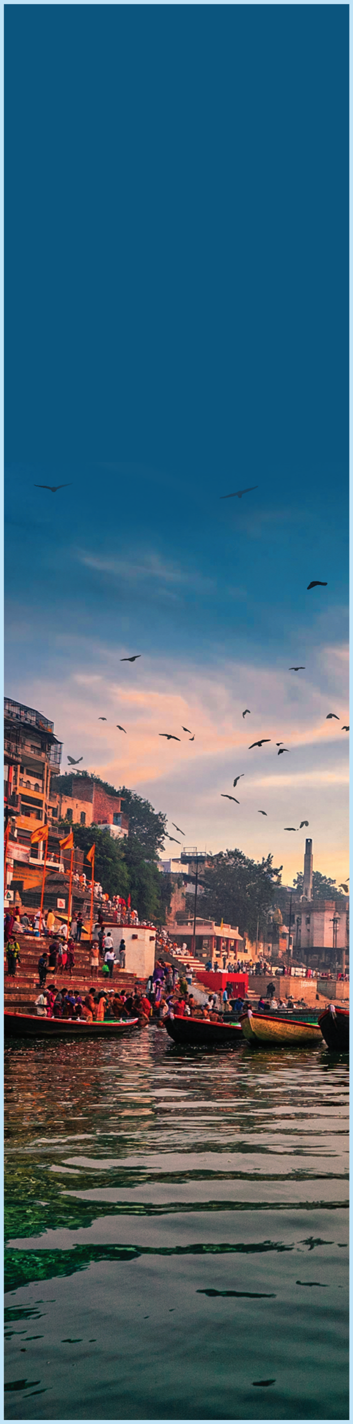
WHITEPAPER



TRANSFORMING INDIA'S BUILT ENVIRONMENT

Decarbonize, Democratize and Digitalize India's Built Environment:

A 2050 Vision for Wellness and Resilience

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Executive Summary – Transforming India's Built Environment

This white paper attempts to summarize and provide a structured perspective on transforming India's built environment, taking stock of emerging realities attributed to climate change and sustainability (planet, people, and prosperity). While the COVID-19 pandemic provided the original backdrop to review the status of the built environment and its resilience, climate change continues to manifest as an existential threat.

Three interdependent, concurrent drivers, Decarbonize, Democratize, and Digitalize are essential for the required transformations in the built environment. Decarbonization aims to drop the exponentially accruing carbon footprint attributed to modern society to fundamentally restore and reset planetary systems that society is attuned to. Democratization aims to overcome deprivation and marginalization, to be inclusive of diversity in culture, geography, and aspirations in providing a healthy and resilient living environment. Digitalization could provide the ubiquitous digital connectivity and Internet of Things as the unifying fabric encompassing environmental stewardship to network, facilitate, operate, and underscore transformations across all seven sectors in the built environment, viz., residential, agriculture, administration, industry & commerce, education & research, infrastructure services, and transport and communication. Decarbonize, Democratize and Digitalize, like in a triple helix, are intricately linked, and may be achieved through five actionable levers: Research and Development, Technology, Human Capital, Policy and Economic Investment. This structure aims to support wellness and resilience in the built environment and restore planetary stability.

Wellness provides the much-needed paradigm to unify the outcomes emerging from the seven built-environment sectors. Clarity needs to emerge on the definition and assessment of wellness and sustainability, as it would apply to various activities and stakeholders, to achieve carbon neutrality. There is an imminent need for restoring ecosystem services and enhancing biodiversity. Wellness as a fundamental right permeates all aspects of the built and natural environment and the planet. The built environment (urban to be specific) also needs to be reconfigured keeping in mind human scale and socio-temporal sensitivity, e.g. open spaces, pedestrian mobility, social inclusiveness, nature and recreation. In addition to equitable and affordable access to a healthy living environment, meeting inter-generational aspirations is crucial.

This white paper has taken stock of current status and challenges in the built environment while also identifying multi-sectoral recommendations at the building, community and regional/national scales. Each of the three drivers has been articulated in detail, highlighting challenges and opportunities in terms of market barriers, policy and institutional challenges, and societal saliency.

Decarbonization approaches include reduction in embodied and operational carbon and circularity of materials, products and spaces. Democratization approaches include provision of inclusive, healthier built environments and communities, resilience to unprecedented health and climate risks, and reinforcing positive sustainable behavior. Digitalization approaches include all stages of building lifecycle, community-scale systems, and unlocking region-specific transformations. This involves a national computing and networking infrastructure, archiving and revival of traditional knowledge, and adoption of machine learning and artificial intelligence based analytics for the built environment.

At the UN Climate Change Conference 2021, India announced a target of net zero emissions by 2070. India will reduce its projected Carbon emissions by 1 billion tonnes and the carbon intensity of its economy by 45% by 2030.

In order to approach, and as we believe, surpass this target, it is absolutely critical to transform the built environment that constitutes nearly 40% of global energy-related GHG emissions. While other energy sectors such as centralized renewables may require significant infrastructure change and investment, building technologies can create quick climate wins. In India where half of the buildings and homes that will be standing in 2050 have yet to be built, but once built will last 50-100 years, this is a historic opportunity. It is also a contrast to decarbonizing sectors such as transport where the assets are short lived. The built environment thereby lends itself to democratization and faster adoption as one of the most cost effective and deep carbon abatement wedges while being the human theater for wellness and health.

The following ten key considerations have been identified along the three drivers with a vision of a zero-carbon built environment promoting digitally enabled equitable wellness and resilience for all.

Decarbonize

GOAL: Net zero emissions-built environment by 2050

1. Breakthrough, low-embodied, robust materials and assemblies adopting aggressive conventional and unconventional high-performance measures amenable to circularity and planetary ecosystem services;

2. Low-carbon, region-specific, durable and disaster-resilient building typologies constructed and operated with cost-effective, integrated passive and active resource efficient technologies;

3. Building-to-grid community-scale integration with cost-effective distributed energy resources to harness demand flexibility while providing equitable, reliable energy access.

Democratize

GOAL: Equitable access to wellness for a resilient built environment, that includes clean air, energy, water and sanitation, mobility, biodiversity and open spaces.

4. Resilience to counteract warming and pollution levels and providing equitable access to a clean, remedial, health-promoting built environment;

5. Attitudes and technologies leveraging a culture of resource conservation and restoring environmental vitality;

6. Knowledge management through educational, vocational, and workforce training in architecture, engineering, sciences, and sustainability through integrated living environment curricula.

