

Building Information Modelling (BIM) provides a three dimensional and data rich representation of a facility that continues to evolve throughout its life. While initially adopted to improve design coordination, BIM now incorporates time, cost, sustainability and operational information within a single model. Geometry is linked with equipment data, construction sequencing and maintenance requirements, creating a holistic view of the asset. After construction, BIM models act as digital twins that support asset management, maintenance planning and energy optimisation. Operators can visualise systems, simulate interventions and plan upgrades with confidence. The use of open standards ensures that this information remains accessible and interoperable over decades, protecting long term value and institutional knowledge.

Collaborative Product Innovation (CPI) builds upon PLM by formalising collaboration as a managed process rather than an informal activity. It aligns people, processes and information so that designers, manufacturers, contractors and clients operate as one extended enterprise. Transparency increases, rework reduces and operational feedback flows naturally back into the design environment. More importantly, CPI embeds lifecycle thinking into everyday decision making. Participants are encouraged to consider performance over time rather than short term delivery alone. In this way, CPI becomes the cultural bridge between CAPEX and OPEX, reinforcing the idea that design success is measured not only at commissioning but across decades of operation.

8.2 Digital Frameworks Enable CAPEX and OPEX Collaboration

Taken together, these digital frameworks create a continuous environment in which design, construction, procurement, operation and maintenance function in synchrony.

PLM governs engineering truth, ERP manages execution, ALM controls digital change and BIM provides spatial and asset context. Updates flow across systems without manual intervention, ensuring consistency and accountability.

The digital twin sustained through PLM and BIM extends design intelligence into operation, while operational data feeds back into future projects. Change remains governed through traceable approval, protecting safety and compliance.

At the same time, immersive visualisation technologies allow teams to jointly understand assets before and after construction. Lessons learned are retained as institutional memory, strengthening future outcomes and reinforcing long term value creation. CPI and PLM Maturity Stages

Stage 1 Intra Enterprise Integration: Internal processes connect design, engineering and production through a unified data environment. A central repository serves as the single source of truth. Early feedback from manufacturing improves design quality. Benefits include reduced rework, faster design to build cycles and improved manufacturability.

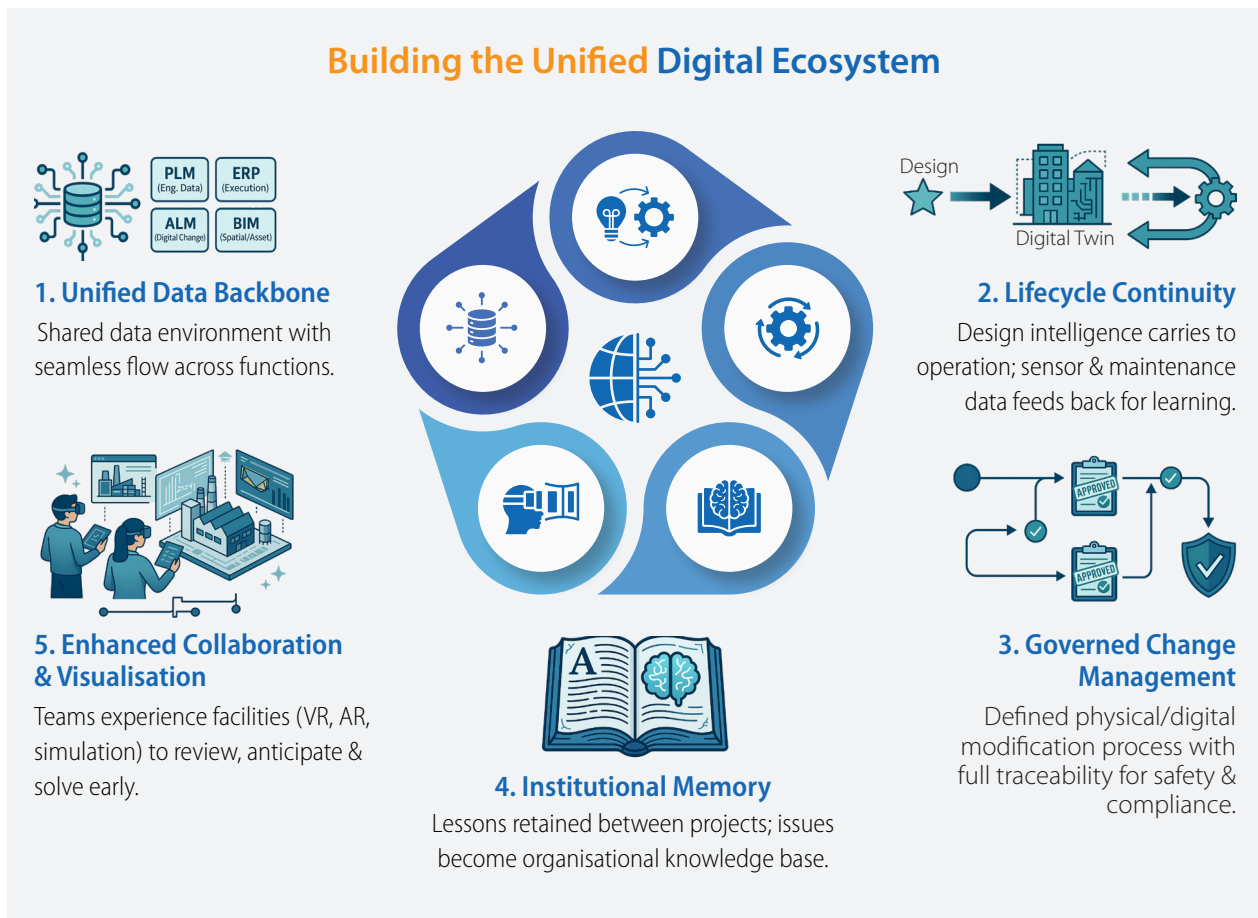
Stage 2 Inter Enterprise Integration: Collaboration extends to suppliers, contractors and clients through shared platforms and secure portals. Virtual project teams work toward common milestones using aligned data and processes. Benefits include fewer late stage changes, faster transition from prototype to production and stronger innovation from partners.

Stage 3 Dynamic Network Collaboration: Collaboration becomes modular and responsive. Partners connect through standardised digital interfaces that enable automatic data exchange. Project teams form and evolve rapidly, supporting open innovation. Benefits include faster response to change, reduced integration effort and first time right delivery.

Framework	Primary Function	Application in CAPEX Phase	Application in OPEX Phase	Key Benefit for Integration
PLM	Manages product and asset data across lifecycle.	Coordinates design documents, specifications and approvals.	Maintains as-built records and supports maintenance planning.	Ensures that the built asset reflects design intent.
ERP	Integrates resources, procurement and cost management.	Controls materials, budgets and project schedules.	Manages spares, workforce and operational expenditure.	Connects financial and technical data for informed decisions.
ALM / EAM	Tracks software or asset configuration and maintenance.	Governs commissioning and software setup.	Manages updates, reliability and compliance.	Preserves consistency between digital and physical configurations.
BIM	Provides 3D and data-rich representation of infrastructure.	Facilitates clash detection, sequencing and cost control.	Supports facility management, energy optimisation and safety planning.	Creates a live model that links design to operation.
CPI	Integrates people and processes for collaborative innovation.	Unites design, procurement and construction teams on shared platforms.	Connects operational feedback to design improvements.	Builds trust and accelerates innovation through structured cooperation.

Table 7.5 (b): Digital Frameworks and Their Contribution to CAPEX–OPEX Integration

When deployed together, these digital frameworks create a continuous operating environment in which design, construction, procurement, operation and maintenance function in harmony.



8.3 Embedding Collaborative Innovation as a Cultural Foundation

Technology alone cannot bridge the divide between capital creation and operational excellence. Culture plays an equally important role. When collaboration is embedded formally into processes, incentives and performance evaluation, its impact multiplies. Collaborative process integration turns cooperation into a repeatable organisational habit rather than an individual effort. It provides a structured environment where creativity and discipline reinforce one another.

For example, when a design engineer proposes a new material or system configuration, procurement, manufacturing and maintenance specialists can be engaged early through a shared product lifecycle interface. Their combined insight refines the design before it reaches execution, reducing uncertainty and avoiding costly rework later. Such early alignment strengthens both design quality and operational readiness. This structured collaboration creates what many organisations recognise as an innovation friendly operations environment.

Engineers spend less time searching for information and more time improving design intent and process performance. As digital frameworks and collaborative practices mature together, organisations evolve from siloed departments into a continuous loop of creation and care.

Design excellence strengthens operational reliability, while operational insight enriches future design. Experience from global industries shows that the digital thread is now as critical as the physical supply chain. Nations that invest in these frameworks are effectively building the nervous system of their engineering economy. For India, such systems offer a powerful opportunity. They ensure that every new project carries forward the intelligence of the previous one, converting accumulated experience into durable national capability.

By embedding Collaborative Product Innovation principles into organisational culture, collaboration becomes a sustained capability rather than an individual initiative. Integrating the right tools and mindsets improves outcomes through early alignment, lifecycle feedback and shared learning.

Projects become more predictable, operations more reliable and innovation more purposeful. For India's ambition of design led industrial growth, such integrative frameworks are essential. Many of the traditional gaps between design capability and operational efficiency can be bridged through modern lifecycle systems and collaborative platforms. These tools institutionalise the principle of collaboration without override, enabling structured interaction while preserving professional accountability.

Investments in product lifecycle systems and collaborative platforms should therefore be viewed not as information technology expenditure, but as strategic infrastructure. They underpin CAPEX and OPEX unity and support a national engineering ecosystem that works in step. Designers, engineers, operators and manufacturers share knowledge in real time and respond collectively to change.

In summary, collaborative innovation frameworks provide the process and technology foundation for the cultural shift India seeks. They embed cooperation into daily work and make the interaction between creation and operation systematic and repeatable. When championed by leadership, these enablers support the larger goal of design sovereignty by ensuring that intelligence, experience and accountability flow seamlessly across the lifecycle of national assets.

8.4 Sectoral Practices Bridging Design and Operations Across Industries

Each industrial sector offers a distinctive expression of how design and operation can collaborate without losing professional identity. From semiconductor fabrication to power generation, digital integration and disciplined governance enable assets designed today to perform reliably tomorrow.

The following examples illustrate how global leaders align capital creation with operational excellence through data continuity, systems integration and shared learning.

Semiconductor Sector Digital Integration and Precision Execution

The semiconductor industry represents one of the most advanced examples of how capital creation and operational excellence are connected through digital intelligence. Building and running a fabrication facility demands extreme precision, where even small variations in vibration, temperature or air purity can affect outcomes at the atomic level.

Design engineers use electronic and mechanical computer aided design tools to create detailed digital blueprints for circuits, layouts and supporting infrastructure. During construction, cleanroom structures, ventilation systems, chemical delivery networks and ultra pure water systems are modelled digitally to coordinate thousands of parallel activities and eliminate error. Once operations begin, a different but connected digital ecosystem takes over. Manufacturing execution systems track production in real time, sensors feed operational data into digital twins and analytics are used to improve yield and reduce downtime.

The same digital model that guided construction evolves into a live operational twin. This continuity between design and performance makes semiconductor facilities among the most efficient industrial environments in the world. Success comes from treating design and operation as distinct domains connected through shared data, mutual respect and constant feedback. Each improvement in one domain strengthens the other.

For India's emerging semiconductor ecosystem, this model offers a clear pathway to combine design excellence with manufacturing reliability. Integrating product lifecycle management, building information modelling, enterprise resource planning, asset lifecycle systems and digital twins from the outset ensures that each unit of capital investment continues to generate value throughout the life of the facility.

Category	Details
Key Tools and Systems (eCAD, mCAD, PLM, ERP, ALM)	Design: Electronic CAD for chip design and Mechanical CAD or BIM for fab facilities and equipment. Enterprises are adopting central data hubs or PLM platforms to connect these domains. Execution: Semiconductor MES and ERP systems manage production scheduling, materials and supply chains. Trend: The industry earlier relied on separate EDA tools, but it is now moving towards unified platforms that integrate product, process and plant data.
Digital Twin Adoption	Fab Digital Twins: Leading chipmakers are creating digital twins of fabrication plants to optimise processes. Example: Samsung Electronics built an Omniverse based fab digital twin to improve throughput and yield. NVIDIA and Samsung began developing a full digital twin platform for fab infrastructure in 2025. Process Simulation: Twins simulate workflows and equipment behaviour before real-world changes, reducing disruption. This is essential in fabs, where downtime is extremely costly.
5D to 7D BIM and Lifecycle Modelling	BIM for Fab Construction: State of the art fabs use BIM for 3D design, 4D scheduling and 5D cost control. Example: Intel's Fab 38 used 4D and 5D BIM to coordinate thousands of tools, pipes and schedules, enabling clash detection and timely, on-budget delivery. Lifecycle Data: BIM models create a foundation for ongoing modification and facility management, evolving into 6D or 7D models for operations and maintenance once the fab becomes live.
PLM and ERP Integration	Integrated Planning: Semiconductor projects require early synchronisation between design, procurement and construction. Real-time data integration connects design teams, contractors and suppliers through shared systems. Dynamic Updates: Design changes automatically update schedules and budgets. The iterative approach in fab construction, inspired by the software industry, resolves risks earlier and keeps all stakeholders aligned.
ALM (Software or Asset Lifecycle)	Software in Tools: Semiconductor manufacturing uses complex automation software to control processes and recipes. Integration of ALM is at an early stage, but fabs apply rigorous change management to all software updates. The industry is gradually adopting lifecycle management for automation code similar to product designs. Asset Lifecycle: Predictive maintenance systems track equipment health, feeding data back to engineering teams to refine tool designs and recipes, thus completing the loop between operation and design.
Advanced Visualisation and Collaboration	Augmented Reality: AR overlays 3D models onto the construction site, guiding precise equipment and pipe installation. Omni scale Simulation: Platforms such as NVIDIA Omniverse unify CAD, simulation and live operational data. Engineers can visualise the plant, run virtual tests and collaboratively refine performance. Robotics and Scanning: Autonomous robots perform laser scanning and feed real-time progress data into digital models for continuous quality control and as-built verification.

Table 7.5 Digital Integration in the Semiconductor Sector

Aviation Sector Digital Continuity and Operational Safety

The aviation industry provides one of the most mature and safety critical examples of how digital engineering bridges design and operation. Every aircraft begins as a comprehensive digital model, and that model remains active throughout decades of service. Design engineers, manufacturing teams and maintenance professionals collaborate through connected platforms that link product lifecycle, enterprise resource and asset lifecycle systems. The same data thread that begins at the design workstation continues into the airline hangar. This continuity ensures that decisions made during design directly inform maintenance strategies, safety procedures and operational performance.

Operational experience is systematically captured and fed back into future aircraft designs, while design improvements refine operational practices. Safety, reliability and innovation are achieved through disciplined digital collaboration rather than role overlap. Design and operation work as equals, each retaining authority while contributing to a shared objective. For India's growing aerospace ecosystem, this model offers a strong benchmark. Whether in aircraft manufacturing, maintenance or airport development, adopting unified digital platforms can help achieve the same balance of creativity, accountability and operational excellence that defines global aviation success.

Category	Details
Key Tools and Systems (eCAD, mCAD, PLM, ERP, ALM)	Design Engineering: Aircraft manufacturers use integrated mechanical CAD and PLM systems such as Dassault 3DEXPERIENCE at Airbus to design airframes, systems and assemblies. These platforms manage millions of parts and configurations and are tightly coupled with requirements management. Supply Chain and Manufacturing: Aviation relies on extensive use of ERP platforms such as SAP for production planning and supplier management, linked directly to PLM for bills of material. Specialised electronic CAD tools support avionics and electrical systems, while ALM systems manage aircraft software development. Systems Engineering: Model Based Systems Engineering connects software and hardware domains so that mechanical, electrical and digital systems evolve in harmony throughout the product lifecycle.
Digital Twin Adoption	Product Twins: Aerospace pioneers the use of digital twins that mirror the physical aircraft from design to in-service operation. Airbus uses digital twins of its aircraft families to simulate performance, maintenance and safety. The A320 family's digital mock-up serves as the master reference for all design, production and service activities. Operational Twins: Aircraft engines and systems are embedded with IoT sensors that constantly send performance data. Manufacturers such as Rolls-Royce and GE maintain digital twins for each engine in operation to predict wear and plan maintenance. Airbus's Skywise platform connects over twelve thousand aircraft to virtual models, enabling predictive maintenance and saving millions by preventing unplanned downtime.
5D to 7D BIM and Lifecycle Modelling	Digital Mock-up and 4D Factories: Aviation was among the first sectors to adopt three-dimensional modelling and simulation. Four-dimensional modelling is now used to plan and manage complex assembly sequences such as wing and fuselage integration. At Airbus's Hamburg facility, real-time production progress is automatically tracked and compared with the digital plan to ensure that assembly stays on schedule. 5D and 6D in Infrastructure: When constructing factories and maintenance facilities, aerospace firms apply 5D BIM for cost and 6D for facility management. Boeing used BIM and 5D cost control to construct its 777X composite wing factory, ensuring accuracy from concept to commissioning. These models remain active through the operational phase as 7D BIM references for maintenance and repair documentation.

Category	Details
PLM and ERP Integration	Threaded Systems: The aviation industry achieves deep integration between PLM and ERP environments. Design data such as material specifications and component definitions flow automatically into ERP systems that handle procurement and logistics. Airbus uses the 3DEXPERIENCE PLM platform alongside SAP ERP to maintain real-time synchronisation between design and production. Maintenance Integration: The integration extends into after-sales and maintenance. Spare parts catalogues and service schedules in ERP systems are directly linked with engineering models. Boeing's Airplane Health Management system exemplifies this, ensuring that every maintenance action is informed by the latest design data and inventory information.
ALM (Software or Asset Lifecycle)	Avionics and Software Management: Modern aircraft rely on millions of lines of code. ALM systems such as IBM Rational or PTC Windchill RV and S are used to manage software configuration and link it with hardware design data. This ensures that every software change corresponds with the necessary hardware adjustment. Asset Lifecycle: Airlines and manufacturers share lifecycle data through digital platforms such as Airbus Skywise, which serves as a hub for operational performance, maintenance and engineering updates. This shared database bridges the gap between design authority and operational responsibility, ensuring continuous improvement across the fleet. Standards: The industry follows open data standards such as STEP for 3D models to enable interoperability among PLM, ERP and ALM systems, given the long service life and global supply network of aircraft.
Advanced Visualisation and Collaboration	Immersive Visualisation: Boeing and Airbus both use virtual and augmented reality for design reviews, assembly and training. Boeing's design teams collaborated entirely in virtual reality to develop the T7A jet trainer, significantly reducing development time. Augmented Reality in Manufacturing: Airbus equips its workforce with smart glasses that display wiring diagrams and component locations on the aircraft structure, reducing errors during assembly. Digital Twin Dashboards: Engineers interact with high-fidelity three-dimensional models that integrate real-time sensor data for live fleet monitoring. The combination of NVIDIA Omniverse and Siemens Teamcenter adds photorealistic rendering to these models, allowing teams to inspect aircraft virtually. Collaborative Platforms: Aviation thrives on global collaboration. Suppliers connect to the manufacturer's PLM systems through secure access to co-design parts and systems. The move towards cloud-based PLM and IoT platforms has accelerated this connected working model, enabling teams across continents to collaborate seamlessly.

Table 7.5 (c2): Digital Integration in the Aviation Sector



Steel Sector Intelligent Manufacturing and Lifecycle Integration

The steel sector is undergoing a significant digital transformation that is reshaping how heavy industries design, construct and operate large scale assets. Once regarded primarily as a traditional manufacturing field, steelmaking today stands out as one of the most advanced examples of how digital engineering can connect capital creation with operational excellence. Modern steel plants function as integrated ecosystems where three dimensional design, automation, artificial intelligence and predictive analytics work together across the full lifecycle. From furnace and rolling mill design to daily process control, decision making is increasingly guided by data.

The integration of engineering, operations and information systems has created a continuous digital thread that enhances safety, quality and productivity. This transformation demonstrates how digital integration can elevate a traditional heavy industry into an intelligent manufacturing environment. With predictive analytics, integrated enterprise systems and real time digital twins, each plant becomes a learning system that continuously refines its own performance.

For India, where steel capacity expansion is a strategic national priority, embedding such digital frameworks from project inception offers a clear advantage. Designing new plants with integrated three dimensional modelling, building information modelling, artificial intelligence and predictive maintenance ensures that facilities are not only competitive in output but also resilient, efficient and sustainable in operation. This approach supports the creation of a new generation of smart steel plants that combine innovation with reliability and long term value.