Digitalize

GOAL: Scalable, secure solutions to enable dynamic effectiveness of the built environment

7. Digital tools and modeling frameworks throughout the building life-cycle including digital supply chains, energy modeling, benchmarking, and circularity;

8. Resource management and information systems that provide data analysis and scientific underpinnings for performance of traditional, passive, and active systems at building, community and regional/national scales;

9. Cost-effective, ubiquitous cyber secure, sensors and controls integrating building- to-(micro)grids.

Demonstration

GOAL: Demonstrate key strategies, tools and technologies to create net zero communities.

10. Design, implement, and operate a net zero carbon community, with a cost-effective, scalable technology suite, human capital development, that leads to wide spread policy adoption and investment.

This white paper offers breakthrough pathways, that are generically inclusive of diverse stakeholders, and through well intended stakeholder inclusion provide meaningful take aways for radical transformation towards acheiving equitable wellness and planetary resilience by 2050.

A Note from the Authors: Guided by the Past... Inspiring the Future

"Why not use the lockdown to plan a roundtable discussion for the post-COVID normal", was how it all started in 2020. Given the disrupted normal, it was clear that this had to be a virtual event. We examined the opportunity that the lockdown offered, as a window of paused time for modern society to reconcile on the path to wellness and examine the severe parallax in the trajectory we were on.

Climate change is already a ravaging reality. India is at a tipping point. Amongst many catastrophic events across the country, the recent Nanda Devi glacier collapse manifested the urgency of climate change and the clear and imminent existential threat to the nation's prosperity, security, and well-being.

The dual disruptions of frequent climate events and the killer pandemic have revealed how off-target and vulnerable we stand as modern society. Calamity is teaching us lessons the hard way--that only ambitious and focused action can avert the worst. India's private and public leadership need to rise up to mobilize urgent climate and planet action and for wellness, both for India and the world.

Wellness is undeniably fundamental, emerging as a unifying theme that balances human development with environmental vitality and biodiversity revival. The COVID -19 lockdown led to sharp emissions reductions, in line with the Paris Agreement. Modern communications and digital adoption provided the vital fabric to keep us together.

From this fabric emerged humility, solidarity, opportunity, and our resolve that were reaffirmed with fresh air and a clearer view out of our windows.

Given that work-from-home was already occupying a larger share of our time, we kept the roundtables (event) very short, and leveraged the invited experts' shared perspective on the challenges, opportunities and solutions for critical transformations in the built environment for planetary stability and wellness. A framework (forming) of three key strategies: Decarbonize, Democratize, and Digitalize, provided the basis for brainstorming (storming) during the roundtable discussions, the outcomes of which we have synthesized (norming) in this White Paper.

We earnestly hope that this "BIGathon+ White Paper" aids in furthering multi-stakeholder public-private collaborations and Indo-U.S. partnerships that drive effective action to achieve the collective vision of transforming India's built environment. To rise to this unprecedented challenge, India needs to elevate environmental and societal wellness to the first rank of every Indian's priorities and a central organizing principle using five levers: Research and Development, Technology, Human Capital, Policy, Economic Investment and to achieve wellness for all.

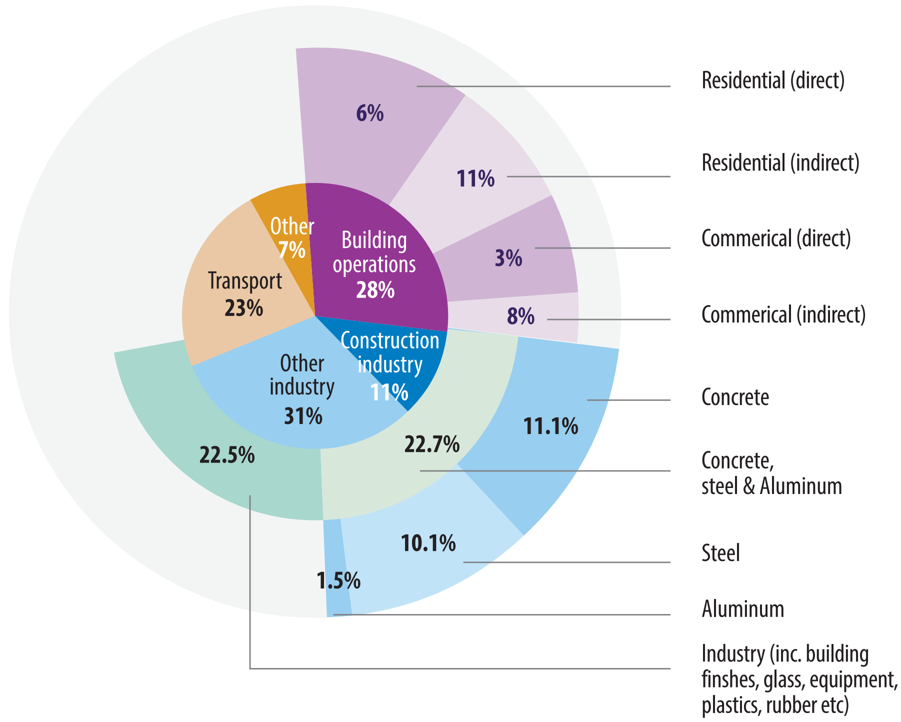
This is the decisive decade. Time is of the essence.

Transforming India's Built Environment

1. Introduction

Globally, the built environment represents the largest impact opportunity for transformative climate action.[2] Among all end-use sectors, the building sector plays a central role for a zero-carbon future. Buildings globally already account for ~40% of global greenhouse gas (GHG) emissions[3] (Figure 1) with building operations accounting for 28%, and embodied CO2 emissions from materials and construction accounting for 11%. The construction industry is also the most rapidly growing sector. New construction and retrofits of buildings offer some of the greatest opportunities for reducing emissions. While curbing resource waste, and using creative circularity are huge opportunities, buildings also are an inherent home for rooftop solar, wind, energy storage (electric and thermal), and electric transport's charging infrastructure that makes the context for building decarbonization even more significant.

Figure 1: Emissions from the buildings and construction sector, showing a breakdown of embodied and operational emissions.[3]



The built environment represents the highest carbon intensity, economic might, and emotional connect amongst all sectors of the economy.

Over the course of 2020-21, the world has undergone unprecedented change across all sectors of modern society to uncover a new normal that is yet to reveal itself. The COVID-19 era has put a lot of things out of focus, but on the other hand highlighted areas that are integral to the safe and sustainable future of our planet and its inhabitants. The massive shift in the way people work, collaborate and live within their communities and the increased focus on wellness, has emphasised the need for transformation on how a 'place', its surroundings and environment needs to be managed and operated.