Category	Details
Key Tools and Systems (eCAD, mCAD, PLM, ERP, ALM)	Engineering Tools: Steel plant design now relies on powerful CAD and plant design management platforms such as Intergraph SmartPlant and Aveva E3D to model furnaces, mills and utilities. These 3D environments are now standard in new projects. Operations IT: Automation and Internet of Things systems form the backbone of operations. Steel plants integrate process control systems, manufacturing execution systems and ERP platforms for planning and inventory. Under Industry 4.0, automation, analytics and IoT converge into a unified digital ecosystem. Data Platforms: Though traditional product lifecycle management was less common in steel due to its commodity nature, many companies now adopt PLM-like systems for process data and quality metrics. Tata Steel, for instance, developed an end-to-end digital dashboard that tracks data across the full process lifecycle.
Digital Twin Adoption	Process Digital Twins: Steelmakers have begun developing virtual replicas of their plants and processes, including blast furnaces and continuous casters. These digital twins simulate output, test process settings and evaluate new operating conditions before implementation, reducing physical risks. Predictive Operations: Digital twins powered by real-time sensors enable predictive maintenance and optimisation. For example, POSCO in South Korea uses an AI-based twin of its hot rolling mill to optimise cooling rates and maintain consistent quality. Virtual Commissioning: New equipment such as furnaces can be tested in digital twin environments before physical integration. This shortens ramp-up times and reduces commissioning risk.
5D to 7D BIM and Lifecycle Modelling	BIM for Construction: Building a modern steel plant or upgrading existing facilities now follows Building Information Modelling practices similar to those in infrastructure sectors. Contractors use 3D and 4D BIM to plan layouts, detect clashes and sequence heavy structural work. 5D and 6D Aspects: Integration of cost and schedule data (5D) enables tight control over large budgets. Some projects extend BIM into 6D and 7D formats for facility management and safety planning after commissioning. Examples: A European steelmaker used BIM to coordinate over one hundred kilometres of piping and cabling for a new blast furnace, reducing construction time through visual simulation and crane movement optimisation.

Category	Details
PLM and ERP Integration	Enterprise Integration: Steel companies now link shop-floor data directly with enterprise systems. Tata Steel's Jamshedpur plant connects its predictive maintenance analytics with ERP, where AI models forecast equipment failure and automatically generate maintenance work orders, reducing downtime. Supply Chain Integration: Product development in steel increasingly uses PLM principles. When a new alloy is designed, its chemical composition and process settings are shared with ERP and production systems, ensuring alignment between design intent and manufacturing reality. Closing the Loop: Customer feedback on material performance is now fed into plant databases, allowing continuous process improvement. This evolving feedback network reflects the early stages of full lifecycle integration.
ALM (Software or Asset Lifecycle)	Assets and Maintenance: Steel plants manage massive rotating and thermal equipment such as furnaces, cranes and rolling mills through advanced asset management frameworks. Predictive maintenance using IoT sensors helps forecast wear and plan shutdowns efficiently. Integrated IT and OT: Modern plants integrate information systems with operational controls. Maintenance software now accesses live data from control systems to issue alerts automatically. Digital twins enhance this process by predicting degradation such as refractory erosion in furnaces, enabling pre-emptive maintenance. Software Systems: While steel does not involve consumer software, automation programs that run the plants are controlled under centralised systems and tested through simulation to ensure reliability.
Advanced Visualisation and Collaboration	Industry 4.0 Technologies: Steel companies use robotics and autonomous drones for inspection, stockpile mapping and hazardous tasks. ArcelorMittal employs drones for remote inspection of high structures, improving worker safety. AR and VR Training: Virtual reality simulators help operators learn complex procedures such as furnace start-up or crane operation in safe, virtual environments. Augmented reality helmets display live equipment data like temperature or vibration to assist field engineers. AI and Analytics: Artificial intelligence enhances process control and product quality. For instance, Thyssenkrupp applies AI for real-time surface defect detection in steel coils, while analytics dashboards share insights across plants, promoting a data-driven culture of improvement. Many global producers are now creating shared digital platforms that connect their engineering and production teams to support collaboration between capital creation and daily operation.

Table 7.5 (c3) Digital Integration in the Steel Sector



Power Sector Connecting Design Intelligence with Operational Excellence

The power sector illustrates how engineering, technology and data can converge to align capital creation with sustained operational performance. Power plants, whether thermal, nuclear or renewable, are among the most complex engineered systems in existence. By embedding digital design, simulation and lifecycle data from concept through operation and eventual decommissioning, the sector has established a mature model for how design and operations can work in harmony.

Advanced software tools now allow engineers to design with high precision, simulate plant behaviour before construction and manage assets through predictive analytics after commissioning. The same digital models used to design turbines, boilers or substations evolve into operational twins that continuously learn from real time data and improve performance.

The power sector demonstrates how digital intelligence can transform conventional engineering into a continuously learning system. Design decisions are increasingly informed by operational data from existing plants, while insights from operations feed directly into future designs. This creates a virtuous cycle of improvement across generations of assets.

For India, this level of digital integration presents a strong opportunity. As the country expands both renewable and conventional generation capacity, embedding lifecycle modelling, digital twins and predictive analytics from the outset can enhance reliability, efficiency and environmental performance across the power value chain. By combining design foresight with operational discipline, India's power infrastructure can become resilient, adaptive and future ready.

Category	Details
Key Tools and Systems (eCAD, mCAD, PLM, ERP, ALM)	Engineering Design: Power generation companies and engineering contractors use BIM and plant design tools extensively. For new plants, detailed 3D models are created for civil, mechanical and electrical systems. Major equipment manufacturers such as Siemens Energy and GE employ PLM software like Siemens Teamcenter to design turbines and other machinery, generating complete digital definitions and bills of materials. Project Management: During construction, ERP systems integrate with BIM to track materials, costs and schedules. Specialised project management tools link with 4D BIM models to ensure alignment between design and progress. Operations IT: Once operational, plants use SCADA or distributed control systems for real-time control and enterprise asset management systems for maintenance and reliability management. These are now increasingly connected to design data, forming the foundation for lifecycle digital management.
Digital Twin Adoption	Plant Digital Twins: The power industry was among the first to adopt digital twins for asset performance. GE and Siemens Energy have developed digital models of turbines that receive live sensor data to predict wear, faults and performance losses. Siemens Energy's twin for a combined cycle power plant turbine and heat exchanger can forecast corrosion and reduce downtime across global fleets. Grid and Network Twins: Utilities now create digital replicas of transmission networks to simulate load flows, faults and energy distribution. These digital grids support both planning of new investments and real-time operational control. Performance Monitoring: Many modern plants have full-facility digital twins. Hundreds of sensors feed data into these models, allowing engineers to test different scenarios such as how fuel composition or weather affects efficiency. The insights also inform future plant designs, creating a feedback loop between operation and engineering.

Category	Details
5D to 7D BIM and Lifecycle Modelling	5D and 6D BIM in Projects: Power projects routinely use 4D BIM to plan construction sequences and 5D BIM to integrate cost data for financial control. Leading EPC companies now link 3D models to procurement databases for real-time budget monitoring. 7D BIM for Operations: After commissioning, the BIM model becomes the foundation for facility management. Each valve, pump and instrument is tagged in the model, linking to maintenance schedules and manuals. For example, nuclear plants use 7D BIM to trace inspection records of critical welds and components. Lifecycle Extensions: When upgrading pollution control systems or adding renewable capacity, engineers simulate new installations within the same digital environment, predicting construction logistics, cost impacts and operational effects before implementation.
PLM and ERP Integration	Integrated Data Environment: Modern power projects unify design, construction and procurement data through linked digital systems. When a boiler design is finalised in PLM or BIM, the bill of materials flows into ERP for procurement. Construction progress and cost data then return to the BIM system to update dashboards automatically. Operations and Maintenance Handover: A structured digital handover package is provided to plant operators. It includes the as-built 3D model, equipment specifications and maintenance plans. Operators begin with fully populated maintenance databases linked directly to ERP, enabling instant access to part histories and technical records. Holistic Planning: Asset investment tools are now connected to both engineering and finance systems, allowing companies to simulate different capital and operational scenarios for long-term asset management.
ALM (Software or Asset Lifecycle)	Asset Lifecycle Management: Long-term reliability is central to the power industry. Operators use asset management systems integrated with sensor data to predict remaining life of turbines, generators and critical components. These systems automatically generate maintenance tasks and track execution. Software and Control Logic: Power plants contain extensive automation software for control and protection systems. Configuration management tools ensure that all software changes are documented, tested in simulations and approved before deployment. Regulatory Lifecycle: The sector also applies ALM principles to compliance management. Each major asset has inspection cycles mandated by regulators, and digital systems monitor due dates, findings and reports to ensure full traceability.
Advanced Visualisation and Collaboration	Digital Twin and Artificial Intelligence: Siemens Energy and others combine real-time plant data with physics-informed machine learning models visualised in immersive platforms such as Omniverse. Engineers can study internal fluid dynamics, predict corrosion and evaluate mitigation strategies virtually before implementing changes. Extended Reality in Training and Maintenance: Many utilities now use virtual reality simulators to train operators in complex or hazardous procedures. In the field, augmented reality headsets overlay live sensor data and 3D diagrams on physical equipment, improving accuracy and safety. Collaborative Modelling: Large projects such as nuclear plants rely on shared digital platforms where engineers, contractors and clients can explore the facility together in 3D. These collaborative reviews help detect design issues early and align operational considerations before commissioning.

Table 7.5 (c4) Digital Integration in the Power Sector

Across the steel and power sectors, a consistent pattern emerges. Digital tools, lifecycle systems and collaborative practices enable capital creation and operational performance to reinforce one another. When engineering insight, data continuity and governance are aligned, assets achieve higher reliability, efficiency and sustainability throughout their life. The continuous exchange of information between design and operation reduces silos, minimises rework and strengthens performance. By adopting such digital frameworks and collaborative systems at scale, Indian industry can accelerate its transition from project based excellence to lifecycle based mastery. This shift supports engineering sovereignty rooted not only in the ability to build, but also in the capability to sustain, learn and improve continuously.

These outcomes are not confined to individual sectors. Across advanced industries, similar approaches to digital integration are increasingly evident. Organisations are using shared lifecycle systems to connect design, construction and operation into a single and coherent process. This ensures that assets do more than meet initial objectives. They continue to evolve and improve through structured learning over time. The following sections draw together these sectoral experiences and distil the common principles that underpin effective CAPEX and OPEX integration. A comparative overview is presented subsequently to highlight the digital tools, lifecycle systems and collaborative methods that enable this alignment across industries.

8.5 Integration of Digital Tools with CAPEX and OPEX Cycles

Bridging capital creation and operational performance requires more than individual tools. It depends on how engineering, construction and operations are connected across the full lifecycle of an asset. When these functions share a common digital foundation, collaboration becomes structured, predictable and repeatable rather than dependent on personal effort. Enterprises that integrate their engineering and operational systems through platforms such as product lifecycle management, enterprise resource planning, asset lifecycle systems, building information modelling and digital twins create a continuous working environment.

In such settings, design, construction and operations teams operate with shared visibility and a common understanding of intent. This continuity forms the basis on which CAPEX and OPEX professionals collaborate effectively throughout the life of an asset.

At the core of this integration lies a shared data backbone. Lifecycle systems provide a single, authoritative source of design and engineering information. When these systems are linked with planning and asset management platforms, every function from procurement and construction to operation works with the same validated data. This alignment reduces ambiguity, avoids duplication and ensures that what is designed is built and maintained as intended.

Lifecycle continuity further strengthens collaboration. Digital twins and advanced BIM models extend the value of capital investments long after commissioning. These models evolve through operational data gathered from sensors and field activity, enabling predictive maintenance, real time optimisation and informed decision making across the operating life of the facility. Process integration adds discipline to how physical assets and control systems evolve. Application lifecycle frameworks ensure that every change is reviewed, tested and documented. This is particularly important in safety critical sectors, where operational adjustments must always be validated against engineering intent.

Visualisation and immersive technologies take collaboration a step further. Platforms that support three dimensional simulation, virtual walkthroughs and augmented field support allow teams to explore facilities digitally, test scenarios and identify potential conflicts before they appear on site. Design engineers, project managers and operators can engage within the same digital environment, removing traditional barriers between planning and execution. Together, these systems create what is commonly described as the digital thread. This seamless connection links innovation and execution into a single continuum. Collaborative Product Innovation principles embedded within these frameworks help organisations remain adaptive, resilient and cost effective. Learning from one project is retained, refined and reused in the next.

The way these tools are applied varies by sector, reflecting differences in risk, scale and operational complexity. However, the underlying pattern remains consistent. Leading industries use integrated digital systems to ensure that design intelligence and operational discipline reinforce one another. The following comparative overview highlights how this integration is achieved across key sectors.

Sector	Key Tools and Systems	Digital Twin Adoption	5D to 7D BIM and Lifecycle Modelling	PLM and ERP Integration	ALM Asset or Application Lifecycle	Advanced Visualisation and Collaboration
Semiconductor	Electronic CAD for chip design, mechanical CAD and BIM for fab layouts, PLM for design data, ERP for supply chains, manufacturing execution systems for production and ALM for process control software	Digital twins of fabrication plants simulate cleanroom workflows and tool behaviour, enabling predictive maintenance and throughput improvement	4D BIM supports construction sequencing, 5D integrates cost control and 6D or 7D supports facility upgrades and maintenance	Integrated dashboards connect design changes to procurement and construction schedules, maintaining accuracy and cost discipline	ALM frameworks track equipment lifecycle and process recipe evolution, improving tool reliability	Augmented reality supports maintenance while immersive platforms enable collaborative plant visualisation
Aviation	Mechanical CAD and PLM for aircraft design, electronic CAD for avionics, ERP for manufacturing and supply chains, manufacturing execution systems for assembly and ALM for avionics software	Aircraft and engine twins track wear, performance and maintenance. Platforms such as Skywise connect fleet data to engineering models	4D BIM manages factory setup, 5D monitors cost, 6D focuses on sustainability and 7D enables maintenance planning	PLM updates automatically trigger ERP changes while operational data flows back to manufacturers	ALM manages hardware and software lifecycle with full traceability and regulatory compliance	Virtual and augmented reality support training, maintenance and global design reviews
Steel	Three dimensional plant design tools, process simulators, manufacturing execution systems, ERP for procurement and inventory, enterprise asset management for maintenance and ALM for process control	Digital twins of furnaces and rolling mills optimise yield and energy use while plant wide twins support predictive operations	4D BIM enables construction planning, 5D links cost data and 6D or 7D supports lifecycle documentation	Engineering specifications feed directly into ERP and production data is returned to design teams for improvement	Asset management systems monitor equipment health while ALM captures process evolution	Augmented reality supports maintenance, virtual reality aids safety training and control rooms visualise live twin data

Sector	Key Tools and Systems	Digital Twin Adoption	5D to 7D BIM and Lifecycle Modelling	PLM and ERP Integration	ALM Asset or Application Lifecycle	Advanced Visualisation and Collaboration
Power	BIM and plant design tools, simulation software, ERP for projects and operations, SCADA or DCS for control, enterprise asset management and ALM for control logic	Digital twins of turbines, boilers and grids support efficiency optimisation, predictive maintenance and training	4D BIM supports construction phasing, 5D manages cost, 6D supports sustainability and 7D enables full asset lifecycle management	Engineering data updates ERP and asset systems automatically, enabling smooth digital handover	ALM tracks equipment and software lifecycle including compliance and predictive analytics	Remote control centres, augmented reality field tools and immersive training support collaboration
Oil and Gas	Three dimensional plant and piping design, process simulation integrated with PLM, ERP for procurement, asset management for maintenance and ALM for control systems	Digital twins of refineries, platforms and pipelines enable predictive maintenance and scenario planning	4D BIM supports logistics, 5D manages cost and 6D or 7D supports lifecycle asset tracking	PLM based delivery keeps design, procurement and operations data aligned	ALM governs all equipment and control software changes with traceability	Augmented reality enables remote support, virtual reality supports emergency training and digital twins enable collaboration

Table 7.5 (d) Digital Integration Across Key Sectors

Embedding Learning through Structured Feedback Loops

Design sovereignty depends not only on building assets, but on retaining and reusing the knowledge created in building and operating them. Too often, valuable learning remains local to a project or a site and is lost once teams disperse. Embedding learning as a formal process is therefore essential. Every major project should include a mandatory post-commissioning review after a defined period of operation. This review should be conducted jointly by design and operations teams and focus on performance against design intent, maintainability, safety and lifecycle cost. Findings should be documented in a structured and anonymised format.

At an industry and national level, these lessons should feed into shared repositories managed by professional institutions or public bodies. Over time, this creates a living library of engineering experience that improves design standards, training curricula and procurement practices. Digital platforms make this embedding of learning practical. When operational data, maintenance records and incident reports are linked back to original design models, learning becomes continuous rather than episodic. Each new project then begins at a higher level of maturity than the last. By making learning systematic and visible, India can ensure that excellence compounds rather than resets with every project cycle.

Chapter 9: Building Domestic Champions

Case studies of resilience and innovation demonstrate what Indian institutions can achieve under pressure. Yet for intellectual independence to be sustainable, India cannot rely on occasional successes. It must build permanent institutions that stand as champions of national expertise. Domestic consulting and advisory firms, research institutes and knowledge enterprises must be nurtured into organisations with scale, credibility and visibility equal to their global peers. The task is not to copy foreign models but to adapt lessons from them while building champions rooted in Indian conditions and values. This chapter explores why domestic champions are essential, what holds them back, and how policy, investment and collaboration can propel them into leadership roles.



Further to the discussions of section 5.2, A Bayh Dole style framework in India could fundamentally transform the innovation landscape. Such a law would allow private companies to own or license intellectual property generated from CSR-funded research, provided the outcomes serve national interests.

Research conducted jointly by a company and a public institution could be commercialised in a manner that benefits both parties, with safeguards ensuring that strategic technologies such as sustainability, renewable energy and defence are prioritised.

Benefits of a Bayh Dole Style Framework

- Reduces dependence on foreign technologies through indigenous alternatives
- Creates high-value employment in advanced technology sectors
- Boosts exports and competitiveness through patentable products and services
- Strengthens academia–industry collaboration through transparent IP models
- Aligns with Atmanirbhar Bharat and Viksit Bharat by positioning India as a producer of innovation rather than a consumer

CSR funds can thus be channelled more strategically. Instead of being limited to short-term community projects, they can become catalysts for long-term innovation, creating a cycle where research leads to commercialisation, employment and social benefit.

Aspect	Current CSR Framework	Bayh Dole Style Potential
Intellectual property ownership	Not explicitly permitted for private entities	Permitted under structured public private collaboration agreements
Use of CSR funds for research	Allowed primarily for public institutions and non profit outcomes	Extended to joint public private research with defined national interest safeguards
Commercialisation of outcomes	Limited by non profit character of CSR expenditure	Enabled through transparent licensing and commercial pathways
Incentives for industry participation	Indirect and weakly defined	Clear incentives through ownership, licensing and revenue sharing
Academia industry collaboration	Encouraged but largely informal	Formalised with predictable intellectual property and governance frameworks
Alignment with national priorities	Indirect alignment through social impact	Direct alignment with strategic sectors such as sustainability, energy and critical technologies

Table 9.1: Comparing the Current CSR Framework with a Bayh Dole Style Model

India has already put in place a strong policy foundation to support domestic capability building. National initiatives in manufacturing, infrastructure, digital systems and skills have created scale, demand and direction. Together, they signal a clear intent to strengthen self reliance while remaining open to global engagement. These initiatives, however, are only enablers. They do not automatically create domestic champions. Their impact depends on how effectively Indian firms convert policy intent into institutional strength. This requires organisations that can absorb opportunity, retain knowledge, build talent and scale with confidence. The programmes outlined below illustrate how public policy has created the conditions for domestic leadership. The next challenge is to translate these conditions into strong firms, trusted institutions and visible global players. The sections that follow examine how Indian enterprises can rise to this challenge by addressing talent, branding, scale and partnerships in a coordinated manner.

Converting National Opportunity To Global Capability & Leadership



Figure 9.1: National initiatives create opportunity. Domestic firms must convert it into capability and leadership.

9.1 The Paradox of Indian Talent Abroad

India produces some of the world's most respected professionals. Many lead global corporations in technology, finance and healthcare, while others hold senior roles in research institutions and advisory bodies across continents. Their achievements show the strength of India's education system and its capacity to nurture excellence. Yet within India, domestic firms often struggle to attract or retain talent of the same calibre.

This contrast exists because the environment for professional growth and recognition is more established abroad. A young graduate joining an international organisation in India may soon find opportunities to work on global assignments, interact with diverse teams and earn competitive rewards. The same graduate, if employed by a domestic firm, may find fewer avenues to participate in projects of global visibility or to lead innovation. Even when the technical skills are equal, the exposure, mentorship and recognition differ widely.

The outcome is a continuing loss of talent from domestic institutions to global employers. This situation not only affects individual career choices but also weakens the pool of professionals available to build strong national institutions. Over time, it reinforces a perception that Indian firms are not the first choice for ambitious professionals.

Unless this imbalance is addressed through policy, investment and brand strength, domestic firms will continue to face difficulty in retaining their best minds. Creating meaningful opportunities for leadership and visibility within India is therefore essential for long-term intellectual independence.

9.2 Branding and Visibility of Indian Firms

Reputation is central to consulting and advisory work. Clients select firms not only on technical competence, but on trust, credibility and the confidence that knowledge will endure beyond a single engagement. Global firms have built strong reputations through sustained visibility, consistent communication and the ability to demonstrate learning across projects and geographies. They publish thought leadership, participate in international forums and invest deliberately in how their expertise is presented.

Indian firms, by contrast, have often remained less visible despite strong technical capability. Modest communication budgets, conservative professional norms and a limited tradition of public knowledge sharing have constrained their presence. As a result, even capable domestic firms may not always receive equal consideration for complex or high visibility assignments. This creates a cycle where limited exposure restricts reputation, and limited reputation reduces opportunity.

Breaking this cycle requires Indian firms to treat visibility as an extension of learning and leadership. Publishing technical insights, sharing case studies, contributing to policy dialogue and engaging with academic institutions allow firms to demonstrate depth rather than promotion. Each such engagement strengthens national credibility and signals confidence in indigenous capability.

Public platforms can further support this effort by showcasing Indian engineering and consulting expertise to international audiences. Collective visibility initiatives, similar to those that supported the growth of India's information technology sector, can help domestic firms gain recognition as trusted knowledge partners. When Indian firms are seen consistently and credibly, talent retention improves and client confidence follows.

9.3 Scale, Capital and Global Reach

Scale is essential in consulting and knowledge based industries because it enables sustained investment in research, technology and people. Global firms achieve influence not only through expertise, but through the organisational capacity to learn across projects, retain knowledge and apply it repeatedly. Indian firms often remain mid sized and domestically focused, which limits their ability to accumulate and institutionalise learning.

Building scale in India therefore requires more than financial growth. It requires structures that break organisational silos and embed learning across functions, sectors and geographies. Access to long term capital, patient investment and transparent procurement frameworks can support firms that contribute to national capability rather than short term execution alone.

Public policy can play a constructive role by recognising lifecycle performance and institutional learning in procurement and qualification criteria. When firms are rewarded for how well they retain expertise, train professionals and improve outcomes over time, scale becomes a by product of capability rather than a barrier to entry.

As domestic firms build scale and financial resilience within India, they can expand into emerging markets across Asia, Africa and Latin America. These regions value practical expertise, contextual understanding and cost conscious design, areas where Indian firms have natural strengths. Expansion into such markets also reinforces learning, exposing firms to diverse conditions and strengthening institutional maturity.

The evolution of India's information technology sector demonstrates how domestic enterprises can move from local relevance to global leadership through a combination of policy support, skill development and continuous learning. Consulting and engineering firms can follow a similar path, provided scale is accompanied by mechanisms that capture experience, share knowledge and refine practice.

9.4 Strengthening Industry and Academia Partnerships

If self reliance is the vehicle of national capability, collaboration between industry and academia is the engine that sustains its movement. For India to design and deliver strategic systems with confidence, research institutions and industry must work together in a continuous and structured manner. The objective is not only to generate knowledge, but to translate research into usable technologies and convert academic insight into solutions that address national priorities.

Universities and research centres play a critical role in creating knowledge and developing skilled graduates. Industry contributes practical experience, market understanding and the ability to implement solutions at scale. When these two communities operate in isolation, innovation remains fragmented and its impact limited. When they collaborate, education aligns more closely with economic needs and research remains connected to real world application.

India has already taken important steps in this direction. Programmes linked to skills development and higher education reform have encouraged greater participation of industry professionals in curriculum design. Leading academic institutions are partnering with companies to establish Centres of Excellence and specialised laboratories. The National Education Policy of 2020 reinforces this approach by supporting technology parks, incubation centres and applied research within universities, making innovation part of everyday learning.

Evidence from Indian institutions shows the value of this model. The research park at the Indian Institute of Technology Madras brings companies and researchers together in a shared physical environment, enabling hundreds of collaborative projects and new technologies. Similar partnerships across the country have led to advances in areas such as telecommunications, artificial intelligence and advanced materials, demonstrating that collaboration accelerates both learning and application.

Government policy further strengthens this ecosystem. The Anusandhan National Research Foundation encourages research projects that include industry partners and demonstrate social or economic impact. Fiscal measures that allow companies to direct a portion of Corporate Social Responsibility funding towards academic research, along with incentives for industry linked innovation, help align long term research with national development goals.

These partnerships function not only as technical arrangements but also as cultural bridges. Students gain exposure to real engineering challenges. Faculty members contribute directly to national missions. Companies gain access to talent, ideas and long term research capability. Over time, this creates a shared innovation network where learning flows in both directions and experience is retained rather than lost.

By strengthening industry academia partnerships, India can embed learning into its innovation system and reduce the gap between research and execution. This integration is essential for building domestic champions that do not merely adopt technology, but help create, refine and lead it with confidence on the global stage.

9.5 Role of Domestic Champions in Nation Building

Domestic champions are more than commercial enterprises. They are institutions that contribute directly to national strength, strategic autonomy and long term capability. Their role extends beyond contracts or profits. They generate knowledge, shape professional culture and ensure that India's growth is guided by its own priorities, values and context.

In critical sectors such as energy, transport, semiconductors, renewables and digital governance, excessive reliance on foreign advisors or contractors can introduce strategic vulnerability. When design authority, data ownership or key decision making lie outside national control, self reliance is weakened. Domestic firms, by contrast, bring contextual understanding, institutional memory and a sense of national purpose to complex projects. Prioritising Indian leadership in such sectors helps ensure that knowledge, capability and control remain within the country.

The table below highlights sectors that are central to India's future and explains why leadership by Indian firms in these areas is essential for sustained national capability.

Sector	Importance to India's Future	Rationale for Indian Led Execution
Semiconductors	Foundation of the digital economy and critical industries	Builds control over technology supply chains and nurtures a domestic high technology ecosystem
High speed transport	Mobility, connectivity and urban decongestion	Strengthens national design capability and ensures knowledge retention for future corridors
Energy and refineries	Energy security and value added exports	Keeps project value within the domestic economy and deepens indigenous engineering expertise
Nuclear and clean energy	Clean power and strategic autonomy	Promotes self reliance in sensitive technologies and supports long term energy sustainability
Renewable energy and pumped storage	Green transition and grid stability	Builds capability in next generation energy systems aligned with climate goals
Pharma and biotech	Health security and global competitiveness	Reinforces domestic research, development and process engineering strength

Table 9.2 Strategic Sectors and the Case for Indian Led Execution

Domestic champions also play an important cultural and educational role. They mentor young engineers, encourage innovation and uphold ethical standards in professional practice. By offering training, leadership and long term career paths within the country, they build confidence among future generations of scientists, technologists and consultants.

In moments of national crisis, domestic champions can mobilise quickly because they understand local conditions, institutions and communities. Their proximity and practical knowledge allow them to act as reliable partners in emergency response and recovery. In periods of opportunity, they can design solutions rooted in Indian realities and adapt them for global application, carrying Indian innovation to international markets.

Over time, such firms accumulate intellectual capital that is as vital as physical infrastructure or industrial capacity. They become symbols of national competence and confidence. Building and sustaining domestic champions must therefore be treated as a strategic priority. Without them, India risks continued dependence on external design and advice. With them, India gains the ability to define its own future and contribute knowledge to the world.

9.6 Engineering Sovereignty and Professional Licensing

India's aspiration for technological and design sovereignty cannot be realised without engineering sovereignty. This requires the ability to conceive, validate and certify designs within a trusted and accountable professional framework. India has a deep pool of engineering talent and strong technical institutions, yet it does not currently have a statutory professional licensing system comparable to those in the United States, Canada, the United Kingdom or Australia.

In these countries, engineering deliverables that affect public safety and national infrastructure are certified by licensed professionals who are personally accountable to a regulatory authority. This system builds trust, ensures safety and reinforces professional credibility. It also reflects national confidence in engineering capability. In India, the absence of a comparable framework has created a structural gap in professional recognition and accountability. As a result, international engineering and advisory firms continue to lead many advanced projects in sectors such as semiconductors, hydrogen infrastructure, nuclear systems and advanced manufacturing. Their engineers carry globally recognised credentials that allow them to certify designs and assume formal responsibility. Indian engineers, despite having deep expertise, are often placed in supporting roles. This limits India's ability to assert ownership over its designs and reduces the visibility of domestic consulting capability.

To address this gap, India should consider establishing a National Professional Engineering Regulatory Authority through legislation. This authority would define transparent pathways for engineers to become licensed professionals based on accredited education, supervised experience, examination and continuous professional development. Each engineering discipline should have clearly defined licensing standards, including civil, mechanical, electrical, chemical, process and control engineering.

Emerging sectors such as renewable energy, semiconductors, hydrogen systems and digital automation should have specialised licensing categories aligned with national priorities. Once established, licensed engineers should be responsible for certifying all designs, drawings and technical documents submitted to statutory bodies. This reform would strengthen professional standing, assure investors and partners of quality and ensure that accountability remains within national boundaries.

A professional licensing framework would also enhance collaboration. Foreign consultants could continue to participate in Indian projects, but in partnership with licensed Indian professionals. This approach would support genuine knowledge transfer, adherence to local standards and responsibility for safety and compliance within the country. Mutual recognition agreements could allow Indian engineers to work globally while preserving the primacy of Indian certification.

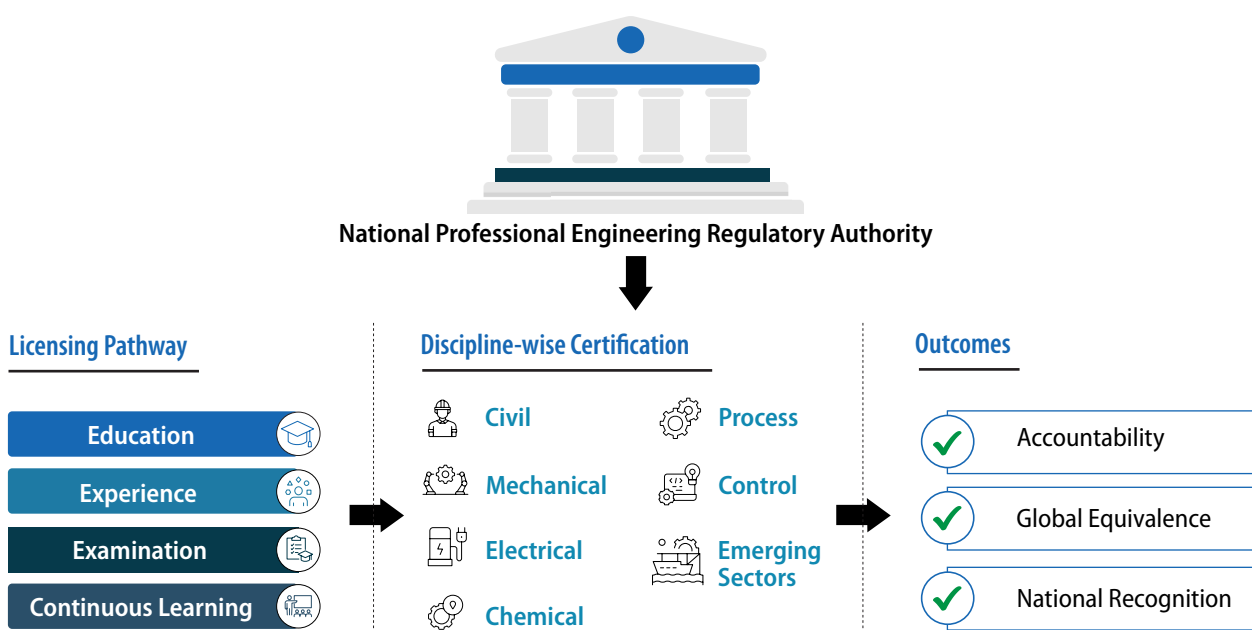


Figure 9.2: Professional Licensing Framework - Suggested Structure

Such a charter would elevate engineering from a technical occupation to a profession grounded in public trust. It would create a clear pathway for young engineers to achieve global competence without leaving the national system. Over time, it would strengthen domestic consulting and engineering firms and enable them to lead projects of national importance.

Design sovereignty begins with professional legitimacy. Just as India's nuclear programme built credibility through indigenous validation and responsibility, the next phase of national progress must rest on a statutory system that recognises and empowers Indian professionals. The seal of an Indian Professional Engineer should come to symbolise competence, reliability and confidence, reflecting a nation that designs, certifies and owns its future with assurance.

9.7 Trust as the Foundation of Design Sovereignty

No nation has ever achieved technological sovereignty by accident. It is built deliberately through sustained support in domestic institutions, engineers and enterprises, often long before global recognition follows.

At the heart of design sovereignty lies policy reform, industrial capacity, and confidence that national challenges are best understood and solved by domestic capability. When a country supports its own technical design, aspiration turns into architecture and intent becomes institution.

For much of India's industrial development, growth has been supported by foreign consultants, licensors and engineering firms. These partnerships have brought global exposure, access to finance and established methodologies. At the same time, they have often limited the long term retention of design knowledge within the country. In strategic sectors such as semiconductors, hydrogen systems, advanced mobility and digital infrastructure, design authority, certification and intellectual ownership frequently remain outside Indian jurisdiction. Infrastructure is delivered, but institutional learning does not always accumulate locally.

In many projects, international firms operate through Indian delivery centres or joint ventures where domestic engineers contribute substantially to execution. However, conceptual control, system architecture and formal certification often remain offshore. Though described as collaboration, this model functions largely as intellectual subcontracting. It creates employment and short term capability, but does not consistently build enduring design institutions. Other nations have adopted a more deliberate approach. China, for example, embedded design authorship within its own institutions across rail, power, metallurgy and semiconductors. Design institutes acted as national knowledge centres rather than project offices. International partnerships were welcomed, but structured so that learning cycles, standards and ownership remained domestic. Over time, participation was converted into authorship, and authorship into mastery.

From Policy to Trust: The Journey to Design Sovereignty

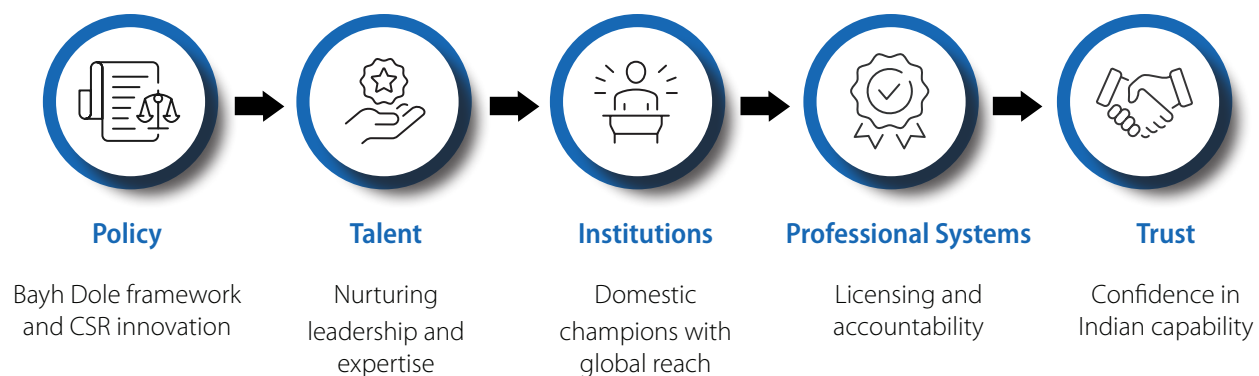


Figure 9.3: The Journey to Design Sovereignty

India can draw an important lesson from this experience. Moving from Make in India to Design in India requires that a significant share of design, engineering and project leadership in strategic sectors is anchored within the domestic ecosystem. International collaboration should continue, but on terms that promote reciprocity, shared authorship and long term capability development.

India already has strong foundations for this transition. Several public sector enterprises have built multidisciplinary capability over decades in energy, transport, water, metallurgy and infrastructure. These institutions carry engineering discipline, institutional memory and public accountability that cannot be created quickly. Alongside them, a capable private design and consulting sector has emerged that is Indian owned, globally experienced and technically mature. With supportive policy, access to research partnerships and professional recognition, these firms can form the backbone of a modern national design ecosystem.

Nation building is not the responsibility of the state alone. It is a shared national endeavour. Public institutions provide continuity and scale. Private enterprises contribute agility, innovation and global awareness. Together, they express self reliance through ownership and competence rather than isolation.

One growing risk to India's technological independence lies in the back office model of global consulting. In this model, Indian talent contributes to international projects while intellectual authorship and design authority remain external. While this approach creates employment, it limits empowerment. Over time, decision making shifts from engineering design to financial structuring, and technology choices begin to reflect external funding priorities over national priorities.

To address this, India must strengthen support for its domestic design ecosystem. Procurement and funding frameworks should place greater emphasis on intellectual authorship, lifecycle responsibility and retention of design knowledge. Strategic sectors should be encouraged to source the majority of design and engineering work from Indian registered firms with domestic ownership.

International firms should be welcomed as collaborators and should operate through Indian institutions in ways that enable genuine transfer of knowledge, standards and capability.

Professional engineering certification and national design institutions are central to this shift. When Indian engineers certify complex infrastructure, the sovereignty of that technology becomes professional, institutional and intellectual. These frameworks must be closely linked with universities and research centres, ensuring that learning flows from research into applied design and then into execution.

Domestic firms should have direct access to public programmes, research linked grants and national missions without dependence on foreign intermediaries. Experience across countries shows that sustained support for domestic engineering capability is often the most effective industrial strategy.

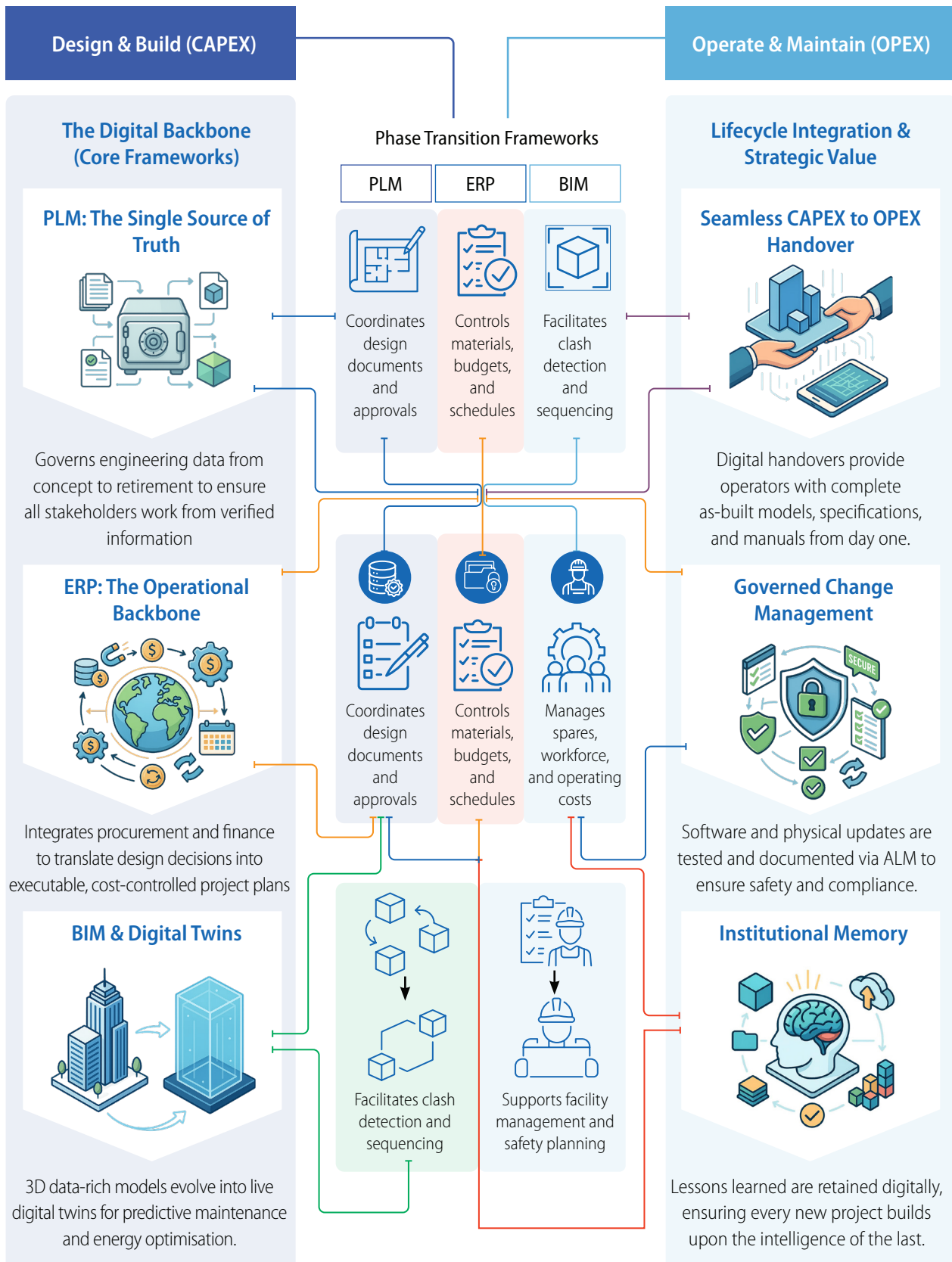
True global cooperation is built on equality. India should engage the world from a position of design strength, welcoming partnerships based on shared authorship and mutual contribution. This requires a shift from outsourcing to co creation, and from delivery support to design leadership.