This won't be the first time in history that cities and buildings will be redesigned in response to an increased understanding of a disease. Consider Haussmann's renovation of 1800s Paris, London's reconfigured infrastructure in the wake of the city's 1854 cholera epidemic, and 19th-century New York's reaction to the squalid conditions of tenement housing. The early months in 2020 saw a push for advancements in the built environment with a clear focus on reduced density in spaces or more automation to mitigate contagion. COVID-19 has accelerated the development of touchless technology, installing antibacterial fabrics and finishes,[1] and ventilation systems that allow for removing potentially contaminated air. But more importantly in a country like India this is a true call to action- for reimagining the built environment given the crowded housing and working spaces that so many of our citizens are forced to survive in. Healthy built environments are today indispensable to the safety and well-being of the environment and society.

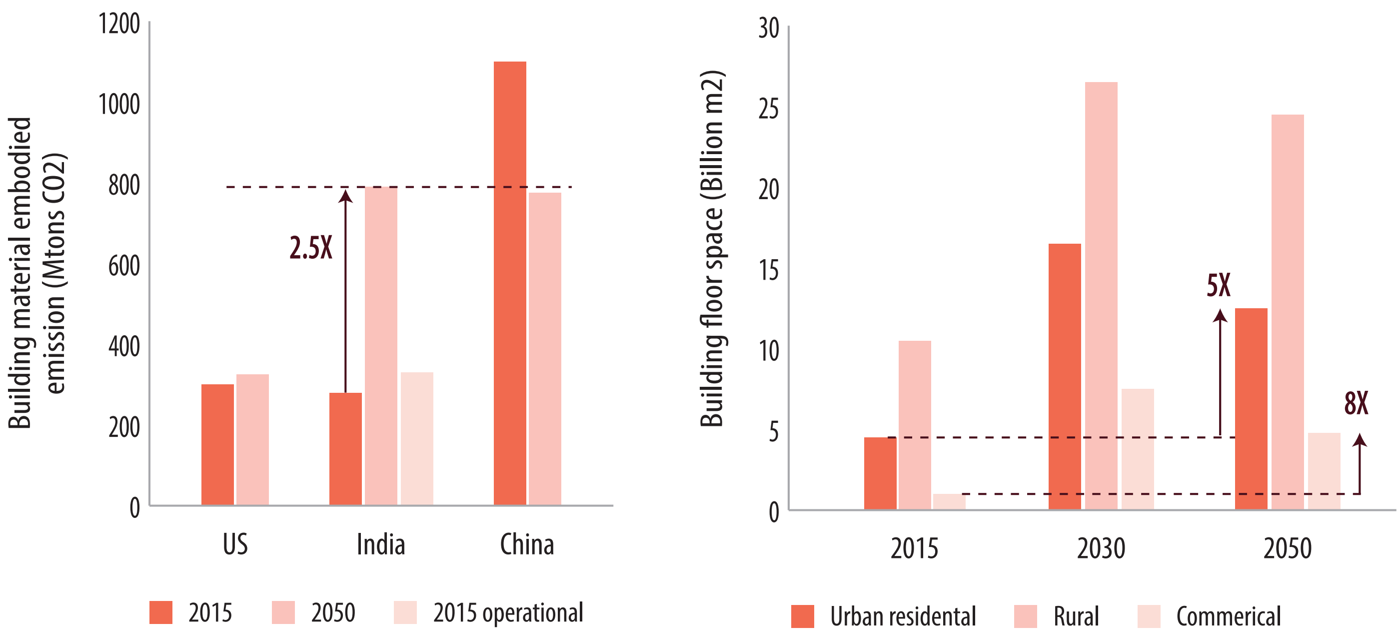
Through all this, rapid climate change is coming down like a sledge-hammer on thousands of communities with extreme floods, droughts, wildfires of increased frequency, duration, and intensity. Some communities are also experiencing these hazards for the first time in their histories and they do not have a tradition of knowledge to be resilient to these events. Climate change is inducing increased heat, drought and insect outbreaks, risk of further pandemics, declining water supplies, reduced agricultural yields, health impacts in cities due to heat, and flooding and erosion in coastal areas are additional concerns. Effectiveness, resilience, and health in the built environment is right at the crosshairs for both the public and private sectors, and from the highest echelons of leadership to every single common person.