In this vision, domestic champions act as custodians of national design knowledge. Every project they lead strengthens collective capability. Every design they author adds to institutional confidence. A sovereign India must first support its own capacity. It must support its engineers to innovate, its institutions to guide and regulate, and its enterprises to compete with integrity.

The journey from designed elsewhere and made in India to designed in India and built for the world will be shaped by policy, procurement and institutional support. When India places greater confidence in its own technical design capability than in external financial assurance, it will recognise that the blueprint for self reliance was never imported. It has always been present, ready to be realised through Indian design and leadership.

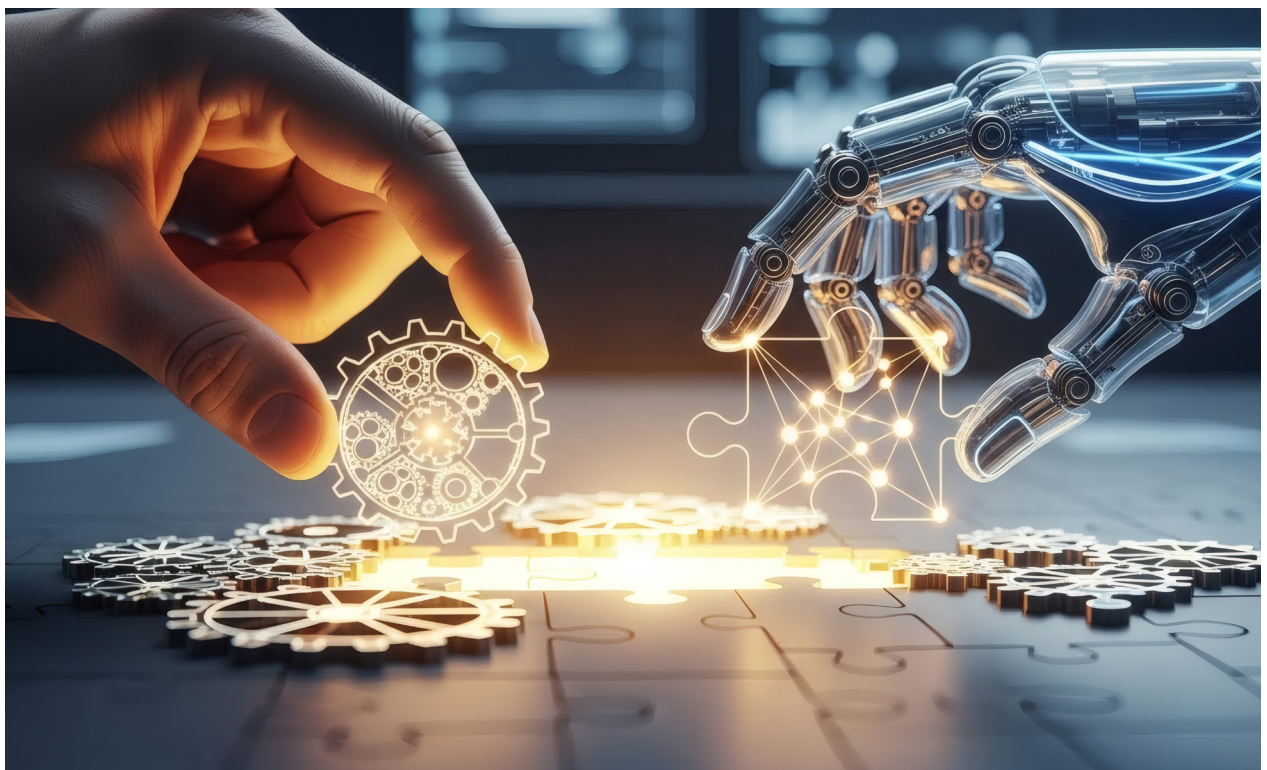
Building the Unified Digital Ecosystem: Bridging Design and Operations

Modern enterprises use a “Digital Thread” to link capital expenditure (CAPEX) with operational performance (OPEX). By integrating frameworks like PLM and ERP, organisations ensure that design intelligence is preserved, creating a “single source of truth” that reduces rework and maximises long-term asset value.



Chapter 10: Engineering Sovereignty in the Age of Artificial Intelligence

India enters the age of artificial intelligence with significant strengths. It has one of the world's largest engineering talent pools, a diverse industrial base, respected academic and research institutions, expanding digital infrastructure and experience in developing technology platforms at population scale. These foundations provide India with an opportunity to use AI not only to improve productivity, but also to strengthen its capacity to design, build and manage the systems that will support its development through 2047.



The preceding chapters have examined India's journey from dependency towards design sovereignty and the institutional, research, industrial and policy capabilities required to sustain it. Artificial intelligence can accelerate this journey by connecting scientific knowledge with engineering practice, making accumulated experience more accessible, improving the quality and speed of decisions, and supporting innovation across the lifecycle of physical assets. Its value will be greatest when digital intelligence is combined with domain knowledge, field experience and a clear understanding of Indian priorities.

India's achievements in digital public infrastructure demonstrate what can be accomplished when public purpose, policy direction, institutional coordination, open standards and private innovation work together. Aadhaar, the Unified Payments Interface and CoWIN were developed around the scale and diversity of Indian requirements while creating common foundations on which multiple participants could build. They offer a valuable precedent for the next stage of national capability: ***applying a similar approach to engineering, manufacturing, energy, healthcare, mobility and infrastructure.***

This next stage will require more than access to computing capacity or advanced AI models. It will require trusted engineering datasets, interoperable knowledge systems, stronger domestic engineering software, research connected to national missions and clear frameworks for professional accountability. It will also require meaningful opportunities for young engineers to combine technical depth with digital capability. By bringing these elements together, India can develop technologies that respond to its own conditions, strengthen Atmanirbhar Bharat and offer affordable, resilient and scalable solutions to the world.

Artificial intelligence should therefore be viewed as an enabler of engineering sovereignty rather than as a separate technological objective. The opportunity before India is to translate its scale, diversity, engineering knowledge and digital experience into a new generation of indigenous capability. By 2047, India can progress from being a major adopter and implementer of technology to becoming an influential designer of engineering systems, platforms and standards for the world.

10.1 Indian Conditions as an Engineering Specification

India's scale and diversity provide a distinctive environment for engineering innovation. Its varied climate zones, population density, languages, economic conditions, infrastructure systems and patterns of technology use create requirements that few other countries encounter within a single national market. Technologies developed successfully across these conditions are likely to be resilient, adaptable and affordable. India can therefore convert the complexity of its operating environment into a strategic design advantage.

For India 2047, Indian conditions should be treated as formal engineering inputs rather than as adjustments introduced after a product or platform has been developed. Design specifications should account for heat, humidity, dust, monsoon exposure, intensive utilisation, variations in power quality, differing levels of field capability, maintenance constraints and long asset lives. They should also recognise that conditions vary considerably across regions, institutions and user groups. Designing for this range will help produce systems that perform reliably beyond ideal or average operating environments.

Artificial intelligence makes this approach particularly important. The reliability of an AI system is influenced by the data on which it is trained, the assumptions embedded in its design and the conditions under which it is validated. Indian datasets, combined with engineering knowledge and field experience, can enable models to recognise local patterns more accurately and produce recommendations that are technically appropriate, economically viable and operationally practical.

Healthcare illustrates the opportunity. India's health requirements reflect regional disease patterns, tropical and vector-borne illnesses, air and water quality, nutrition, heat exposure, demographic diversity and varying access to care. Ethically governed Indian datasets can support diagnostic and predictive systems that account for district-level epidemiology, local-language reporting, comorbidity patterns, referral systems and public-health delivery. Such capability can improve access and outcomes within India while contributing affordable healthcare solutions for countries facing similar conditions.

The same principle applies across the economy. Mobility systems can be designed around mixed traffic, varied road conditions and different patterns of use. Energy solutions can reflect regional demand, renewable-energy variability and the requirements of a large and evolving grid. Agricultural technologies can account for local crops, soil conditions, water availability and farm sizes. Infrastructure and industrial systems can incorporate Indian materials, codes, construction practices, vendor ecosystems and maintenance environments. In each case, the combination of local data, domain expertise and operational feedback can create solutions that are more relevant and dependable.

Establishing Indian conditions as engineering specifications will require representative datasets, common testing environments, transparent performance measures and greater participation by Indian engineers, institutions and industry bodies in developing standards. Technologies should be evaluated across the range of conditions in which they will operate, with results feeding back into design and continuous improvement. This will strengthen confidence in AI-enabled systems and help accelerate their responsible adoption.

This approach does not suggest technological isolation. India should continue to draw on global science, international standards and collaborative research. The objective is to combine global knowledge with domestic insight and retain the capability to understand, adapt and validate technologies independently. Solutions proven across India's diversity and scale can become valuable offerings for the Global South and other markets seeking resilient, inclusive and cost-effective systems. Indian conditions can thus become not only a national design specification, but also a foundation for global engineering leadership.

Indian conditions as a design advantage

Turning national diversity into resilient, affordable and globally relevant engineering solutions

Indian Operating Context

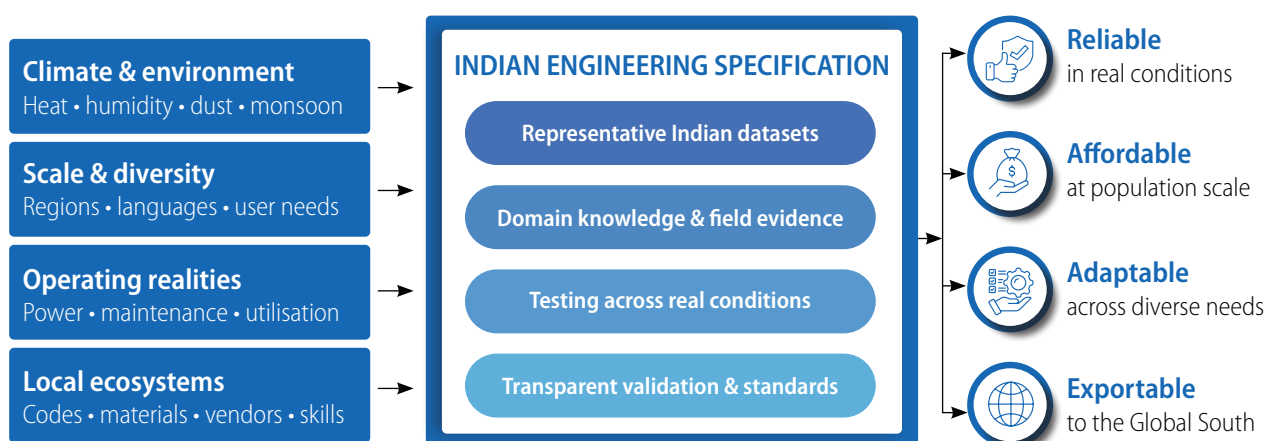


Figure 10.1: Indian conditions as a design advantage

10.2 From Digital Public Infrastructure to Engineering Infrastructure

India's digital public infrastructure offers an important model for building national capability. The Unified Payments Interface succeeded because it combined a clearly defined public purpose with common standards, institutional coordination and space for continuing private innovation. It was designed around Indian requirements, including low-value transactions, mobile-first behaviour, small merchants, bank interoperability, instant settlement and the need to operate at population scale. Its significance extends beyond payments: it demonstrates India's ability to create trusted foundational systems on which a wider ecosystem can develop.

A similar approach can support the next phase of India's engineering development. The country possesses substantial knowledge across infrastructure, manufacturing, energy, mining, mobility, healthcare and the process industries.

Much of this knowledge, however, remains distributed across organisations, projects, technical documents, legacy systems and individual experience. Design assumptions are contained in drawings and specifications; operational knowledge resides in maintenance records and asset histories; execution lessons are captured in site reports, quality records, vendor correspondence and commissioning documentation. When these sources remain isolated or unstructured, each organisation must repeatedly solve problems for which relevant experience may already exist elsewhere.

India can address this through a trusted engineering knowledge infrastructure. This would not require unrestricted sharing of proprietary or confidential information. It would establish common methods for describing, contributing, validating and accessing engineering knowledge under defined permissions.

Organisations could retain control over sensitive information while contributing anonymised data, benchmark results, standardised failure patterns, safety observations, asset-performance trends and other knowledge of wider national value.

Interoperability will be central to such an infrastructure. At the data level, information should carry clear descriptions of its source, quality, units, location, time period, access rights and applicable operating conditions. At the knowledge level, systems should distinguish among a statutory requirement, a design assumption, an established practice, a vendor limitation, a field exception and professional judgement. At the performance level, AI-enabled engineering tools should be evaluated not only for speed, but also for accuracy, explainability, safety, constructability, maintainability, cost, environmental impact and lifecycle reliability.

Common standards would allow different organisations to develop their own tools while remaining connected to a larger ecosystem. Engineering firms could build domain-specific applications; academic institutions could develop and test new models; asset owners could compare lifecycle performance; startups could address specialised problems; and regulators and professional bodies could define the evidence required for responsible adoption. Shared taxonomies and benchmarks would reduce duplication without requiring every participant to use the same technology platform.

Policy can accelerate this development by creating a clear and consistent direction. India's experience with electric mobility illustrates the importance of combining market incentives with domestic component capability, testing infrastructure, charging standards, grid readiness, quality assurance, consumer confidence and long-term service ecosystems. Programmes such as FAME and PM E-DRIVE have helped establish the direction and stimulate demand. Their evolution also shows that technology transitions become stronger when policy incorporates operational learning and connects adoption targets with manufacturing, standards, infrastructure and skills.

The same principle applies to AI-enabled engineering. Computing capacity and foundational models are important, but national capability will emerge when they are connected with trusted datasets, domain institutions, industrial problem statements, research funding, procurement pathways, standards, intellectual-property frameworks and professional accountability. Policy should encourage experimentation while creating the confidence required for long-term investment and adoption.

India's engineering infrastructure need not reproduce UPI literally. Engineering data is more varied, sector-specific and commercially sensitive than payment information. The transferable principle is the creation of trusted common foundations that enable participation, interoperability and innovation. By applying this principle to engineering knowledge, India can convert experience accumulated across thousands of projects and assets into a shared national capability, while preserving confidentiality, competition and institutional ownership.

10.3 Building Sovereign Engineering Data and Software

India's strength in information technology has established a global reputation for software development, digital services and complex systems delivery. Artificial intelligence now creates an opportunity to connect this digital capability more deeply with core engineering. The next generation of engineering software will extend beyond drawing production, calculations and document management. It will support design reasoning, option evaluation, code compliance, quality assurance, constructability, procurement, commissioning, asset optimisation and the systematic reuse of lessons learned.

This convergence can bring together capabilities that have often developed separately. India has civil, mechanical, electrical, chemical, mining, metallurgical, power and instrumentation engineers, alongside software architects, data scientists and AI specialists.

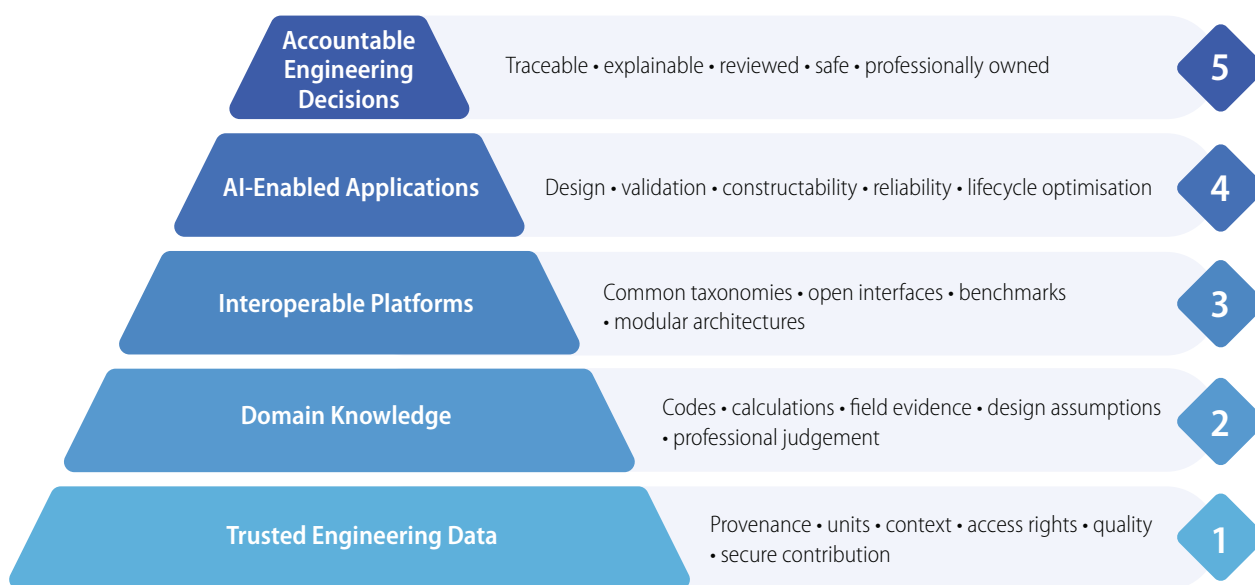
When these disciplines work together, they can develop domain-specific platforms and tools for process design, power-system studies, structural review, equipment sizing, plant layout, pipeline routing, cost estimation, safety analysis, regulatory compliance and technical due diligence.

Engineering data will provide the foundation for this development. Unlike general text or consumer data, engineering information is highly contextual. A measurement has meaning only when its units, location, time, equipment condition and operating environment are known. A design recommendation must be connected to the applicable code, calculation, assumption and professional review. A failure record is useful only when the equipment history, maintenance regime and duty cycle are understood. Creating reliable engineering AI will therefore require well-structured datasets supported by clear provenance, consistent taxonomies and domain validation. India already possesses large volumes of such knowledge across engineering firms, industrial organisations, public-sector undertakings, utilities, infrastructure agencies, research institutions and government departments. The opportunity is to make this knowledge more usable without weakening confidentiality, security or commercial ownership.

Federated systems can allow data to remain with its owner while approved models or users access defined information under controlled conditions. Anonymisation, access tiers, purpose limitation, licensing, audit trails and secure computing environments can further enable responsible collaboration.

Sovereignty in this context does not require every application to be developed entirely within India or every global platform to be replaced. It requires India to retain the capability to understand and validate the tools on which critical decisions depend. Indian organisations should be able to assess model assumptions, examine data lineage, modify systems for domestic requirements, integrate them with local platforms and maintain continuity when technology or commercial arrangements change. Open interfaces, modular architectures and interoperability standards can reduce dependence on any single supplier while allowing India to benefit from global advances. The development of Indian engineering software can begin with focused domain applications rather than attempting to reproduce every established global platform.

The engineering sovereignty stack



OUTCOME India can understand, validate, adapt and own the technologies supporting critical systems.

Figure 10.2: The engineering sovereignty stack

AI-assisted code checking, design validation, document intelligence, equipment selection, safety review, construction planning, predictive reliability and asset-performance analysis are areas in which Indian knowledge can create immediate value. Each successful application can contribute reusable components, datasets and validation methods to a broader engineering-software ecosystem. Indian codes, materials, climate conditions, project-delivery practices and vendor networks can provide important differentiation. Tools developed around these requirements can improve the quality and speed of domestic engineering while lowering the barriers faced by smaller organisations and public agencies.

Over time, validated applications can develop into domain platforms that serve sectors across the asset lifecycle, from concept and design to construction, commissioning, operation and renewal. This capability also has international potential. Many countries across Asia, Africa, the Middle East and Latin America require engineering solutions that combine technical reliability with affordability, adaptability and limited dependence on specialised infrastructure. Software and AI systems proven under Indian conditions can respond effectively to these needs. By connecting its digital strength with physical-world engineering, India can progress from being a major user and service provider for global engineering platforms to becoming a designer and owner of domain technologies for the world.

10.4 AI as a Catalyst for Core Engineering Capability

Atmanirbhar Bharat has created a strong national focus on domestic manufacturing and supply-chain resilience. The next stage is to deepen capability beyond final assembly and extend it across the full engineering value chain. This includes materials, components, process know-how, design intellectual property, manufacturing equipment, testing systems, embedded software and lifecycle support. Artificial intelligence can accelerate this transition by helping Indian organisations develop, validate and improve technologies more efficiently.

India does not need to manufacture every product or component entirely within its borders. Strategic capability lies in understanding the design, identifying critical dependencies, retaining credible sourcing alternatives and possessing the capacity to manufacture, test, maintain or substitute technologies that are essential to national development. The priority should be areas where India has significant domestic demand, strategic importance and a realistic pathway to build globally competitive capability.

AI can support this process at several stages. It can analyse patents and technical literature, identify potential materials and suppliers, generate and evaluate design alternatives, simulate manufacturing processes, predict quality variations and accelerate testing. It can also help organisations interpret operating data, understand failure patterns and improve products after deployment. These applications can reduce development cycles, but their greatest value will arise when they are combined with laboratory research, engineering judgement, manufacturing experience and field validation.

This framework should not be treated as an exhaustive import list. Its purpose is to identify where deeper engineering capability can strengthen productivity, energy security, health security, digital resilience and industrial competitiveness. Priorities should be selected through transparent criteria that consider strategic importance, import concentration, domestic market potential, technology readiness, available research capability and the time required to establish credible alternatives.

Mission-led collaboration can help convert these opportunities into measurable outcomes. For each selected technology, industry, academia and government can jointly map the design gap, materials gap, manufacturing gap, testing gap, software gap and commercial pathway. Shared facilities can support prototyping and validation, while procurement programmes can provide early demand for technologies that meet defined performance and quality standards.

Intellectual-property arrangements should reward inventors and institutions while enabling Indian industry to commercialise successful research.

Capability area	Opportunities for deeper Indian capability	Role of AI-enabled engineering
Electronics and embedded systems	Semiconductors, sensors, printed circuit boards, power electronics, controllers, communication modules and industrial electronics	Design libraries, component selection, failure analysis, supplier qualification and automated testing
Energy-transition technologies	Battery cells and management systems, electrolyzers, fuel-cell components, inverters, high-efficiency drives, rare-earth magnets and grid-control equipment	Materials discovery, degradation analysis, safety modelling, performance optimisation and lifecycle-cost assessment
Critical minerals and advanced materials	Lithium, cobalt, nickel, graphite, rare-earth elements, speciality alloys, catalysts, membranes and high-purity chemicals	Exploration analytics, materials informatics, substitution research, recycling optimisation and strategic inventory planning
Healthcare and medical technology	Diagnostic sensors, imaging systems, medical electronics, implant materials, laboratory automation and clinical platforms	India-relevant diagnostics, low-cost device design, clinical workflow support and equipment-reliability analysis
Industrial equipment and process systems	Compressors, control valves, analysers, advanced instrumentation, rotating equipment, safety systems and process-simulation platforms	Equipment design, process optimisation, predictive reliability, performance benchmarking and design assurance
Construction and infrastructure technologies	Construction equipment, signalling systems, monitoring sensors, digital project controls, asset-inspection tools and geospatial platforms	Constructability analysis, productivity improvement, safety prediction, material optimisation and lifecycle digital twins
Engineering software and domain platforms	Design and analysis tools, plant-design systems, document intelligence, reliability platforms and project-control applications	Domain copilots, automated validation, knowledge reuse, option assessment and compliance support

Table 10.1

This approach would also strengthen smaller manufacturers and startups. Many possess specialised process knowledge or innovative designs but lack access to advanced simulation, test infrastructure, field data or early customers. Common engineering platforms, shared testing facilities and mission-linked datasets can reduce these barriers. Larger firms and public institutions can provide problem statements, validation environments and market access, creating a broader industrial ecosystem rather than a small number of isolated projects.

AI should therefore be viewed as an accelerator of engineering depth, not a substitute for it. Models can generate options and identify patterns, but physical technologies must still be designed, manufactured, tested and proven under real operating conditions. By combining artificial intelligence with materials science, manufacturing capability, domain expertise and long-term industrial policy, India can move progressively from technology adoption to design ownership and from supply-chain participation to leadership in selected areas.

10.5 Creating an Accountable Innovation Ecosystem

The development of AI-enabled engineering capability will depend on the strength of the ecosystem surrounding it. Advanced models and computing infrastructure are important, but they cannot independently convert research into safe and widely adopted engineering solutions. Progress will require sustained collaboration among academic institutions, industry, government, startups, public asset owners, regulators and professional bodies. Each participant contributes a different capability, from scientific research and operational data to validation environments, standards, procurement and commercial scale.

India has a strong base on which to build. Its academic institutions and national laboratories conduct research across artificial intelligence, materials, energy, healthcare, mobility and advanced manufacturing. Work at institutions such as IIT Bombay, together with initiatives such as BharatGen, demonstrates the value of connecting advanced research with Indian languages, documents, operating environments and user contexts. A similar mission-oriented approach can connect AI research with engineering challenges in infrastructure, industrial systems, climate resilience, public health and the energy transition.

Centres of Excellence can provide the institutional bridge between research and application. Their role should extend beyond conferences, training programmes or the publication of research papers. They can identify national problem statements, assemble curated datasets, bring domain experts and researchers together, develop benchmark challenges, create prototypes and validate them in operational environments. They can also support startups, contribute to standards and work with regulators and professional institutions to establish pathways for responsible adoption.

The performance of such centres should be measured through outcomes as well as academic outputs. Relevant measures could include technologies validated, tools adopted, standards developed, components localised, patents licensed, datasets created, industrial problems solved and engineers trained.

This outcome orientation can strengthen the connection between research funding, national priorities and industrial capability while continuing to protect academic freedom and long-term scientific inquiry.

Corporate participation can contribute more than funding. Organisations operating in water, energy, infrastructure, healthcare, mining, agriculture, logistics and manufacturing possess technical knowledge that can help researchers understand real operating conditions. Properly governed contributions could include anonymised equipment-performance data, failure patterns, energy-use profiles, safety observations, maintenance histories, construction-productivity data and environmental measurements. Domain specialists can also help define problems, annotate information, review model outputs and provide access to controlled validation environments.

Corporate social responsibility can support selected initiatives of public value, building on the research partnerships discussed earlier in this white paper. However, such participation must operate within clear legal and governance frameworks. Data should be shared only with appropriate consent, anonymisation, licensing, access controls, audit trails and purpose limitations. Confidential project information, personal data and commercially sensitive knowledge must remain protected. Intellectual-property arrangements should be defined at the outset so that researchers, funding organisations and implementation partners understand how successful outcomes may be used and commercialised.

Clear partnership frameworks can enable credible institutions to collaborate with confidence. Standard agreements for data sharing, intellectual property, conflict of interest, procurement and independent review can reduce uncertainty while preserving accountability. Transparent governance will be particularly important when public institutions, private firms and academic organisations jointly develop technologies that may later be deployed in critical sectors. Professional accountability must remain central to AI-enabled engineering. Engineering decisions influence safety, reliability, cost, environmental performance and public trust.

AI can support the engineer by analysing information, generating alternatives and identifying patterns, but responsibility for critical decisions must remain clearly assigned. Engineers should be able to understand the assumptions behind an output, verify the applicable codes and data, examine its limitations and record the basis on which a final decision was taken. AI-assisted engineering systems should therefore incorporate traceability, version control, confidence indicators, assumption registers and defined review stages. Safety-critical applications should have appropriate human approval and independent verification. These requirements need not slow innovation. By making responsibilities and evidence clearer, they can increase confidence among engineers, asset owners, regulators and the public, enabling successful applications to move from experimentation to wider adoption.

The ecosystem must also create visible opportunities for young engineers. AI can make core engineering more creative, interdisciplinary and influential by combining physical-world knowledge with computation, modelling and data analysis. Emerging roles may include design-automation specialists, digital-twin architects, reliability data scientists, engineering knowledge managers, climate-resilience modellers, AI safety reviewers and industrial-software product owners. Academic curricula, professional certification and corporate career pathways should reflect this convergence. India's engineering talent will be most valuable when digital fluency is built on strong technical fundamentals and field understanding.

Competitive careers, recognition for domain depth and opportunities to work on consequential national challenges can attract young people towards core engineering. An accountable innovation ecosystem must therefore connect research, responsible data use, professional standards and human capability. Together, these elements can ensure that AI strengthens both the quality of Indian engineering and the institutions that sustain it.

10.6 Priorities for National Action

India can translate the opportunity of AI-enabled engineering into national capability through a focused set of initiatives that build on existing institutions rather than create parallel structures. The objective should be to connect engineering knowledge, research, industrial demand, professional expertise and public policy through mechanisms that produce measurable outcomes. Three priorities can provide an initial framework for action.

India Engineering Knowledge Grid

The first priority is the creation of an India Engineering Knowledge Grid: a federated and permissioned framework connecting engineering organisations, public asset owners, academic institutions, national laboratories, professional bodies and startups. Its purpose would be to make selected engineering knowledge more discoverable and usable while allowing contributors to retain control over confidential and proprietary information.



Figure 10.3: Three priorities for national action

The Grid could establish common taxonomies and governed mechanisms for contributing anonymised design cases, standard clauses, failure modes, equipment-performance patterns, safety observations, commissioning issues, constructability lessons, cost drivers and lifecycle records. Information would remain subject to defined access rights, licensing terms, quality checks and purpose limitations. Sensitive project data would not be placed in an unrestricted central repository.

Common standards would allow different participants to develop and test applications against trusted benchmarks. An academic team could examine the prediction of construction delays, a startup could validate an equipment-selection tool, an asset owner could compare lifecycle performance and an engineering firm could develop design-assurance applications. The value of the Grid would arise from shared definitions, curated evidence and trusted access rather than from prescribing a single technology platform. The initiative could begin with a limited number of sectors and clearly defined problem statements. Early pilots should demonstrate that knowledge can be shared responsibly and converted into measurable improvements in safety, productivity, reliability or cost. Independent oversight, cybersecurity, contributor rights and transparent governance would be essential to establishing confidence before the framework is expanded.

AI-Catalysed Capability in Critical Engineering

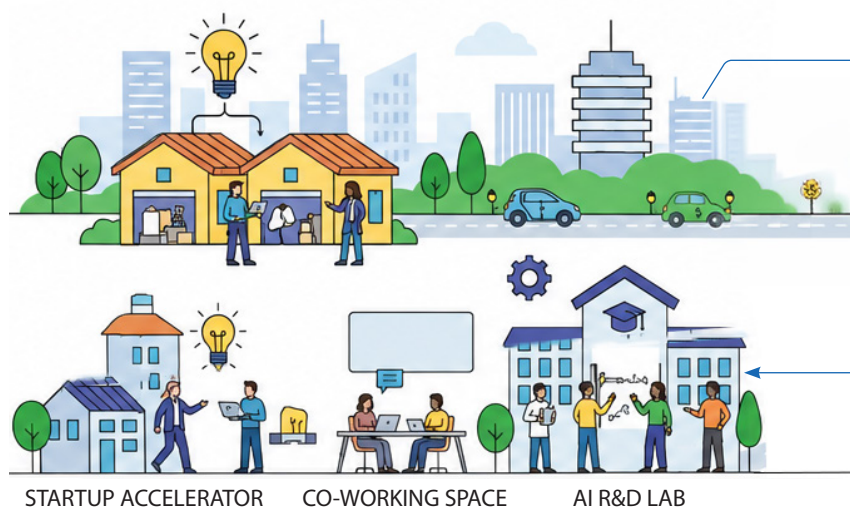
The second priority is a mission-led programme focused on selected critical engineering technologies. The programme would identify components, materials, equipment and software platforms where deeper domestic capability would make a material contribution to national resilience and industrial competitiveness. Selection should be based on strategic importance, import concentration, domestic demand, available research strength, industrial readiness and the feasibility of achieving competitive performance. For each selected technology, a consortium of industry, academia, government and specialist manufacturers could assess the design, materials, manufacturing, testing, software and commercial gaps. The resulting roadmap would specify the research required, validation facilities, applicable standards, intellectual-property arrangements, procurement pathways and milestones for deployment.

This would help ensure that localisation reflects genuine engineering depth rather than only domestic assembly.

Artificial intelligence could accelerate materials discovery, design optimisation, process simulation, supplier identification, quality prediction, failure analysis and testing. However, every technology would still require physical prototyping, certification and performance validation under relevant operating conditions. Progress should therefore be measured through demonstrated capability, such as validated designs, qualified suppliers, licensed intellectual property, tested products and successful field deployment. The programme should focus initially on a manageable portfolio of high-impact opportunities. These could include power electronics, battery systems, electrolyzers, industrial sensors, selected process equipment, medical devices, infrastructure-monitoring technologies and specialised engineering software. Concentrating resources on achievable priorities would create stronger reference cases and develop capabilities that could subsequently be applied to adjacent technologies.

National Pathways for AI-Enabled Engineering Talent

The third priority is to establish clear education and career pathways for engineers working across physical systems and digital intelligence. Universities and technical institutes can combine engineering fundamentals with computation, data analysis, systems modelling, AI ethics, product thinking and field exposure.



Interdisciplinary programmes should continue to preserve the depth required in individual engineering disciplines, because reliable AI applications depend on a strong understanding of the systems they represent.

Industry can support these pathways through problem-based learning, internships, joint laboratories, visiting faculty, professional mentoring and access to appropriate datasets and validation environments. Professional bodies can develop continuing-education programmes and certifications covering AI-assisted engineering, model assurance, data governance and professional accountability. Organisations should also create progression and recognition for engineers who combine domain expertise with digital capability. These pathways would help young engineers see core engineering as a field of innovation and national consequence. They would also strengthen India's ability to retain specialised knowledge, build engineering products and develop the professional leadership required to deploy AI responsibly across critical sectors.

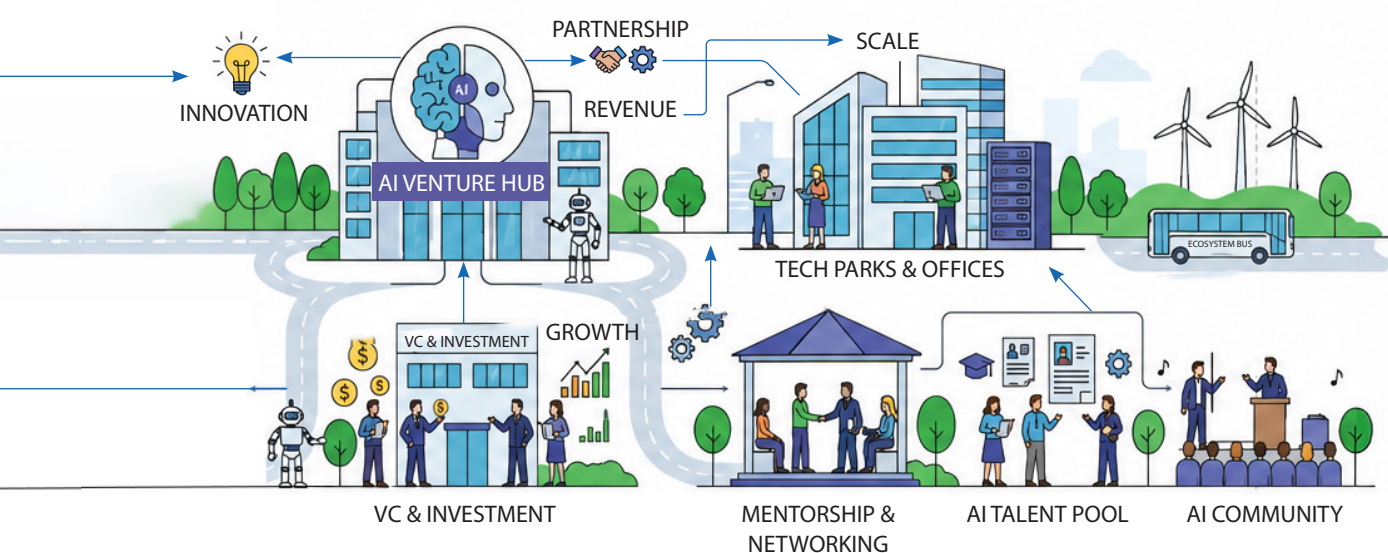
From National Capability to Global Contribution

Together, these priorities provide a practical progression from knowledge to capability. The Engineering Knowledge Grid would create trusted foundations for learning and innovation. The mission-led programme would apply that knowledge to strategic technologies. Education and career pathways would develop the people required to sustain both.

Existing research institutions, industrial organisations and public programmes can provide the base, while clear governance and outcome-based measurement can maintain accountability.

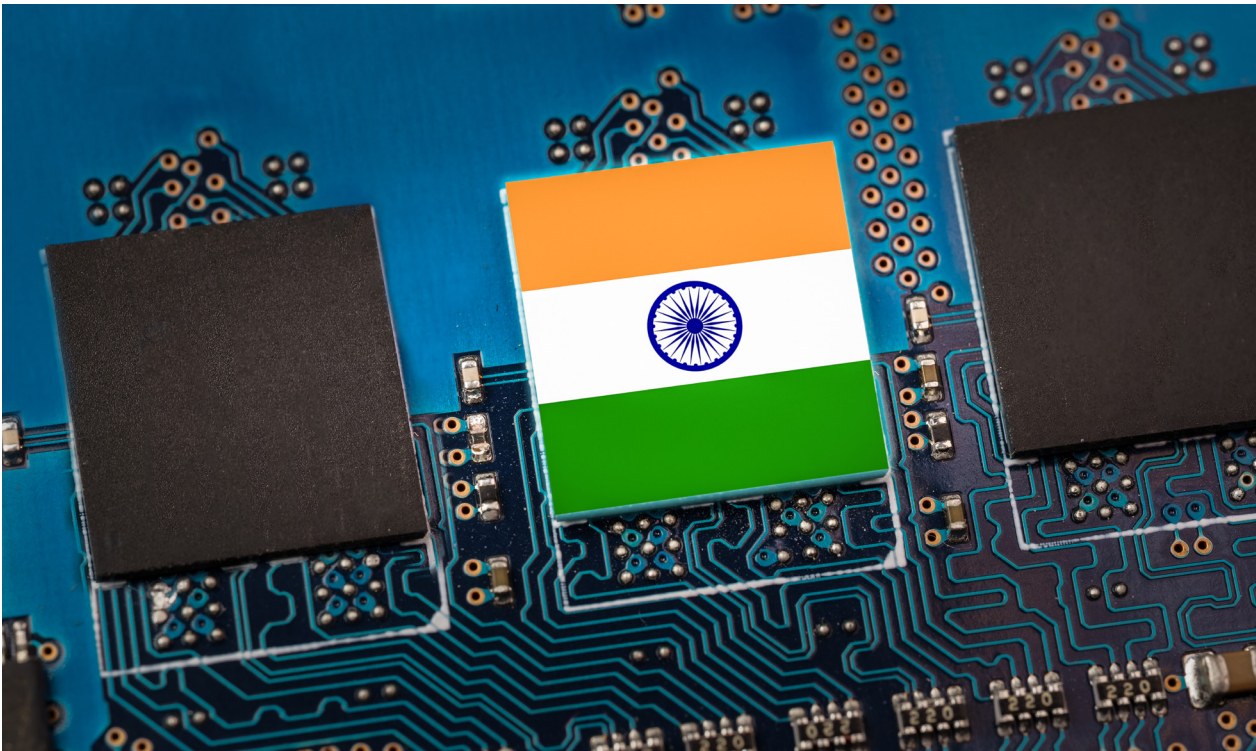
Artificial intelligence gives India an opportunity to convert its diversity, engineering experience and digital capability into a source of national strength. The success of India's digital public infrastructure has shown that population-scale innovation is possible when standards, institutions and enterprise are aligned. Applying these lessons to core engineering can enable India to design systems suited to its conditions, deepen capability across critical value chains and create technologies relevant to the wider world.

By 2047, engineering sovereignty should be reflected not only in the products India manufactures, but also in the standards it helps shape, the software and intellectual property it owns, the institutions it strengthens and the solutions it contributes internationally. AI can accelerate this transition, but the foundations will remain human expertise, scientific inquiry, professional responsibility and the confidence to design for India.



Chapter 11: The Roadmap to 2047

The year 2047 will mark one hundred years of India's independence. This milestone is more than a moment of national celebration. It is an opportunity to define how India chooses to shape its future in a world driven by technology, knowledge and deep global interdependence. In this era, a nation's strength is measured not only by economic scale or physical infrastructure, but by its ability to generate ideas, develop original designs, shape technologies and influence global standards.



Political freedom gave India its identity. The century ahead must give India its authorship. In the 21st century, sovereignty is expressed through the capacity to set one's own direction, to build systems that translate vision into action, and to contribute knowledge to the world with confidence. Progress can no longer be assessed only through roads, factories or production volumes, but through ownership of intellectual capital that guides long term development.

India approaches this moment with strong foundations. Over the decades, the country has demonstrated its capability to build institutions, invest in science and deliver large scale outcomes.

The Green Revolution strengthened food security and rural resilience. The Indian space programme established global credibility through precision, reliability and cost effectiveness. Digital public infrastructure has transformed access to services, while indigenous nuclear capability has reinforced national self reliance in a highly complex strategic domain.

Alongside these achievements are innovations rooted in inclusion and human need. The Jaipur Foot and the Aravind Eye Care model show how Indian solutions, designed for scale and affordability, can influence global practice.

These examples demonstrate that excellence and inclusion can advance together, and that India can lead in creating solutions that are both technically sound and socially impactful. They build confidence that the nation can move from adoption to leadership in research, design and innovation.

The journey to 2047, however, requires more than isolated successes. It calls for a coherent and long term plan that strengthens domestic capability while remaining connected to global knowledge networks. It demands resilient institutions, sustained investment in people and research, and the ability to respond to technological, economic and geopolitical change. Above all, it requires continuity of intent across decades, beyond individual policies or programmes.

This chapter presents that roadmap. It is structured around a clear progression. First, it defines guiding principles that anchor long term capability building and provide consistency in decision making. Second, it outlines phased timelines that move systematically from capacity creation, to capability consolidation, and finally to global leadership. Each phase builds on the previous one, allowing scale, learning and confidence to deepen over time. Third, it identifies cross cutting pathways that run through all phases, ensuring resilience, adaptability and sustained momentum.