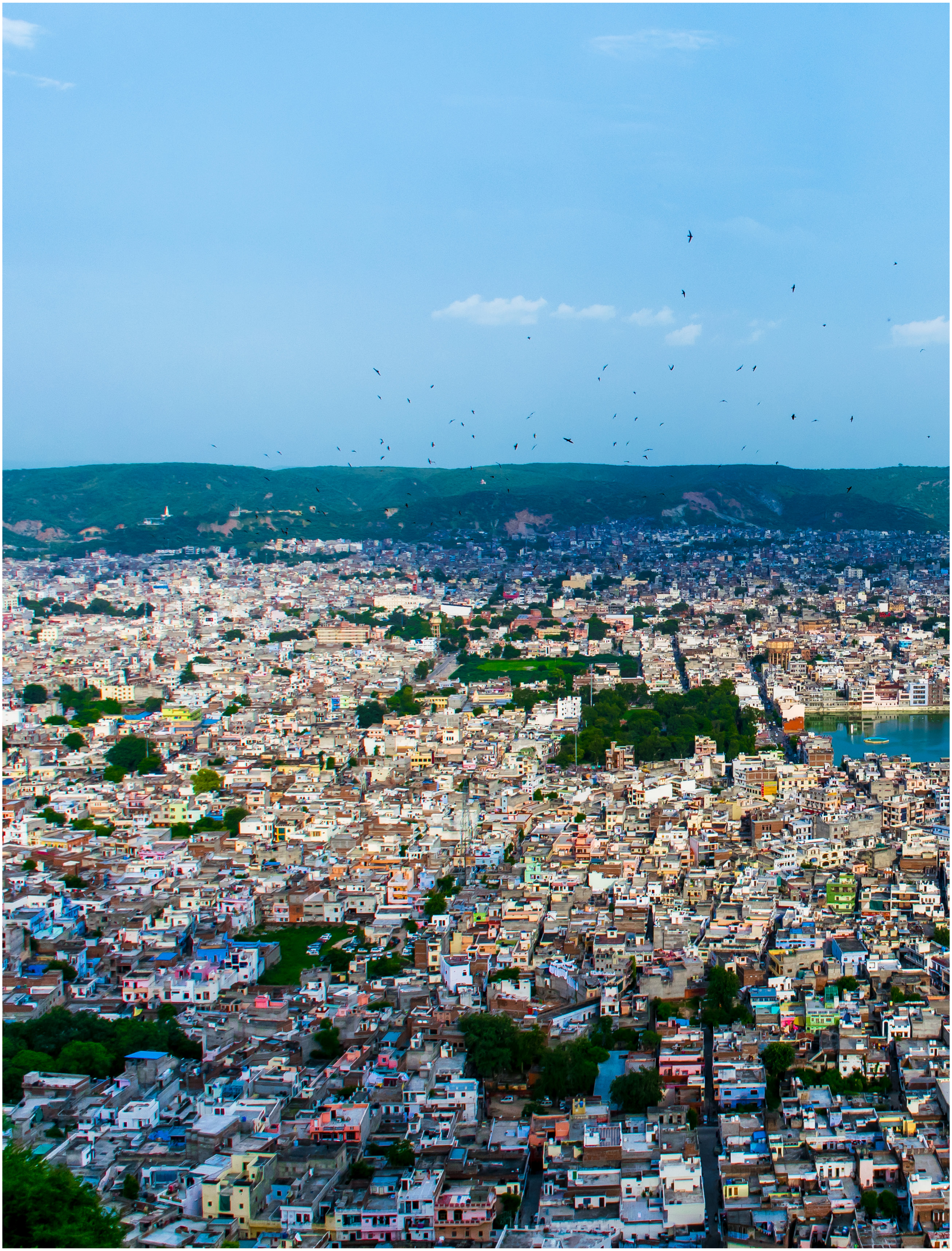
India is the world's third-largest energy consuming country, thanks with rising incomes and improving standards of living. Energy use has doubled since 2000, with 80% of demand still being met by coal, oil and solid biomass. On a per capita basis, India's energy use and emissions are less than half the world average, as are other key indicators such as vehicle ownership, steel and cement output. Even though at 2.47 TCO2e India's per capita emissions is lower than OECD countries (per Climate Watch by World Resources Institute), due to it's sheer population India is the third largest GHG emitter in the world, after the U.S. and China. A study conducted by the Research Institute for Humanity and Nature has found that the top 20% of high expenditure households in India generate nearly seven times the carbon emissions compared to low-expenditure households. Electricity consumption was the highest contributor to household carbon footprints – ranging from 26% in low-expenditure households to 36% among the rich – given India's reliance on coal-based power plants. As India recovers from a COVID-induced slump in 2020, it is re-entering a very dynamic period in its energy development. Over the coming years, millions of Indian households are set to buy new appliances, air conditioning units and vehicles. India could become the world's most populous country, adding the equivalent of a city the size of Los Angeles to its urban population each year. To meet growth in electricity demand over the next twenty years, India will need to add a power system the size of the European Union to what it has now. Prior to the global pandemic, India's energy demand was projected to increase by almost 50% between 2019 and 2030, but growth over this period is now closer to 25-35%.[4]

Why is the built environment in India a critical focus for building the future?

India is the world's fourth-largest economy, the third-largest global greenhouse gases (GHG) emitter and fourth-largest electricity consumer. An expanding economy, population, urbanisation and industrialisation mean that India is projected to see the largest increase in energy demand of any country.[4] India is projected to become the biggest producer of embodied carbon emissions from buildings by 2050 with the addition of a massive new footprint with exploding energy use intensity and operational emissions[5] (see Figure 2 (a) & (b)). In

Figure 2 (a) & (b): Projected embodied carbon emissions[7,8,9] and building floor space growth (2015-2050)[4,5]





2017-18, residential and commercial sectors in India consumed 33% of all electricity (9% by commercial, and 24% by residential) that was generated.

In pre-pandemic years there was a high growth trajectory of 8% cumulative annual growth rate (CAGR) in all building sectors, particularly residential, office, and retail. It was estimated that 700 million sq. meters of commercial building space was added over the last 10 years, and projected that 40% of the building stock that will exist by 2037 is yet to be built. Modern transitions (rural-urban transitions) are expected to have a large additional impact, ~10% of projected 2031 national emissions.[10] Even though the per capita resource and energy (electricity) consumption has been among the lowest amongst progressive nations, India's increasing (though disparate) wealth has implied almost a similar scaling of per capita energy increase in the past couple of decades, and its co-issues of increasing energy waste, pollution and emissions.

While a strong policy push in the Indian electricity sector is creating a cusp of a solar-powered revolution, competing with coal's share in the Indian power generation mix within the next two decades, the key contributor to variability between daily energy output and demand will come from rising ownership of air-conditioning and appliances that will triple the share of electricity in residential energy use by 2040. Energy efficiency codes and measures targeting both cooling appliances and buildings can avoid around a quarter of the potential growth in consumption, but electricity demand for cooling still increases six-fold by 2040, creating a major early evening peak in electricity use.[11] The pace of change in the electricity sector puts a huge premium on robust grids, and other flexible sources such as microgrids, buildings and cooling loads, EV charging and battery storage, as well as agricultural pumps.

Indian cities remain vulnerable to factors like urban heat, flash floods, water stress, droughts, and deteriorating air quality.[11] A whopping 77% of Indians are exposed to air pollution levels above the National Ambient Air Quality Standards safe limits. Worsening air pollution not only impacts human health, but also reduces crop yields, alters rainfall patterns, and aggravates biodiversity loss and climate change.[12] The prevailing conditions underscore the need to build resilience.

Another set of crucial problems in India, attributable to the rural-urban migration dynamics, is the ever-growing lack of adequate housing leading to slums and poor living conditions, depletion of urban natural resources such as lakes and vegetation, traffic and transportation congestion, gross waste mismanagement, erratic electricity supply, waterlogging, and egregious violations of building development norms. Notably the loss of social harmony, lack of rural-urban integration, growing mental stresses and marginalization[13] is exacerbating the disconnect between the people and the built environment. The built environment is at the core of achieving wellness and resilience for India.

The National Commission on Population (NCP) in India predicts that in the next 15 years (i.e., by 2036), about 38 % of Indians (600 million) will live in urban areas. India is set to more than double its building space, with 270 million people set to be added to India's urban population over the next two decades, and 70% of new construction happening in urban areas[4]. The country is on track to see the rise of 7 megacities with a population of 10 million each. Rapid urbanization could see a 50-50 share between rural and urban population by 2045. A large population implies high demand for goods and services, and requirement of efficient systems for urban planning, management and governance.

Compared to other sectors, however, productivity in the construction sector is relatively low. Where on a global level, productivity increased by 2.8% per year on average, the construction sector is falling behind with an average productivity growth of 1% per year.[14] The time is ripe for strategic investment, innovation and transformation in the built environment.

While India has been piecing together efforts to address climate change, the COVID-19 crisis has effortlessly dismantled the very resource-intensive fabric that underlies our economy and brought forth disastrous consequences of unprecedented magnitude. At a most immediate time-scale, it is critical to address the nexus between the built environment and health. The two-meter social distancing for COVID-19 is but a proxy for space and ventilation requirements.[15] Studies have shown the association of crowded built environments such as restaurants, closed public buildings and transport, and by extension, residential quarters with higher risk of being infected, and duration of suffering from COVID-19.[16,17] Exacerbating mental health through the use of outdoor spaces for recreation, dining, and play is precluded by the paucity of urban open space and cleanliness.

Given the significant disruption the pandemic has made on regular operations, in the backdrop of climate change enterprises are highly concerned about creating safe and healthy buildings to conduct business, and secure spaces for all employees to operate in. A renewed focus on individual, organizational and societal empowerment is seen as a definitive path forward to leverage the opportunities created by COVID-19: a drastic drop in emissions, unprecedented merging of multiple stakeholder and sectoral interests, and emergence of digital technologies as a unifying factor, as detailed in the following sections.

Drastic Drop in Emissions

An unintended positive impact of the COVID lockdowns were the drastically reduced GHG emissions globally, (with country wise variations as shown in Fig 3 (a) & (b)). Both primary energy consumption and carbon emissions from energy use fell at their fastest rate seen since the Second World War. The fall was driven mainly by oil (accounting for almost three quarters of the net decline), while the share of gas in primary energy continued to rise – reaching a record high of 24.7%. Renewable energy continued its trajectory of strong growth, with wind and solar power recording their largest ever annual increase – growing by a colossal 238 GW in 2020 – 50% larger than at any time in history. By country, the U.S, India and Russia saw the largest declines in energy consumption. China saw the largest increase (2.1%), one of only a handful of countries where energy demand grew during the pandemic.

At their peak, emissions in individual countries decreased by 26% on average.[18] During lockdowns, electricity demand dropped to Sunday levels, with dramatic reductions in services and industry, only partially offset by higher residential energy use. However, electricity demand recovered and now stands above 2019 levels after weather adjustment.[19]

In India, there have been some positive energy-related changes:[20]

- Primary energy consumption fell by 5.9% in 2020, the first fall in consumption this century due to the coronavirus pandemic. The largest decline in energy demand occurred in oil with a drop of 9.9% reflecting reduced road and air transport activity.
- The share of coal in India's primary energy mix in 2020 was 55%, compared to 27% at a global level. But renewables generation increased from 139 Terawatt-hour (TWh) to 151 TWh, with a trend towards crowding out coal.

Can the steep fall in India's carbon-intensive footprint during the pandemic, with the environment showing unprecedented recovery be bolstered and sustained with additional human intervention? Can we commit to radical decarbonization targeting negative emissions?

Unprecedented merging of stakeholder and sectoral interests

The lockdowns also transformed our perception of both dwellings and workspaces, giving us an opportunity to deeply reflect on resuming activities on an environmentally resilient note. The unprecedented merging of home and work/office now warrants the same wellness lens. Factors that govern productivity, environment quality, social health, etc. are indeed a common denominator. Erstwhile divergent stakeholders

Figure 3(a): (Left) Drop in CO2 emissions in 2020 with reference to 2019.[21]

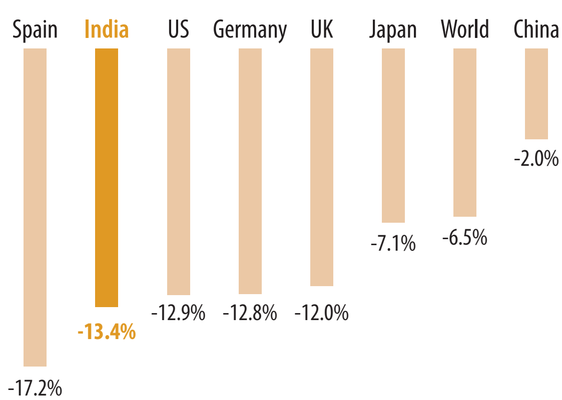
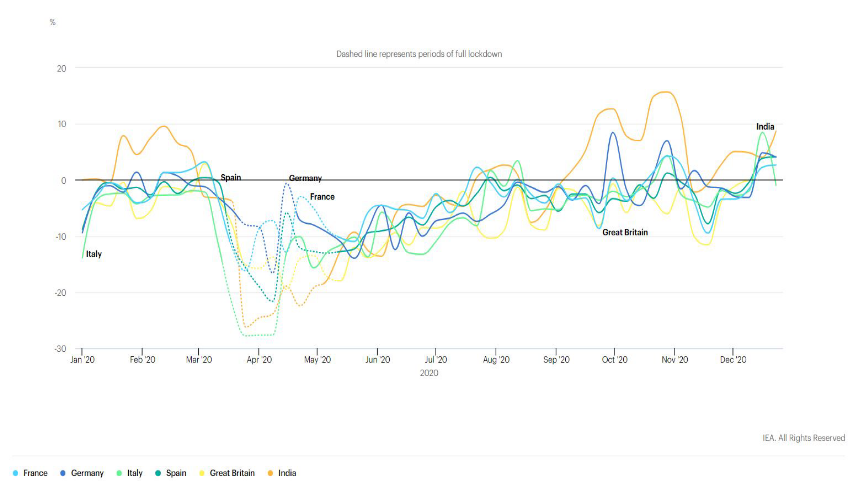


Figure 3(b): (Right) Year-on-year change in weekly electricity demand, weather corrected, in selected countries, January-December 2020[22]



are now amalgamated - industry with residence, renewables with agriculture; administration with people; infrastructure with ecology/ environment to name a few.

Can we commit to widespread democratization to achieve equitable access to well-being and resilience in the built environment?

Emergence of Unifying Digital Technologies

Despite unabting lockdowns, advanced communication technologies have remained resilient from a total shut-down, and bolstered the endurance of modern society to varying degrees and maintained the bare-essentials of human sustenance. The digital backbone of today resonates to achieve the larger environmental and social wellness goals, for the building and the communities at large. What it means is that we are creating paradigms that are instrumented, interconnected and intelligent; thereby creating opportunities for energy savings, optimization, and revenue-generating potential across multiple sectors. Digital platforms should address the issues of data provenance and integrity, stability, and secure interoperability, and importantly, equitable digital access across all sections of society.