Intellectual independence is built through patient investment, steady institution building and a shared national vision. This roadmap recognises transformation as a cumulative process. By aligning principles, phased action and enduring pathways, it lays the foundation for India's intellectual independence by 2047. It envisions an India that meets its own needs with confidence, contributes ideas and solutions to the world, and engages globally from a position of strength grounded in knowledge, capability and self belief.

11.1 Guiding Principles for a Long Journey

India's journey towards design sovereignty and intellectual strength must rest on a small set of clear and enduring principles. These principles serve as practical filters against which policies, investments and institutional reforms can be evaluated over the long term.

Any initiative that weakens these foundations should be reconsidered, regardless of short term gains.

1. Sovereignty in ideas and infrastructure:

In the 21st century, sovereignty extends beyond territorial control. It is expressed through the ability to design systems, govern digital space, protect data, build institutions and ensure continuity of essential services under all conditions. Sovereignty demands confident openness, where India collaborates internationally while retaining command over the critical layers of design, data and delivery.

When design capability is domestic, the nation decides how systems behave. When data is governed under Indian law, citizens' rights are protected by Indian institutions. When delivery capacity is local, India can act decisively without dependence on external actors.

India's experience in strategic sectors illustrates this clearly. Indigenous pressurised heavy water reactors, the development of new small reactor designs and advances in nuclear fuel cycles show how long term capability can be built patiently while still engaging globally on safety, research and materials science. Similarly, the Indian space programme demonstrates how domestic design ownership combined with operational excellence creates both strategic autonomy and global credibility.

To strengthen accountability and elevate professional standards, India should establish a Chartered Engineer Certification Framework under statutory regulation. Countries such as the United States, the United Kingdom, Canada and Australia require licensed engineers to take personal responsibility for critical designs that affect public safety. A similar framework in India would improve design rigour, strengthen public trust, enable globally recognised credentials for Indian engineers and support the growth of domestic design and consulting firms.

2. **Inclusion** means that India's intellectual independence must be broad based. Innovation should extend beyond metropolitan clusters and elite institutions. It should reach state universities, regional colleges, start ups and small and medium enterprises, so that all can participate equally in the national knowledge ecosystem.

Inclusion strengthens resilience because it multiplies the number of problem solvers and diversifies perspectives. India's own experience confirms this. The Jaipur Foot emerged from a regional need and became one of the most widely used prosthetics in the world. The Aravind Eye Care System, developed in a tier two city, became a global model for accessible healthcare. Rural innovation networks have produced practical solutions in agriculture, clean energy and water management. These examples show that inclusion is the most effective pathway to sustained national creativity.

3. **Resilience:** Sovereignty requires the ability to absorb shocks and recover quickly. Technological and economic resilience must therefore be treated as core national capabilities. This includes redundant digital infrastructure, trusted supply chains, domestic repair and maintenance capacity, and secure legal and regulatory systems.

Energy resilience plays a critical role in this context. Nuclear power provides clean, stable base load electricity that is insulated from fuel price volatility and geopolitical disruption. India's indigenous reactor designs and long standing nuclear programme strengthen energy sovereignty and ensure that critical infrastructure can continue operating during global stress. Resilience also depends on system architecture. India's experience with large scale digital platforms such as Aadhaar and the Unified Payments Interface shows that resilient, modular and interoperable systems can support scale, maintain continuity during crises and expand economic participation.

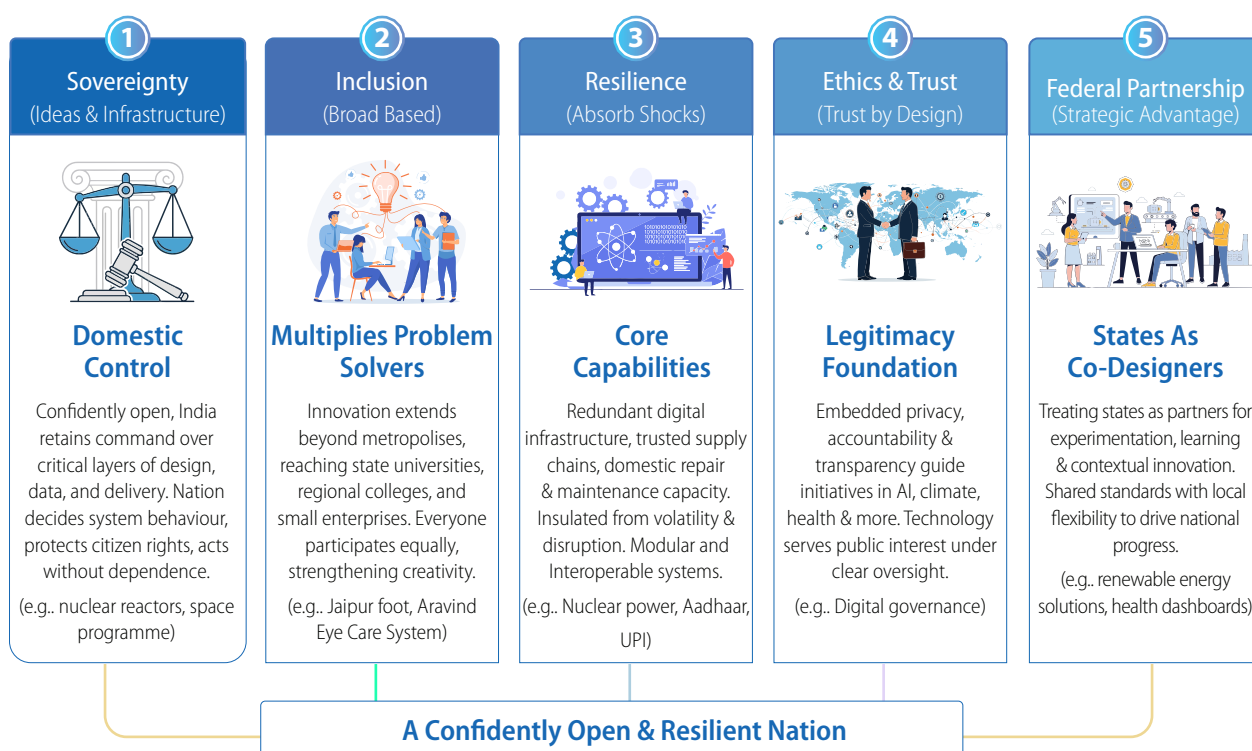
4. **Ethics and trust:** Trust is the foundation on which modern digital and scientific systems operate. India's digital public infrastructure gained wide acceptance because privacy, accountability and transparency were embedded into system design from the outset. Trust by design must guide future initiatives in artificial intelligence, biotechnology, defence research, climate systems and health technologies.

Ethics and trust determine legitimacy. Citizens must be confident that technology serves public interest and operates under clear regulatory oversight. Without trust, even technically sound systems fail to scale. India's experience in digital governance has demonstrated that secure, inclusive and privacy respecting systems can strengthen democratic participation while enabling innovation.

5. **Federal partnership:** India's federal structure is a strategic advantage. The diversity of its states enables experimentation, rapid learning and contextual innovation. States must be treated as co designers in the national journey towards design sovereignty, not merely as implementing agencies.

Shared standards and interoperable frameworks are essential for scale, but they must coexist with flexibility for local adaptation. The expansion of digital payments, the adoption of renewable energy solutions and the use of real time public health dashboards illustrate how state level innovation drives national progress. Stronger cooperation between the Union and the states will allow successful models to scale quickly while respecting regional diversity.

Guiding Principles For India's Design Sovereignty



Making the principles operational

To translate these principles into action, India should adopt a Bayh Dole style framework for intellectual property generated through publicly funded and CSR supported research. Such a framework would allow universities and enterprises to co own or license intellectual property within Indian jurisdiction, while safeguarding national interest. It would align incentives, strengthen industry academia partnerships and accelerate technology transfer.

In parallel, a national Atmanirbhar Research Fund can pool CSR contributions and philanthropic capital through mechanisms such as the Anusandhan National Research Foundation or the Department of Science and Technology. This fund can support long term, mission driven research in clean energy, affordable health technologies, hydrogen storage, advanced materials and secure digital infrastructure.

India's leading companies collectively contribute significant resources through CSR each year. Even a focused share of this funding, directed through clear intellectual property frameworks and national missions, could substantially strengthen domestic capability.

Such an approach would reduce dependence on foreign technology, create high value employment, enable export ready products and reinforce the goals of Atmanirbhar Bharat and Viksit Bharat.

11.2 Phase One (2025 to 2030): Laying the Foundation

Having defined the guiding principles, the next step is to convert intent into action. Phase One focuses on removing structural barriers that prevent domestic capability from becoming visible national power. The emphasis is on reform, capacity building and institutional credibility. This phase creates the conditions under which Indian design, research and delivery capability can scale with confidence.

- 1. Reforming procurement for capability building:** Public procurement plays a decisive role in shaping industrial and intellectual capacity. In Phase One, procurement systems must shift from rewarding global presence to recognising proven performance in Indian conditions. Delivery across diverse states, ability to manage local complexity and evidence of contextual innovation should be treated as indicators of suitability and scale.

Model tender documents should allocate explicit weight to relevance, frugal innovation and sustainability. In strategic sectors such as energy systems, logistics, defence and digital identity, leadership consortia must include at least one Indian institution with genuine decision making authority. This ensures that learning, system understanding and design ownership remain within the country.

Global expertise remains essential in advanced domains such as high speed transport, semiconductors and new materials. However, international collaboration must be structured around knowledge absorption. Foreign funded projects should include clear provisions for technology transfer, joint design and long term capability development, enabling India to internalise global best practice while strengthening domestic institutions.

2. Funding research and translating outcomes:

India should raise research investment towards 1% of GDP by 2030, with a strong focus on translation into usable systems and products. The Anusandhan National Research Foundation can anchor this effort if it is provided autonomy, predictable multi year budgets and a mission oriented structure.

Sectoral councils in areas such as semiconductors, clean energy, biotechnology, nuclear small reactors, advanced materials and secure computing should bring together universities, public laboratories and private firms around clearly defined national missions. Shared national facilities for chip design, hydrogen storage, bioengineering and materials testing must be affordable and accessible to state universities and small enterprises.

Research grants should reward prototypes in real use, patents licensed to domestic firms and measurable societal outcomes, alongside academic publications. Enhanced research deductions for expenditure incurred in India should be reinstated, with higher incentives for collaborative projects involving IITs, IISc, CSIR laboratories and accredited universities.

Fast track patent processing and super deductions should be offered where industry co funds academic research. Public sector undertakings should be required to maintain a minimum research outlay, with a defined portion earmarked for co funded projects with national laboratories.

In parallel, a share of large company CSR expenditure should be channelled into the Atmanirbhar Research Fund with tax deductibility. This approach will convert obligatory spending into long term capability creation, supporting missions such as green steel, low cost medical devices, hydrogen storage and Indian language artificial intelligence. By the end of this phase, India should demonstrate credible design leadership in at least three strategic sectors.

3. **Professional visibility and technological sovereignty:** Phase One must also elevate professional visibility. India's design and consulting ecosystem should actively publish methods, share learning and participate in open professional forums. Visibility attracts talent, builds credibility and accelerates capability growth. Many Indian successes gained global recognition because their creators shared knowledge openly and responsibly.

Technological sovereignty in this phase extends beyond physical assets to digital systems and intellectual property. Control over data, cyber space and core platforms is essential for meaningful independence. India's digital public infrastructure provides a strong base. The focus now must be on stronger cyber security, domestic data governance, trusted cloud services and partnerships in emerging fields such as artificial intelligence, quantum technologies and digital safety.

4. **Strategic sectors for early leadership:** The following sectors (see [Table 10.1](#)) are critical to India's long term sovereignty and offer strong potential for Indian led execution during Phase One.

Sector	Importance to India's Future	Rationale for Indian Led Execution
Semiconductors	Foundation of the digital economy and key to strategic industries	Builds control over critical technology supply chains and develops a domestic high-technology ecosystem
High Speed Transport	Mobility, connectivity and urban decongestion	Strengthens national design capability and ensures knowledge retention for future corridors
Energy and Refineries	Energy security and value-added exports	Keeps project spending within the domestic economy and enhances indigenous expertise
Nuclear and Clean Energy	Clean power and national strategy	Promotes self-reliance in sensitive technologies and supports long-term energy sustainability
Renewable Energy and Pumped Storage	Green transition and grid stability	Strengthens engineering capacity in next-generation energy systems and supports India's climate goals
Pharma and Biotech	Health security and global competitiveness	Reinforces domestic research, development and process-engineering capacity

Table 10.1: Strategic Sectors and Indian Execution Potential

Outcome of Phase One

By 2030, India should have institutionalised fair and capability oriented procurement, expanded mission driven research funding, strengthened professional standards and demonstrated leadership in selected strategic sectors. Phase One does not seek immediate dominance. It lays the foundations upon which consolidation and global leadership can be built in the phases that follow.

11.3 Phase Two (2030 to 2040): Consolidation and Global Reach

With the foundations laid in Phase One, Phase Two focuses on consolidation, scale and international credibility. The objective of this phase is to deepen institutional strength, expand domestic capability and position Indian organisations to participate confidently in global markets on merit.

1. **Scaling capability through long term partnerships:** Public procurement should evolve from project based contracting to long term partnerships anchored in measurable outcomes. India's experience with national missions such as digital identity platforms, large scale vaccination systems and renewable energy deployment demonstrates the value of continuity, institutional memory and stable delivery frameworks. These approaches allow learning to accumulate and capability to mature over time. Domestic firms that have demonstrated competence in Phase One should now be entrusted with leadership roles in large and complex assignments. Global collaboration remains essential, but partnerships must increasingly reflect parity, with Indian institutions shaping system design, integration and long term operation.
2. **Research depth and translation at scale:** Research funding during this phase should rise to levels comparable with leading emerging science economies. The Anusandhan National Research Foundation should expand challenge based grants that move solutions from laboratory to field within defined timelines. The emphasis must shift from proof of concept to proof of deployment. A national repository of patents, prototypes and validated designs should be created to enable enterprises to adopt and scale proven solutions quickly. Such a platform would reduce duplication, accelerate diffusion of innovation and strengthen domestic adoption of publicly funded research. Capital markets must also play a supporting role. Consulting, design and technology institutions that meet quality and governance norms should be able to access public markets, enabling them to scale talent, invest in research and compete internationally.

3. **Expanding global presence:** Export credit agencies and development finance institutions should actively support Indian organisations bidding for assignments in Asia, Africa and Latin America. These regions value India's experience in affordability, renewable energy deployment, digital public goods and large scale service delivery. Structured financial backing will allow Indian firms to compete effectively with established global players. India's global engagement during this phase should emphasise partnership rather than dominance, offering deployable technologies, operational models and institutional frameworks adapted to local contexts.
4. **National branding and standards leadership:** A curated national platform titled Designed in India should make India's achievements visible to the world. It should highlight measurable outcomes such as time saved, cost reduced and inclusion achieved. Success stories across renewable energy, nuclear safety, semiconductor design, public health engineering and digital governance should be documented and updated regularly. India must also play a more active role in shaping global standards. Indian experts should chair and contribute to international committees in areas such as digital identity, public digital goods, energy engineering, smart mobility and sustainable design.

Leadership in standards allows India to influence how technologies are governed and adopted worldwide.

5. **Strengthening Union and State cooperation:** Phase Two requires deeper cooperation between the Union and the states. A national scorecard should track indicators such as domestic participation in tenders, adoption of research outputs and improvements in design quality. Fiscal incentives can reward states that demonstrate progress in inclusive innovation, sustainable infrastructure and indigenous design capability. States that move faster can support others through shared toolkits, mentoring arrangements and peer learning networks. This approach allows national capability to rise without forcing uniformity.

Outcome of Phase Two

By 2040, India should have domestic firms and institutions with sustained global presence, deployable technologies across strategic sectors and recognised leadership in selected international platforms. Phase Two establishes credibility at scale and prepares the ground for the final transition to global leadership in the decade that follows.

Phase Two (2030 - 2040): Consolidation And Global Reach

The Transition to Strength at Scale & International Credibility

 Scaling capability through long-term partnership	 Research depth & translation at scale	 Capital markets & global presence	 National branding & standards leadership	 Strengthening union & state cooperation
Deepen institutional strength	Comparable funding	Access to public markets	Curated platform: designed in India	Deeper cooperation
Measurable outcomes	Expand challenge-based grants	Invest in research & competitiveness	Visible Achievements Renewable energy	National Scorecard
Entrust leadership to proven firms	Shift from proof of concept to proof of deployment	Bidding for assignments in Asia, Africa, Latin America	Nuclear	Track Domestic Participation & improved design
Global parity in design & integration	National repository of patents & designs	Structured Financial backing	Semiconductor	Shared Toolkits & mentoring
			Digital governance	
			Active role in Shaping Global Standards (digital id, energy, mobility)	

11.4 Phase Three (2040 to 2047): Design Leadership at Scale

By the 2040s, India should have moved beyond capability building and consolidation to a position of recognised global leadership. Phase Three converts accumulated strength into agenda setting power. The objective is to participate in global systems, and to shape how those systems are designed and governed. India should set global benchmarks in areas where technology intersects directly with public interest. These include areas such as renewable energy integration, long duration energy storage, carbon management, digital privacy, verifiable credentials and resilient public platforms. Leadership in these domains allows India to influence both technical standards and ethical norms.

Public systems in this phase must demonstrate maturity and balance. Health systems should combine digital continuity with accessible and humane care, ensuring that technology strengthens rather than replaces human judgement. Transport systems should integrate real time data with safety, sustainability and inclusion. Urban infrastructure should increasingly rely on digital twins and predictive modelling to improve planning, resilience and quality of life.

Resilience becomes a defining feature of leadership. India must institutionalise regular stress testing of critical systems, including cloud infrastructure, supply chains and financial networks. Strategic reserves of computing capacity, cryptographic assets and essential raw materials should be maintained to ensure continuity under extreme conditions. A joint civilian and defence cyber command, operating on trusted hardware and auditable software, should protect national digital infrastructure while respecting democratic oversight.

Energy resilience will be central to this phase. Nuclear power should play a sustained role through indigenous small modular reactors, advanced fuel cycles and continuously strengthened safety frameworks. Stable and clean base load power will support industrial scale, digital systems and climate commitments. At the same time, India should remain engaged in global research on materials science, waste management and fusion technologies, ensuring that domestic capability evolves alongside global progress.

Design leadership also requires intellectual presence. By the mid 2040s, Indian thought leadership should be visible in international forums shaping innovation, safety, sustainability and public digital infrastructure. Indian universities should host international centres focused on digital public goods, energy transition and inclusive technology governance. These centres should attract global talent while remaining rooted in Indian priorities. Domestic firms and institutions should become partners of first choice for nations seeking capacity rather than dependence. India's value proposition at this stage is not lowest cost, but trusted systems, adaptable designs and long term partnership. Leadership is expressed through reliability, ethical practice and the ability to help others build their own capability.

Outcome of Phase Three

By 2047, India should stand as a design led nation that shapes global standards, exports knowledge with confidence and operates resilient systems at scale. Sovereignty at this stage is the ability to engage the world from a position of strength, grounded in ideas, institutions and trust. By the mid 2040s, India's thought leadership should be visible in international forums shaping innovation, safety, sustainability and public digital infrastructure.

11.5 Cross Cutting Pathways, Governance and Global Engagement

The three phases of the roadmap are bound together by a set of enduring pathways that ensure continuity, credibility and resilience. These pathways belong to multiple phases. They operate across decades, allowing reform, consolidation and leadership to reinforce one another rather than exist in isolation. Procurement shall evolve from a compliance driven process into a form of national stewardship. Buyers must develop the capability to evaluate innovation, assess long term value and recognise domestic design ownership. Procurement decisions shape markets, talent flows and institutional confidence. When aligned with national intent, they become one of the most powerful instruments of capability building.

Research and intellectual property systems shall reward collaboration while protecting national interest. Open science should be encouraged, with clear and fair mechanisms for ownership and licensing.

A Bayh Dole style framework for publicly funded and CSR backed research allows universities and enterprises to co own outcomes while keeping strategic assets within Indian jurisdiction. A national intellectual property exchange can make Indian patents visible, licensable and commercially usable through transparent royalty sharing.

Talent systems must support the full lifecycle of capability creation. Design thinking should be embedded across education and professional training. Re entry pathways should enable diaspora professionals to return and contribute without friction. Domestic firms and public institutions should invest in in house academies so that learning remains continuous and aligned with evolving national needs. Digital and data governance shall preserve a trusted national architecture for identity, consent, payments, secure exchange and cyber protection. Control over these foundational layers ensures that innovation can scale without compromising rights, security or sovereignty. Finance systems must complement this architecture by enabling patient domestic capital. Insurance funds, pension pools and long term investors should be aligned with design quality, durability and societal value.

Federalism remains a central strength. The Union must set clear standards and interoperable frameworks, while states retain the freedom to experiment and adapt. Fiscal transfers and incentives should reward adoption of domestic designs, inclusive innovation and sustainable infrastructure. Successful state level models should be shared openly so that progress spreads without uniformity being imposed. Sustainability must be embedded at every stage of design and delivery. Infrastructure, industrial systems and urban development should reduce environmental impact, encourage circular use of resources and strengthen climate resilience. Sustainability is not an additional objective. It is a design discipline that determines long term viability.