Can we commit to transformative digitalization to achieve decarbonization and democratization?

2. The BIGathon+ Goals

The authors convened roundtables, called BIGathon+ with fifty selected private-public leaders from India and the United States. The BIGathon+ goals were:

- to effectively use this unprecedented period of disruption as a time for reflection and an opportunity for transformation of the Indian built environment
- to leverage the momentary drop in global emissions due to the COVID-19 lockdowns and address the emerging constraints and challenges that have crippled public health, economic, and environmental realities.

The connected vision of BIGathon+ is a strategic transformation of India's diverse built environment to achieve radical decarbonization and inclusive wellness and resilience. This requires balancing the three spheres of people (equity), planet (environment), and prosperity (economy).

- **People:** Can the shift towards equitable health and wellness help transform the built environment? In essence, this is the equity consideration.
- **Planet:** Can we sustain this momentum of environmental revitalization made possible by the drop in GHG emissions? In essence, this is the environmental consideration.

- **Prosperity:** Can we harness the emerging collective concern to redefine consumerism and develop business models that promote environmental vitality and wellness? In essence, this is the economic consideration.

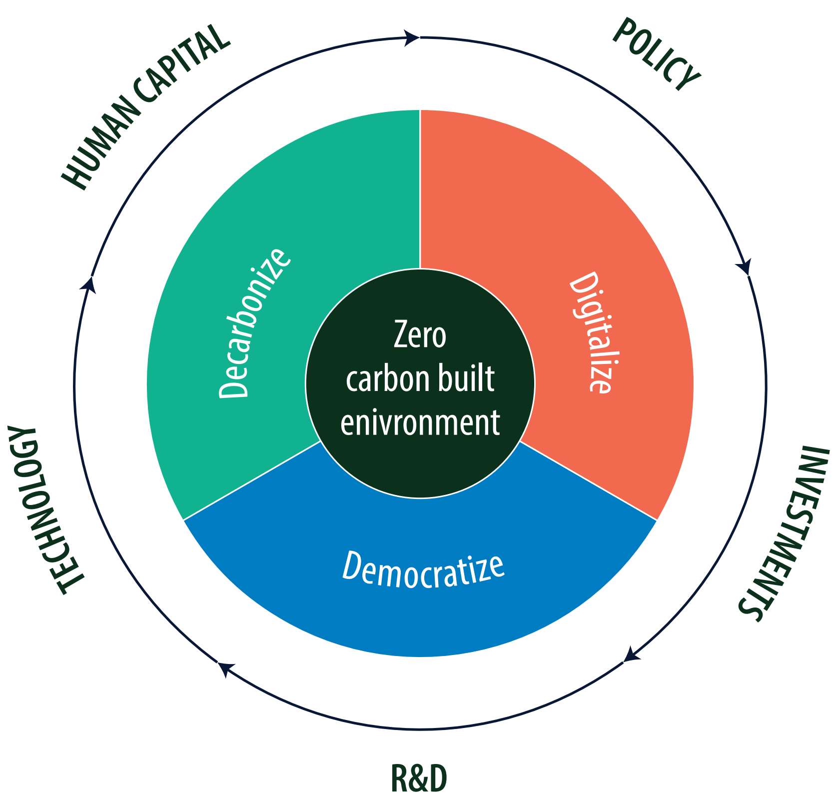
3. Methodology: Deep-dive into the three drivers for zero carbon built environment.

The BIGathon+ methodology extends beyond the Building Innovation Guide (BIG)[23] that recommended best practices for high-performance buildings and the ensuing BIGathon+ workshops held in 2019 across five cities in India.[24] The BIGathon+ Roundtables in 2020 engaged fifty multi-stakeholder private-public leaders from India and the United States. The process aligned with the Delphi method.[25] These leaders synergistically responded to targeted surveys, participated in two virtual BIGathon+ Roundtables[26] and provided focused feedback on priorities for the Indian built environment.

We leveraged the experts' shared perspective on the challenges, opportunities and solutions for critical transformations in the built environment for planetary stability and wellness. A framework (forming) of three key drivers, Decarbonize, Democratize, and Digitalize, provided the basis for brainstorming (storming) during the roundtable discussions, the outcomes of which we have synthesized (norming) in this White Paper. The muti-disciplinary leaders represent categories of stakeholders, each with their sphere of influence in the built environment and their specific levers where they can take action. Our framework thus includes five levers of action: R&D/Innovation, Technology, Human Capital, Policy/Regulation and Economic Investment, each of which are of paramount importance.

A potent vision of a zero carbon built environment promoting equitable wellness and resilience may be achieved through three critical drivers: Decarbonize, Democratize, Digitalize (Figure 4).

Figure 4: The BIGathon+ Framework: A vision for a zero carbon built environment promoting equitable wellness and resilience



Enabled by three drivers:

Decarbonize: Radically reduce emissions for a zero-carbon built environment

Democratize: Provide equitable wellness for a resilient living environment

Digitalize: Smartly connect buildings, distributed energy resources, people, and businesses

Across stakeholders influencing five levers:

1. R&D / Innovation
2. Technology
3. Human Capital
4. Policy
5. Investments

3.1 Decarbonize

How we build today sustainably, will define the course of India's history. This is the decisive decade for survival. How can the Indian built environment achieve net-zero carbon[27] by 2050?

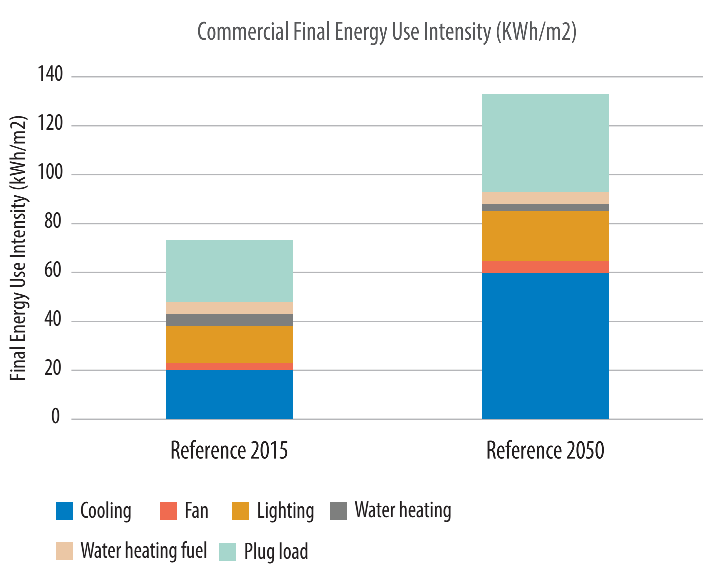
- The built environment is one of the primary cause of climate change and lacks resilience to withstand global warming
- Decarbonization of buildings, through a dramatic reduction in embodied and operational carbon, and circularity of materials and energy, represents the largest and most cost-effective levers for climate action

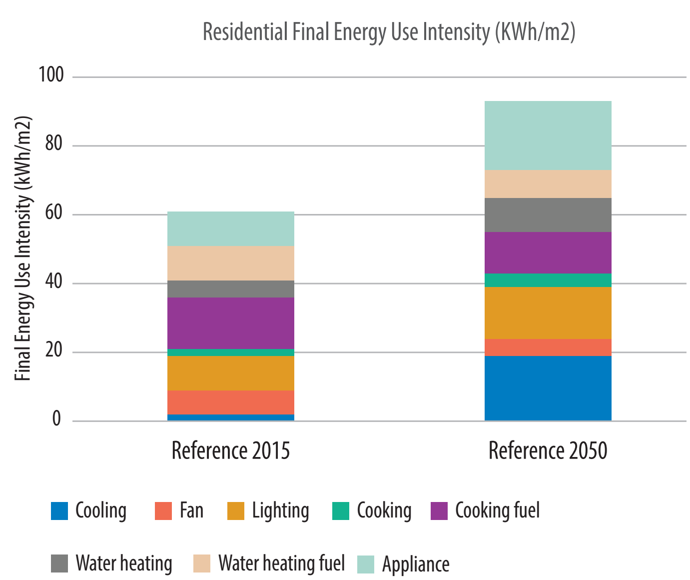
At the UN Climate Change Conference 2021, India announced a target of net zero emissions by 2070. India will reduce its projected Carbon emissions by 1 billion tonnes and the carbon intensity of its economy by 45% by 2030. 80% of India's energy needs are met from coal, oil and solid biomass[4], which are significant contributors amongst GHG emissions. Decarbonization is at the core of climate action, necessary to meet critical GHG goals. Building decarbonization offers the most cost-effective opportunity for deep carbon reduction that can also positively impact the human development index by providing health-inducing spaces and a decent, equitable standard of living.

India's building stock is tripling its energy use intensity (EUI) with commercial buildings slated to average an energy use intensity of ~100+ kWh/sqm/year[28], as compared to indigenous buildings at 30-70 kWh/sqm/year (Fig. 5(a)). In Class A office buildings with IT-intensive operations, a growing building typology, EUI is already at ~300 kWh/sqm/year (Fig. 5(b)), a tripling that is attributable to a young aspirational population, exponential growth in cooling loads given the rapidly warming cities, and increasing computational loads and service levels for commercial and residential buildings. However, achieving 30 kWh/sqm/year through energy efficiency relying on a combination of traditional wisdom and innovative technologies is possible even in commercial buildings.[23] Vernacular dwellings that have low-carbon construction and operations, have been found to be more resilient to climate change when compared with modern dwellings.[29] There is also increasing realisation and scientific validation in the prudence and frugality underlying vernacular habitations that have as a rule sustained on 'close-looped' local ecosystem services.[30, 31]

Businesses are also just opening up to the fact that business-as-usual cannot continue unless environmental (re) vitality is an integral 'target' besides profits. Environmental disruptions could be those impacting ecosystem services required to sustain industrial processes/ manufacturing of cement and steel, and those required to support planetary health and biodiversity.[32] A circular economy carries an immense potential to integrate and transform economic, environmental and social systems,

Figure 5 (a) & (b): Average energy use intensity, past (2015) and projected (2050) for residential and commercial construction in India[5]





and contribute to sustainability.[33] Enterprises are now transitioning towards their sustainability priorities focusing on environmental restoration, protection/enhancement of forests and natural ecosystems (biodiversity) restoration,[34, 35, 36] local community involvement, mediation, waste management,[37] and circular economy upcycling.[38] The recent environmental, social and governance (ESG) agenda provides a converging platform for these concerns.

3.1.1 Context of Decarbonization in the Indian Built Environment

There are three key considerations for decarbonization pathways in the built environment.

- The rightful emerging focus on a healthy built environment that inherently requires adequate space, daylighting, ventilation, and thermal comfort inside and outside buildings. Business-as-usual construction needs significant solutions for resource-intensive HVAC, artificial lighting, and solutions to overcome problematic, overcrowded spaces - that cause energy waste, pollution, burden on the electrical grid and material resources, and highly compromised wellness. Strategic policies, technologies, and market adoption can enable new construction and retrofits to enhance efficiency, economic value, and resilience of the building and energy infrastructure, as well as enhance the wellness of the living environment.
- Energy efficient equipment and consumer appliances such as low-Global Warming Potential (GWP) refrigerant air conditioners and lighting, or rooftop solar are beneficial first steps. However, decarbonization with holistic built-environment strategies is critical. It enables the integration of multiple systems in buildings and

Figure 6(a): Projected urbanization rate in India and per capita GDP (2015-2050)[5]