A roadmap of this scale must be measurable to remain credible. India should publish transparent milestones at regular intervals covering procurement reform, research investment, domestic leadership and digital sovereignty. Independent review panels drawn from academia, industry and civil society should assess progress and publish findings in the public domain.

Ministries and institutions should respond openly to these assessments, creating a culture of accountability rather than defensiveness. Risk management is an integral part of governance, not an afterthought. Economic cycles, talent mobility, supply chain disruption and climate related stress are predictable challenges. The roadmap mitigates these risks through diversity, open standards, global cooperation and competitive markets. Periodic foresight reviews can turn uncertainty into preparedness, ensuring that adaptation becomes routine.

India's engagement with the world must be confident and selective. Partnerships with Asia and Africa can focus on digital public goods, renewable energy, public health engineering and affordable technologies. Engagement with advanced economies can concentrate on frontier research, nuclear safety, semiconductor design, artificial intelligence safety and resilient supply chains. All partnerships shall be structured around joint design, technology transfer and shared learning, rather than dependency.

In multilateral forums, India should advocate open interfaces, fair standards and respect for national jurisdiction. India's unique position allows it to act as a bridge between technology producers and technology users, shaping global rules that are principled, practical and inclusive. Together, these pathways form the operational spine of the roadmap. They bind policy to capability and ambition to execution. They build on the momentum of national initiatives such as Startup India, Digital India, the production linked incentive schemes and the Anusandhan National Research Foundation, while extending their impact over decades.

By 2047, the tricolour should also represent and stand for scientific achievement, trusted systems and intellectual leadership. Political freedom defined India's first century. The next century must define India's authorship. This roadmap brings policy, capability and purpose into a single continuum. It shows how India can convert knowledge into strength and ambition into design leadership. What began in 1947 as a quest for freedom must now continue as a daily commitment to creating ideas, systems and designs that shape India's enduring legacy.

India's Roadmap to 2047: The Quest for Design Sovereignty

Designed in India: Political Freedom to Intellectual Authorship

Phase 1 (2025–2030):

Laying the Foundation

Reforming procurement and raising research investment toward 1% of GDP by 2030.



Phase 2 (2030–2040):

Consolidation & Scale

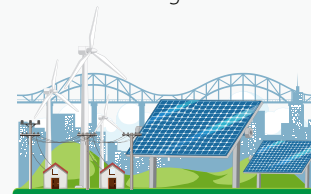
Scaling domestic firms globally and launching the “Designed in India” national branding platform.



Phase 3 (2040–2047):

Global Design Leadership

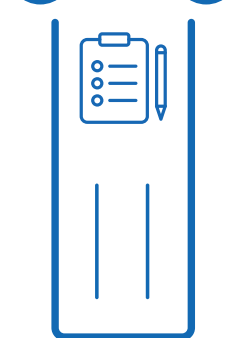
- Renewable energy grids
- Standard-setting areas
- Resilient bridges & cities



Shaping international standards in renewable energy, digital privacy, and resilient public infrastructure.

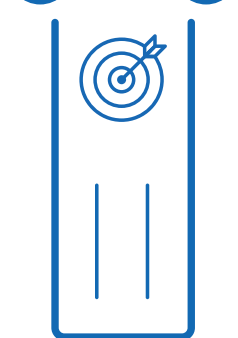


The Guiding Principles



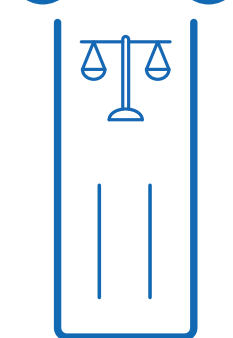
Sovereignty in Ideas & Infrastructure

Retaining domestic command over critical design, data, and delivery layers to ensure independence.



Broad-Based Inclusion

Multiplying problem-solvers by extending innovation to regional colleges, startups, and small enterprises.



Resilience and Ethics

Absorbing shocks through trusted supply chains and embedding privacy into system designs.

High-Impact Strategic Sectors for Indian Leadership



Semiconductors:

Building control over critical high-technology supply chains.



Clean Energy:

Ensuring energy sovereignty through indigenous small modular reactors.



Pharma & Biotech:

Reinforcing domestic research and global competitiveness in health security.

Chapter 12: Engineering Institutions as Catalysts of Design Sovereignty

Design sovereignty cannot be realised through policy intent alone. It requires institutions that can convert national vision into engineered reality at scale. While governments define direction and markets mobilise resources, it is engineering institutions that translate ambition into systems that perform reliably over decades. India's journey towards intellectual and design sovereignty therefore depends not only on frameworks and funding, but on the presence of strong, trusted engineering institutions that can absorb complexity, integrate disciplines and deliver outcomes with certainty.



Engineering institutions play a stabilising role in periods of rapid transformation. As systems grow in scale, interdependence and regulatory scrutiny, the cost of fragmented design and weak integration rises sharply. Engineering institutions provide continuity across political cycles, technology shifts and market fluctuations.

They anchor capability, carry institutional memory and ensure that national objectives are realised through coherent, resilient and efficient systems rather than isolated projects.

12.1 Translating Design Sovereignty from Concept to Capability

The shift from dependence to design sovereignty represents a structural transformation in how a nation conceives, creates and sustains its economic and technological systems. Policies, regulations and innovation ecosystems provide direction, but sovereignty is ultimately tested in execution. It lies in the ability to design complex systems, integrate diverse technologies and deliver outcomes that perform consistently across their full lifecycle.

India is at a defining moment in this transition. Large national programmes across infrastructure, manufacturing, energy and digital platforms are reshaping the country at unprecedented scale. At the same time, there is growing recognition that long term competitiveness depends not only on what is built, but on how systems are conceived, integrated, operated and upgraded over time. Poorly integrated systems may achieve early delivery but impose long term costs in reliability, safety and adaptability.

Design sovereignty therefore extends well beyond ownership of intellectual property or localisation of supply chains. It includes the capability to conceptualise end to end systems, adapt global knowledge to Indian operating conditions, manage interfaces across disciplines and anticipate performance, safety and sustainability across decades. These capabilities cannot be improvised project by project. They must be embedded within institutions that operate across sectors, geographies and time horizons.

This is where mature engineering institutions play a decisive role. By combining technical depth with systems thinking and governance discipline, such institutions translate national intent into engineered outcomes. They retain design ownership, manage risk systematically and ensure that learning from one project strengthens the next. In doing so, they convert ambition into capability and vision into authorship.

The evolution of Tata Consulting Engineers illustrates this institutional role. From its origins as a traditional engineering consultancy, it has developed into an integrated engineering institution engaged across the full asset lifecycle. Its work across infrastructure, energy systems, industrial facilities and advanced technologies reflects an ability to align policy objectives with engineering rigour and operational reality.

Through this evolution, Tata Consulting Engineers demonstrates how engineering institutions support design sovereignty. By integrating global best practice with local context, embedding lifecycle thinking and prioritising certainty in delivery, such institutions help ensure that strategic investments translate into durable national assets rather than short lived projects.

12.2 Tata Consulting Engineers as an Integrated Engineering Institution

Engineering institutions occupy a critical position within the design sovereignty ecosystem. Their role extends beyond technical delivery to shaping how systems are conceived, integrated and sustained over time. The integrated operating model of Tata Consulting Engineers provides a practical illustration of this role. Through its engagement as Owner's Engineer and Project Consultant, Tata Consulting Engineers remains involved from early concept and feasibility through detailed engineering, execution oversight and operational optimisation. This continuity allows engineering decisions to be informed by downstream realities rather than isolated milestones. Constructability, maintainability, safety and operational resilience are embedded into designs at an early stage rather than addressed reactively.

Design ownership, in this sense, becomes a lever for controlling cost, quality and durability. Early engineering decisions have a disproportionate impact on long term outcomes. By anticipating execution constraints and operating conditions, integrated engineering reduces redesign, limits execution risk and strengthens lifecycle performance. A defining feature of this model is multidisciplinary integration. Modern infrastructure and industrial assets are no longer collections of discrete components. They are complex systems in which civil, structural, mechanical, electrical, process and digital elements must function as a coherent whole. Misalignment at interfaces is one of the most common sources of cost overruns, delays and performance shortfalls.

Tata Consulting Engineers has institutionalised integrated design by bringing multiple disciplines together from the earliest stages of planning. Potential conflicts are identified early, interfaces are optimised and design decisions are aligned across functions. Integration is treated not as coordination after design, but as a foundational engineering discipline. In industrial facilities such as refineries and process plants, this integration aligns core process units with utilities, power systems and automation. The result is improved energy efficiency, higher reliability and reduced downtime.

In complex infrastructure systems such as metro networks, early integration across civil works, signalling, traction power and station design supports seamless operations and reduces execution challenges. Urban infrastructure projects further demonstrate how integrated engineering enables outcomes that are resilient, environmentally responsive and socially relevant. This approach positions engineering as a strategic function that shapes outcomes from the outset. It aligns directly with the principles of design sovereignty, where control over system design translates into control over performance, safety and long term value.

12.3 Delivering Design Sovereignty Through Systems Thinking

A defining capability of design sovereignty is the ability to conceive and deliver assets as integrated systems rather than isolated projects. Infrastructure and industrial facilities increasingly operate as interconnected networks of physical assets, digital controls and operational processes. Their performance depends not on individual components, but on how effectively these elements are designed to work together over time.

Transport networks, water systems, urban developments and industrial facilities are inherently interdependent. When designed in silos, they often face inefficiencies, execution challenges and operational constraints. When approached through systems thinking, they deliver reliability, resilience and sustained value. In transportation projects such as metro and rail systems, early integration across civil works, track infrastructure, signalling, power supply and station design enables seamless operations. Coordinated system design improves reliability, enhances user experience and allows networks to scale as demand evolves without disruptive retrofits.

Water infrastructure further illustrates the value of end to end system design. From source identification and treatment through transmission, storage and distribution, integration across engineering disciplines supports efficient resource management and reliable service delivery. Monitoring and control systems strengthen responsiveness, particularly under conditions of variability and stress.

Urban infrastructure projects bring together engineering, environmental and social objectives. Riverfront developments, for example, require the coordination of flood management, structural design, public space planning and ecological considerations. When designed as a single system, the outcome extends beyond functionality to long term environmental and social value. Industrial systems follow the same logic. Refineries, petrochemical plants and metals facilities are integrated ecosystems that combine processes, utilities, logistics, safety frameworks and digital controls. Control over industrial system design directly influences productivity, resource efficiency and competitiveness. Designing for local operating conditions ensures performance is sustained across the full lifecycle of the asset.

Advanced facilities such as semiconductor plants and data centres represent a new frontier of systems complexity. These assets demand precise environmental control, high reliability and continuous availability. Adapting global standards to Indian conditions while retaining design ownership is essential for building domestic expertise and reducing long term dependence. Across sectors, the underlying capability is consistent. It is the ability to integrate disciplines, anticipate lifecycle behaviour and retain control over system architecture. This systems based approach strengthens resilience and reinforces design sovereignty.

12.4 Engineering the Energy and Digital Transitions

The transition to low carbon energy systems and the rise of digital engineering are reshaping the foundations of design sovereignty. Both transitions test a nation's ability to integrate complex technologies into existing systems while maintaining safety, reliability and long term performance. The energy transition requires coordinated integration of renewable generation, energy storage, hydrogen technologies, nuclear power and carbon management solutions. Each element introduces new design and operational challenges, particularly when layered onto legacy infrastructure. System level engineering is therefore essential to ensure grid stability, efficiency and resilience.

Experience from renewable integration and pumped storage projects highlights the importance of early engineering intervention. Optimising hydraulic design, structural systems and operating parameters at the design stage improves both energy security and long term performance. Emerging domains such as green hydrogen, biofuels, carbon capture and sustainable aviation fuel further demonstrate the need for applied engineering capability to translate evolving technologies into practical and safe systems. In parallel, digital technologies are transforming how engineering itself is practised. The shift from static designs to dynamic, data driven systems represents a fundamental change in how assets are conceived, delivered and operated. Digital twins, advanced simulation and analytics allow complex systems to be tested, optimised and validated before physical execution.

Digital integration does not end at commissioning. Continuous monitoring, predictive maintenance and data driven optimisation allow assets to evolve over time rather than degrade. Converting legacy engineering data into structured digital models strengthens lifecycle management and institutional learning. Knowledge management systems, design automation and artificial intelligence further enhance this capability by embedding experience into organisational memory. This reduces variability, strengthens consistency and allows best practices to be replicated across projects and geographies.

Together, energy transition engineering and digital intelligence act as force multipliers for design sovereignty. They deepen domestic capability, reduce dependence on external expertise and enable systems that are resilient, adaptable and continuously improving.

12.5 From Engineering Capability to National Authorship

A mature design ecosystem is defined by its ability to convert knowledge into application at scale. While India has strengthened its research and academic foundations, the translation of innovation into deployable systems remains the decisive step in achieving design sovereignty.

Engineering institutions play a critical bridging role in this transformation. Their proximity to real world projects enables emerging technologies to be adapted, integrated and proven under operational conditions. Cross sector exposure allows learning from infrastructure, energy, industry and digital systems to reinforce one another. Scaling engineering capability requires more than capacity expansion. It demands institutional depth, consistent methodologies, strong governance and widespread adoption of digital tools. Predictability and quality at scale depend on integrated design practices and lifecycle discipline.

Talent development remains central. Engineers must be equipped not only with technical expertise, but with the ability to work across disciplines, apply systems thinking and exercise judgement under uncertainty. Continuous learning within engineering institutions, supported by collaboration with academia and government, strengthens this pipeline. Supportive policy frameworks further amplify institutional capability. Clear intellectual property regimes, structured collaboration models and access to global markets enable long term investment in engineering excellence.

Design sovereignty ultimately manifests in authorship. It is reflected in the ability to conceive, engineer and sustain systems that shape economic and technological trajectories. By strengthening engineering institutions and embedding systems thinking, lifecycle discipline and digital intelligence, India can move from isolated excellence to cohesive national capability. As India advances towards 2047, engineering institutions will remain decisive catalysts of sovereignty. What began as a quest for freedom must now be sustained as a commitment to authorship, where ideas are designed at home, systems are engineered with confidence and national ambition is translated into enduring progress.

12.6 Strengthening Design Sovereignty Through Industry and Academia Collaboration

Design sovereignty is not achieved only through execution capability. It also depends on the ability to continuously renew knowledge, convert research into application and build domestic technology pathways before dependence sets in. Engineering institutions play a unique role in this process because they sit at the intersection of research, application and scale.

Tata Consulting Engineers offers one of India's strongest examples of how corporate social responsibility can be used strategically to strengthen national design capability. Through its structured Industry and Academia Collaboration Programme, TCE has built long term partnerships with premier research institutions including IIT Bombay, IISc Bangalore, CSIR National Chemical Laboratory Pune and the National Institute of Advanced Studies Bangalore.

These collaborations are focused on technologies critical to India's future, including the energy transition, industrial decarbonisation, sustainable fuels and advanced manufacturing. The research is aligned with the United Nations Sustainable Development Goals and India's Net Zero 2070 vision. Most projects operate between Technology Readiness Levels 3 and 5, the stage where academic research must be translated into working prototypes and validated for real world use.

TCE contributes both funding and engineering expertise, creating a co development model rather than a sponsorship arrangement. Engineering inputs ensure that research is shaped by operating realities, scalability constraints and system integration requirements. This institutional involvement is what allows ideas to move beyond laboratories into deployable technologies.

The programme has supported a portfolio of projects spanning green hydrogen, sustainable aviation fuel, carbon dioxide utilisation, 3 dimensional printed construction materials and advanced power cycles. These collaborations have delivered tangible outcomes including prototypes, patents and peer reviewed publications. They have also received national recognition, including the CII Gold Award for Excellence in Industry and Academia Collaboration in 2024.

Green Hydrogen at IIT Bombay

A flagship collaboration between TCE and IIT Bombay focuses on developing indigenous green hydrogen technology suited to Indian conditions. Led by Professor Arnab Datta, the project aims to design affordable and high efficiency water electrolyzers that can operate on impure water sources such as wastewater or seawater using non precious metal catalysts.

In financial year 2023 to 24, the project achieved Technology Readiness Level 4 with a laboratory scale electrolyser using wastewater as feedstock. By mid 2024, hydrogen production using Mumbai seawater was demonstrated with stable performance and 80 percent efficiency. Advanced analytical equipment including high current potentiostats and gas chromatographs were commissioned to assess gas purity and yield.

By early 2025, the project reached Technology Readiness Level 5, produced 2 peer reviewed papers and filed 1 patent on catalyst design. A 10 cell prototype stack is planned. The research has been presented at international forums, positioning India among a small group of countries developing indigenous electrolyser technologies tailored to local water and industrial conditions.

Sustainable Aviation Fuel at IIT Bombay and IISc Bangalore

TCE is also supporting research on Sustainable Aviation Fuel, a critical component of India's energy transition. At IIT Bombay, Professor Arnab Datta's team is developing a pathway to convert captured carbon dioxide into syngas and then into jet fuel using Fischer Tropsch synthesis. This research supports India's target of achieving 1 percent Sustainable Aviation Fuel use by 2025 and reduces dependence on imported fuel technologies.

Complementing this effort, TCE has initiated a project at IISc Bangalore under Professor S. Dasappa to develop Sustainable Aviation Fuel from biomass derived syngas. This dual track approach addresses both carbon dioxide based and bio based feedstocks, making it relevant for India's diverse resource base. TCE has committed support for this work through financial year 2025.

Artificial Photosynthesis for Green Methanol at CSIR NCL Pune

At CSIR National Chemical Laboratory Pune, TCE is funding research led by Dr Gopinath C. S. Retd. and Professor Avishek Saha on artificial photosynthesis for producing methanol directly from carbon dioxide and water using solar energy. The team has developed a photoelectrochemical reactor with an illuminated surface area of 640 square centimetres and achieved a solar to fuel conversion efficiency of around 20 percent under laboratory conditions. This represents a significant step in converting carbon dioxide into usable fuels.

The project has produced 2 working prototypes, several international publications and a patent application. TCE has extended support into financial year 2025 to 26 to scale the reactor to a half square metre device and improve methanol yield beyond 20 percent. If successful, this technology could support a methanol based circular economy and materially reduce industrial emissions.

Circular Economy and 3D Printed Housing at IIT Bombay

Another major collaboration with IIT Bombay focuses on sustainable construction using 3 dimensional printing. Professors M. N. Shariff and Prakash Nanthagopalan are developing printable concrete made entirely from recycled construction and demolition waste combined with industrial by products such as blast furnace slag.

By 2023, the team successfully printed a single room house using 100 percent recycled material, achieving Technology Readiness Level 7. This demonstrated that low cost housing can be built without fresh cement. The project generated patents, journal publications and trained multiple research students. It supports government initiatives such as Housing for All and demonstrates how circular economy principles can be applied at infrastructure scale.

Supercritical CO₂ Power and Energy Storage at IISc Bangalore

Since 2019, TCE has supported research at IISc Bangalore led by Professor Pramod Kumar on supercritical carbon dioxide Brayton cycle technology. This work addresses next generation power generation efficiency and advanced thermal energy storage.

The collaboration has resulted in 1 patent, multiple peer reviewed papers and practical innovations including applications for data centre cooling. It has also trained several postgraduate students, creating a strong domestic talent base in advanced power systems.

Renewable Grid Integration and Stability at IISc Bangalore

TCE's collaboration with IISc Bangalore also includes grid stability research led by Professor Sarasij Das. The focus is on modelling and control of inverter based renewable heavy grids. The team has published more than 10 research papers contributing methods that support grid stability as India's renewable capacity expands towards 500 gigawatts.

Engineering Institutions as Catalysts of Knowledge Sovereignty

Together, these collaborations demonstrate how engineering institutions can use CSR strategically to strengthen national design capability. By operating at the interface of research, engineering and deployment, such institutions accelerate commercialisation, build domestic intellectual property and create skilled talent pools.

This model reinforces design sovereignty not through isolated innovation, but through institutionalised pathways that convert research into systems. It complements the execution focused role of engineering institutions by ensuring that future technologies are conceived, tested and matured within the country. In this sense, engineering institutions do not merely deliver today's infrastructure. They actively shape tomorrow's technological landscape. By linking academia, industry and national priorities, they extend design sovereignty from assets into knowledge, from execution into authorship.

Program Foundation (2019 to 2022)

Tata Consulting Engineers formalises research partnerships with IIT Bombay and the Indian Institute of Science, launching projects in digital twins, supercritical carbon dioxide, and grid studies. Construction begins on the test loop at the Indian Institute of Science.

Launch of Energy Transition Projects (2023)

Through Technical CSR Projects, Tata Consulting Engineers supports new initiatives in green hydrogen, carbon dioxide to fuel conversion, sustainable aviation fuel, methanol, and three-dimensional printed concrete. Research work commences at IIT Bombay, the Indian Institute of Science, and the National Chemical Laboratory.

Three-Dimensional Printed House Demonstration (2023)

IIT Bombay successfully prints a full-scale single-room structure using one hundred per cent recycled material. This milestone provides a first-of-its-kind proof of concept for low-cost and sustainable housing.

Recognition at the CII Gold Awards (2023)

At the Annual Technology Summit of the Confederation of Indian Industry, Tata Consulting Engineers is recognised with the Industry–Academia Partnership Gold Award for excellence in collaboration and innovation.

Green Hydrogen and Carbon Capture Prototypes (Early 2024)

The wastewater electrolyser developed at IIT Bombay achieves advanced efficiency and results in a patent application. A carbon capture prototype created with IIT Bombay removes carbon dioxide and pollutants while producing usable carbonates.

Output Expansion (2024)

By the end of the financial year, joint research produces multiple publications and patents from the Indian Institute of Science's grid and carbon dioxide laboratories. New applied research domains emerge, including Small Modular Reactors and Bio Sustainable Refining, broadening Tata Consulting Engineers' clean energy and circular economy portfolio.

Expansion to New Projects (2024)

The company strengthens its collaboration ecosystem by introducing Small Modular Reactor siting studies at the National Institute of Advanced Studies and advanced electrochemical carbon conversion research at IIT Bombay. These initiatives diversify the focus into next-generation nuclear, biofuel, and sustainable process technologies.

Artificial Photosynthesis Scaled (Late 2024)

The National Chemical Laboratory in Pune develops a laboratory-scale artificial photosynthesis device that achieves high solar fuel efficiency. The project produces international publications and demonstrates multi-module integration.

Continued Success and Scale-Up (2025)

Tata Consulting Engineers is recognised among the country's leading innovative companies. Core collaborations with IIT Bombay, the Indian Institute of Science, the National Chemical Laboratory, and the National Institute of Advanced Studies continue to expand. New projects are added in seawater hydrogen, waste-to-fuel pyrolysis, lithium extraction, Small Modular Reactors, and Bio Sustainable Refining, reinforcing the company's long-term commitment to the energy transition and design sovereignty.



12.7 Emergency Engineering as an Expression of Design Sovereignty

The Pandemic Oxygen Crisis

Design sovereignty is most clearly revealed under stress. During periods of crisis, dependence on external systems, technologies or supply chains becomes visible, and the ability to design, adapt and deliver solutions domestically becomes a matter of national resilience. The medical oxygen shortage during the second wave of COVID 19 in 2021 provided a stark demonstration of this reality.

As demand for medical oxygen surged across India, existing supply systems proved inadequate. The crisis was not only one of production capacity, but of system design. Many industrial oxygen assets existed in the country, but they were not configured for medical use. Rapid conversion, safe operation and regulatory compliance required applied engineering judgement rather than policy intervention alone. Tata Consulting Engineers worked with IIT Bombay to develop and pilot a solution that converted existing Pressure Swing Adsorption nitrogen plants into oxygen generation units suitable for medical use. The first pilot was completed within 3 days, proving the technical feasibility of the approach. Within weeks, more than 65 plants were converted across the country, producing over 35000 litres per minute of medical oxygen.

This intervention demonstrated several dimensions of design sovereignty. First, it showed the value of domestic engineering capability that could rapidly reinterpret existing assets rather than wait for new imports. Second, it highlighted the importance of institutional relationships between engineering organisations and academia, which enabled rapid problem solving under extreme constraints.

Third, it illustrated how design ownership allows solutions to be adapted safely and at scale within regulatory and operational boundaries. Beyond oxygen generation, Tata Consulting Engineers also designed modular hospitals equipped with integrated oxygen lines, solar backup systems and mobile energy infrastructure. These facilities were designed for rapid deployment, reliability and adaptability under emergency conditions. In parallel, the company developed open source blueprints for indigenous oxygen concentrators that could be manufactured by small and medium enterprises using locally available components.

By releasing these designs openly, the intervention extended beyond immediate crisis response. It created distributed manufacturing capacity, reduced dependence on imported equipment and strengthened local engineering ecosystems. The outcome was not only lives saved, but capacity built. From a design sovereignty perspective, the pandemic response illustrates a critical principle. Sovereignty is not exercised only through long term programmes or advanced technologies. It is also exercised through the ability to rapidly redesign systems, repurpose infrastructure and mobilise engineering knowledge when conditions change. The oxygen crisis response showed how mature engineering institutions act as stabilising forces during national emergencies. By combining systems understanding, execution capability and institutional credibility, they can translate urgency into action and uncertainty into functional systems.

In this sense, emergency engineering is not an exception to design sovereignty. It is one of its most visible expressions. The ability to respond decisively under pressure reflects the depth of domestic engineering capability and the strength of institutional authorship over systems that matter. Taken together, the arguments and examples in this chapter point to a central conclusion. Design sovereignty is not an abstract ambition. It is a practical outcome shaped by the strength, maturity and continuity of engineering institutions. Where such institutions exist, national intent can be translated into systems that endure. Where they are weak or fragmented, ambition dissipates into short lived projects and imported solutions.

Engineering institutions give sovereignty its operational form. They integrate disciplines that would otherwise remain siloed. They hold design intent across long lifecycles. They convert research into application, policy into infrastructure and urgency into safe execution. Their value lies not only in technical competence, but in their ability to manage complexity, uncertainty and scale with discipline and foresight. The experience described in this chapter shows that engineering institutions operate across multiple time horizons. In the long term, they shape national capability through systems thinking, lifecycle design and institutional memory.

TCE contributes both funding and engineering expertise, creating a unique model of co development. The company invested to support a portfolio of projects spanning green hydrogen, sustainable fuels, carbon dioxide utilisation, three dimensional printed construction materials, and advanced power cycle research.

In the medium term, they enable technology transitions by integrating energy, digital and industrial systems into coherent architectures. In moments of crisis, they provide stability by rapidly repurposing assets, mobilising knowledge and delivering solutions that save lives while preserving safety and trust.

Industry and academia collaboration strengthens this foundation by ensuring that future technologies are not imported at maturity, but developed, tested and adapted within the country. When engineering institutions engage directly with research at Technology Readiness Levels 3 to 5, they accelerate translation, retain intellectual property and build domestic expertise. This creates a virtuous cycle in which research informs practice and practice refines research.

The pandemic oxygen crisis offers a final and decisive lesson. Sovereignty is not exercised only through ownership or scale. It is exercised through the ability to redesign systems under pressure, to act decisively without bypassing governance and to create capacity rather than depend on imports. The speed and effectiveness of the response demonstrated that when engineering institutions are trusted and empowered, national resilience becomes real rather than rhetorical.

As India advances towards 2047, the challenge is not one of aspiration. The challenge is institutional. Design sovereignty will depend on whether engineering institutions are strengthened, trusted and embedded at the centre of national programmes. It will depend on whether design ownership is retained, whether systems are conceived end to end and whether learning is allowed to accumulate across decades.

What began as a quest for freedom must now mature into a commitment to authorship. Authorship of ideas. Authorship of systems. Authorship of solutions that reflect Indian conditions, priorities and values. Engineering institutions are the instruments through which this authorship is exercised. If India is to move decisively from execution to design, from adoption to creation and from dependence to confidence, it will be through the quiet but enduring work of such institutions. In that sense, engineering institutions are not just catalysts of design sovereignty. They are its custodians.

Chapter 13: Engineering Institutions as Catalysts of Design Sovereignty

Every generation of Indians has faced its own defining challenge. For those who lived through the struggle for freedom, the task was to win political independence. For those who built the foundations of industry and administration after 1947, the challenge was to achieve economic stability and self-sufficiency. For the reformers of the nineteen nineties, the goal was to open the economy and integrate with global markets.



The present generation faces a challenge equally profound. It is the challenge of intellectual independence. In an age where knowledge, design and data define sovereignty, the ability to think independently, to design our own systems and to deliver solutions to our own needs has become as vital as economic strength or military power.

A Synthesis of the Journey

This white paper has shown that intellectual independence is not a distant dream. It is a practical necessity that strengthens national resilience and ensures lasting prosperity.

The opening chapter described the silent contest for sovereignty that India faces today. Borders may be secure, but the real competition lies in who owns the ideas that shape reforms, infrastructure and digital platforms. It is a contest that India cannot afford to lose.

The chapters that followed traced the roots of dependence, examined the paradox of Indian talent flourishing abroad while domestic institutions remained under-recognised, and explored why Indian firms of great competence often stay limited to support roles.

They demonstrated that the shift from execution to design leadership is both possible and necessary. India's long experience as the world's execution engine must now evolve into becoming the design headquarters of the world.

Lessons from other nations show that such transformation is not accidental. It is the result of deliberate policy, sustained investment and cultural confidence. Case studies illustrated that Indian resilience is real and proven. In the darkest days of the pandemic, engineers converted factories to produce oxygen, built modular hospitals and created indigenous medical equipment. Technologists developed CoWIN to manage the world's largest vaccination drive. Scientists at ISRO placed a spacecraft in orbit around Mars on the first attempt and later achieved a soft landing near the lunar south pole. The Unified Payments Interface transformed India into a leader in digital finance. Research institutions advanced solutions in hydrogen, carbon capture and clean energy. These examples show that when Indian institutions are trusted with responsibility, they deliver with distinction.

The Roadmap and its Meaning

The roadmap presented in the preceding chapter outlined a clear path to 2047. It identified three progressive phases: laying the foundation, consolidating capability and achieving design leadership. Each phase is supported by essential pathways that include reforming procurement, strengthening research and intellectual property systems, developing talent, ensuring digital sovereignty, mobilising finance, deepening federal cooperation and embedding sustainability.

The roadmap also emphasised the importance of transparent governance and measurable outcomes so that progress remains visible and accountability is shared. It recognised that risk management and institutional learning are vital. Most importantly, it reaffirmed that intellectual independence will not come through isolation but through confident engagement with the world, where India collaborates globally while retaining control over the critical layers of design, data and delivery.

The Vision for 2047

By 2047, India can be a nation that designs its own future. Its consulting and design enterprises can serve not only Indian ministries and industries but also partner countries that seek to build capacity. Its research institutions can create patents, prototypes and technologies that strengthen domestic industries and contribute to global knowledge. Its digital platforms can set international benchmarks for inclusion, security and scale. Its energy systems can show how a large developing economy can decarbonise without compromising growth. Its universities can nurture the next generation of problem solvers who will serve India and the world with equal skill and pride.

In this vision, India is not just a participant in global debates but a shaper of them. It does not depend on borrowed templates but confidently creates and exports its own. It continues to collaborate and learn, but always on terms that safeguard its sovereignty and reflect its values. It is a nation where young professionals see designing solutions at home as being as fulfilling and prestigious as leading global corporations abroad. It is a society where citizens trust that their data, systems and institutions are guided by Indian minds and Indian hands.

A Call to Action

The responsibility for achieving this vision rests with every part of society. Government must continue to reform procurement, expand research funding, strengthen intellectual property frameworks and support domestic innovators. Industry must invest in design capability, research and talent development. Enterprises must build a culture of innovation and demonstrate thought leadership through ethical and results-based engagement. Universities must translate research into practice, work closely with industry and government, and become partners in the nation's technological progress. States must act as co-designers, experimenting with new models, sharing tools and scaling successful approaches. Citizens must value and support indigenous ideas, recognising that sovereignty is secured not only in parliaments but also in classrooms, laboratories and workplaces.

The task is urgent yet achievable. Just as earlier generations secured political freedom and economic stability, the present generation must now secure freedom of thought and design. The reward will be a nation that is resilient in crisis, inventive in opportunity and confident in identity. India's progress towards becoming a developed nation depends on more than physical infrastructure and financial investment. It depends on the ownership of innovation pipelines and intellectual assets. Sovereignty in the twenty-first century will be measured not only by territorial control but also by who owns the patents, the platforms and the processes that shape tomorrow's economy.

Through the reforms, frameworks and partnerships outlined in this white paper, India now has the opportunity to convert policy intent into institutional strength. Transparent intellectual property mechanisms, strategic research funding and stronger public-private partnerships can ensure that knowledge created in India remains in India and powers its industries. This approach can transform research and development from a fragmented effort into a national mission that secures lasting technological independence.

With these measures, India can realise the true spirit of Atmanirbhar Bharat and move with confidence towards Viksit Bharat. The coming years present a rare opportunity to embed self-reliance in the nation's economic and intellectual foundations. The journey from dependence to design sovereignty has already begun.

What remains is to sustain momentum, deepen collaboration and strengthen public trust. Industry, academia and government must align their goals, and citizens must take pride in using and improving Indian technology.

When this alignment is achieved, India will not merely take part in the global economy but will help shape it. The tricolour will symbolise not only political freedom but also intellectual and technological leadership. Independence will not be a ceremony remembered once a year but a living habit that defines everyday action.

By believing in its own capability, measuring progress with honesty, partnering with purpose and designing with integrity, India can ensure that when it celebrates one hundred years of freedom, it will stand before the world as a nation that is truly self-reliant in thought, in technology and in design. It will be a nation that engineers its own better tomorrow.

True freedom begins when a nation shapes its own destiny. As India looks ahead to its centenary year of independence, the measure of its progress will rest not only on what it builds, but on what it conceives and designs for itself. A truly self-reliant India will be one where ideas are born, developed and realised within its own institutions, and where innovation becomes a shared national habit. This is the essence of design sovereignty and the foundation of a confident, developed and forward-looking India.

Author Declaration on Responsible Use of Generative AI Tools

This white paper has been developed under the intellectual direction and authorship of the contributors listed above. During the stages of drafting, editing, and visualisation, the authors have responsibly used Generative Artificial Intelligence (GenAI) platforms, specifically Gemini, ChatGPT (OpenAI) and Perplexity AI, for the following limited purposes:

- Consolidating and summarising publicly available knowledge;
- Enhancing clarity and linguistic precision of technical content;
- Ideating and illustrating non-sensitive infographics for conceptual visualisation.

The use of these tools was assistive and supplementary, not a substitute for human expertise. All data interpretation, engineering analysis, and strategic recommendations were developed by the authors using verified information, professional judgement, and domain knowledge.

This work upholds the principles of ethical AI use in accordance with emerging guidelines from the Government of India (MeitY) and international frameworks on responsible AI deployment. No confidential, proprietary, or restricted data was shared with any AI system during the preparation of this document.

All GenAI outputs were independently reviewed, refined, and approved by the authors before inclusion. The authors and their institutions retain full responsibility for the integrity, originality, and accuracy of all technical and policy-related content contained herein.

This declaration is made in the spirit of transparency, reaffirming that the use of AI-assisted tools remains consistent with India's broader commitment to trustworthy, human-centric innovation.

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He strongly believes that India's journey towards becoming a developed nation by 2047 will depend on its ability to move from execution to ownership of design. He advocates for strengthening indigenous engineering, building digital and advanced design capabilities, and reducing dependence on imported technologies.

His focus includes digital engineering, industrial applications of artificial intelligence, and sustainable design practices. He sees these as essential to creating self reliant, future ready industrial systems that are competitive on a global scale.

Through his engagement with industry and policy platforms, Amit contributes to shaping conversations on innovation, capability building, and the need for India to establish leadership in engineering design. His work reflects a clear commitment to advancing design sovereignty and positioning India as a global hub for high value engineering.

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His focus areas include energy transition, green hydrogen, clean energy technologies, advanced manufacturing, and digital engineering. He actively promotes the use of artificial intelligence and advanced engineering platforms to improve design quality, efficiency, and long term project performance.

Atul works closely with industry, academia, and technology partners to strengthen engineering capability and innovation. He contributes to building systems that support self reliance, sustainable growth, and global competitiveness.

His work reflects a clear commitment to advancing design sovereignty and helping position India as a global centre for high value engineering and technology led industrial development.

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References

1. Government of India, India at One Hundred Vision Documents, NITI Aayog. <https://www.niti.gov.in>
2. UNESCO, Science Report: The Race Against Time for Smarter Development, 2021. <https://www.unesco.org/reports/science-report/2021>
3. World Bank, Innovation and Knowledge Economies, 2022. <https://www.worldbank.org/en/topic/competitiveness/publication/innovation-knowledge-economies>
4. OECD, Science, Technology and Innovation Outlook, 2023. <https://www.oecd.org/sti/sti-outlook-2023.htm>
5. Reserve Bank of India, Digital Payments and Sovereignty Report, 2023. <https://rbi.org.in>
6. Indian Brand Equity Foundation, Future of Consulting in India, 2022. <https://www.ibef.org/industry/consulting-india>
7. ASSOCHAM and PwC, Building the Indian Consulting Industry, 2019. <https://www.assochem.org>
8. Confederation of Indian Industry, India's Innovation Agenda, 2024. <https://www.cii.in>
9. Ministry of Health and Family Welfare (India), CoWIN Dashboard, 2022. <https://www.cowin.gov.in>
10. Tata Consulting Engineers, COVID-19 Innovation Report, 2021.
11. ISRO, Annual Report, 2023. <https://www.isro.gov.in>
12. NITI Aayog, National Hydrogen Mission Roadmap, 2023. <https://www.niti.gov.in>
13. OECD, Triple Helix Collaboration Models, 2019. <https://www.oecd.org/sti>
14. SIPRI, Defence Spending and Procurement Report, 2022. <https://www.sipri.org>
15. United Nations, Sustainable Development Goals Report, 2023. <https://sdgs.un.org/2023report>
16. Times of India, AI for Science: India's Chance to Leapfrog the R&D Race, 2024, May 5. <https://timesofindia.indiatimes.com/technology/times-techies/ai-for-science-indias-chance-to-leapfrog-the-rd-race/articleshow/124731960.cms>
17. McKinsey & Company, The Next Innovation Revolution Powered by AI: QuantumBlack Report, 2023. https://www.mckinsey.com/~media/mckinsey/business%20functions/quantumblack/our%20insights/the%20next%20innovation%20revolution%20powered%20by%20ai/the-next-innovation-revolution-powered-by-ai_final2.pdf
18. IP.com, How AI-Augmented R&D is Changing the Landscape of Research Industries, 2023, August 10. <https://ip.com/blog/how-ai-augmented-rd-is-changing-the-landscape-of-research-industries/>
19. PGurus, Reimagining Indian R&D for the AI Age, 2024, February 12. <https://www.pgurus.com/reimagining-indian-rd-for-the-ai-age/>
20. R&D World, AI-Driven Research and Development: A Paradigm Shift in Innovation, 2024, March 21. <https://www.rdworldonline.com/ai-driven-research-and-development-a-paradigm-shift-in-innovation/>
21. The Economic Times Government, India's AI Future: Collaboration for Technological Advancement, 2024, April 9. <https://government.economictimes.indiatimes.com/news/technology/indias-ai-future-collaboration-for-technological-advancement-says-meity-secretary/122128005>

22. Project Management Institute (PMI), A Guide to the Project Management Body of Knowledge (PMBOK® Guide), 6th ed., 2017.
23. Malik, P., Projects vs Operations Management: 10 Differences with Examples, PM-by-PM, 2022. <https://pm-by-pm.com>
24. Helmi, J., CAPEX vs OPEX – Why the Difference Matters in Project Decisions, LinkedIn Pulse, 2025.
25. Midwest Engineered Systems, Bridging the Gap Between Design and Manufacturing: A Guide to Process Development, Whitepaper, 2019.
26. ElectronicComponent.com, The Fabless Revolution: Innovation in Chip Manufacturing, 2023.
27. National Council of Examiners for Engineering and Surveying (NCEES), Why Licensure Matters, 2023.
28. Whitman, D., & Carter, J., Professional Engineers Provide the Needed Link Between Industry and Public Welfare, NCEES Communications, 2010.
29. Sharma, A., Collaborative Product Innovation: Integrating Elements of CPI via PLM Framework, Computer-Aided Design, 37(13), 1423–1432, 2005. <https://doi.org/10.1016/j.cad.2005.02.012>
30. All India Council for Technical Education (AICTE), Draft Professional Engineers Bill, 2024.
31. German Federal Ministry for Economic Affairs and Energy (BMWi), Dual Vocational Training – A Recipe for Success, 2020.

Disclaimer

This white paper is a thought-leadership and advocacy document prepared in the spirit of intellectual exploration and nation-building. It offers forward-looking perspectives, conceptual frameworks, and illustrative ideas aligned with the broader India@2047 vision. The insights, recommendations, and models discussed are intended solely for academic, professional, and developmental dialogue.

The contents of this paper do not represent the official policy, strategy, or future direction of Tata Consulting Engineers, any government body, or any corporate entity associated with the authors. The views expressed are conceptual and should not be interpreted as definitive positions, investment advice, or organisational commitments.

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This white paper includes forward-looking statements and scenario-based projections based on assumptions and analysis made at the time of writing. Actual outcomes may vary owing to changes in policy, technology, or market conditions.

The purpose of this publication is to encourage informed discussion, generate new ideas, and contribute to national and global conversations on engineering, technology, and sustainable development. It should not be regarded as a lobbying document, policy proposal, or corporate statement of intent.

The authors and Tata Consulting Engineers hold no obligation to implement or promote any of the ideas presented and disclaim any liability arising from the interpretation, use, or reliance on the contents of this publication.

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