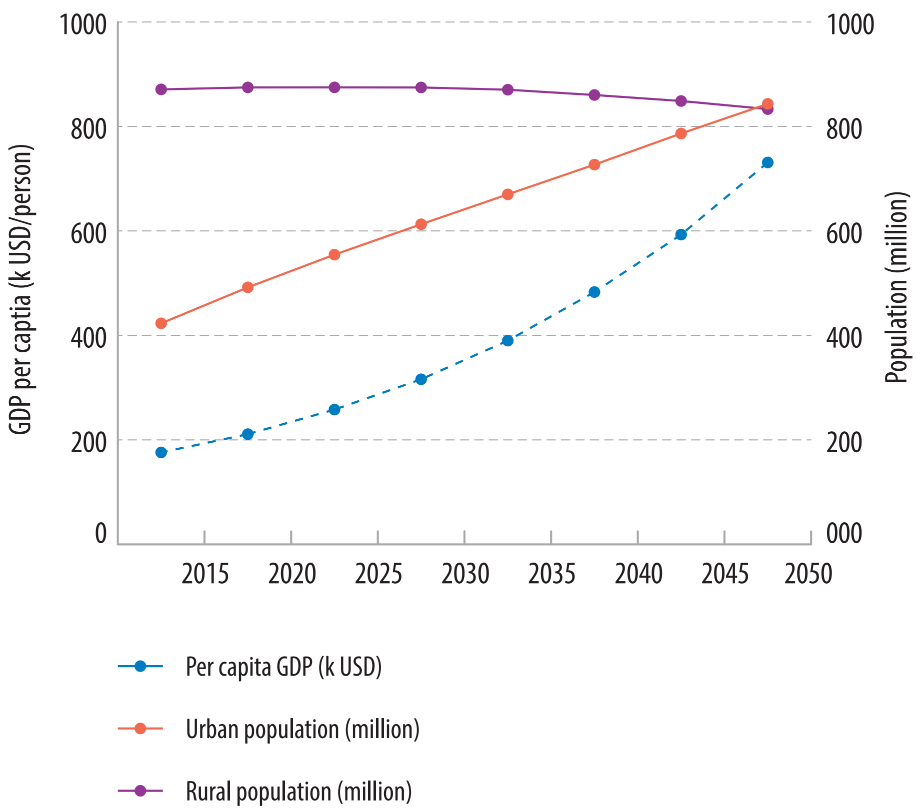
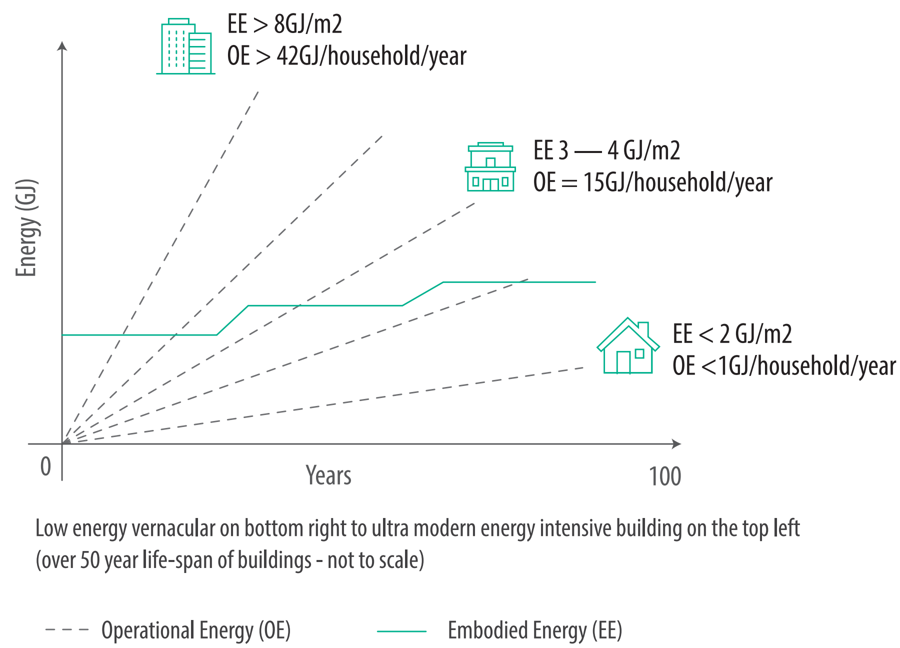


Figure 6(b): Embodied and operational energy for various building typologies.[10]



the building-edge, i.e. urban heat stresses, renewables, thermal and electrochemical energy storage, electric vehicles, given the long life-span of these edifices that need to out-live and out-perform the systems and occupants they house.

The overwhelming issue of rapid urbanization (Figure 6(a)) and the urban-rural divide, with nearly 800 million rural citizens yearning for modern 'urban', technology, resource, and digitally rich lifestyles. The energy and resource demands are exploding, with nearly a 4x and 40x rise in embodied and operational energy respectively (Figure 6(b)). With the evolving Indian economy, there is a definite need to meet the aspirations of rural households while reviving and re-instilling a sense of value and appreciation for traditional practices and vernacular, high-performance construction.

3.1.2 Challenges and Opportunities for Decarbonization

Radical decarbonization with a goal of negative emissions is critical to the very sustenance of modern life on this planet. The COVID pandemic led to a significant drop in the construction/real estate markets. KPMG reports a loss of over Rs 1 lakh crore and a 40% drop in housing demand since the pandemic.[39] The need of the hour is to realign market, policy, institutional, and societal saliency to achieve decarbonization goals. In parallel, technology solutions and industry initiatives must focus on robust decarbonization pathways.

Market barriers include lack of value chains associated with sustainable construction materials and energy. The opportunity lies in the alignment of multiple stakeholders for environmentally viable and affordable access to the built infrastructure. COVID-19 experiences have stressed on reconfigurable spaces, indoor air quality, natural ventilation and filtration. The split incentives between real estate tenants and landlords have come into unprecedented alignment to make healthy spaces for occupants obligatory. Another market focus needs to emerge on redirecting investments from new building infrastructure to retrofits and adaptive reuse of buildings.

Policy and institutional challenges include the presence and yet noncompliance to an overwhelming number of codes/regulations dealing with the built environment. At the Central Government level, the National Building Code (NBC, 2016)[40], the voluntary Energy Conservation Building Code (ECBC, 2017)[41] that as yet requires widespread adoption/compliance, and Nationally Determined Contributions (NDCs) provide strong targets/guidelines. Additionally, there is a gamut of green rating organizations - US

Green Building Council (USGBC), Indian Green Building Council (IGBC), Green Rating for Integrated Habitat Assessment (GRIHA), and others- as well as proprietary organizational ESG/ buildings/energy policies. Due to key shifts in ESG, reduction of operational waste through energy-efficient equipment, digital technologies, and clean energy systems have become possible. The opportunity is in clear action for decarbonisation, by converging the hitherto fragmented buildings industry that also includes an untapped but robust informal construction market.

Societal saliency had been low in recent years around the relationship between the built environment and health,[42] but is being revived. The "hard benefits" of decarbonization are quantifiable, e.g. energy performance indicators which may be conversion-based, such as the coefficient of performance for HVAC, efficacy-based such as energy performance index (kWh/m2/ year) or luminosity (lm/W), or cost-based, such as energy bill savings (INR saved compared to a baseline). On the other hand, critical "soft benefits" such as human productivity, comfort, and happiness achieved through the built environment are emerging as important indicators. Strategies to overcome the paucity of data, and provide comprehensive and standardized methods for measurement of soft benefits are needed for a higher societal salience.

3.1.3 Approaches for Decarbonization

Decarbonization approaches include

(1) Reduction in embodied carbon

(2) Reduction in operational carbon

(3) Reduction in resource use and waste through circularity of materials and energy flows

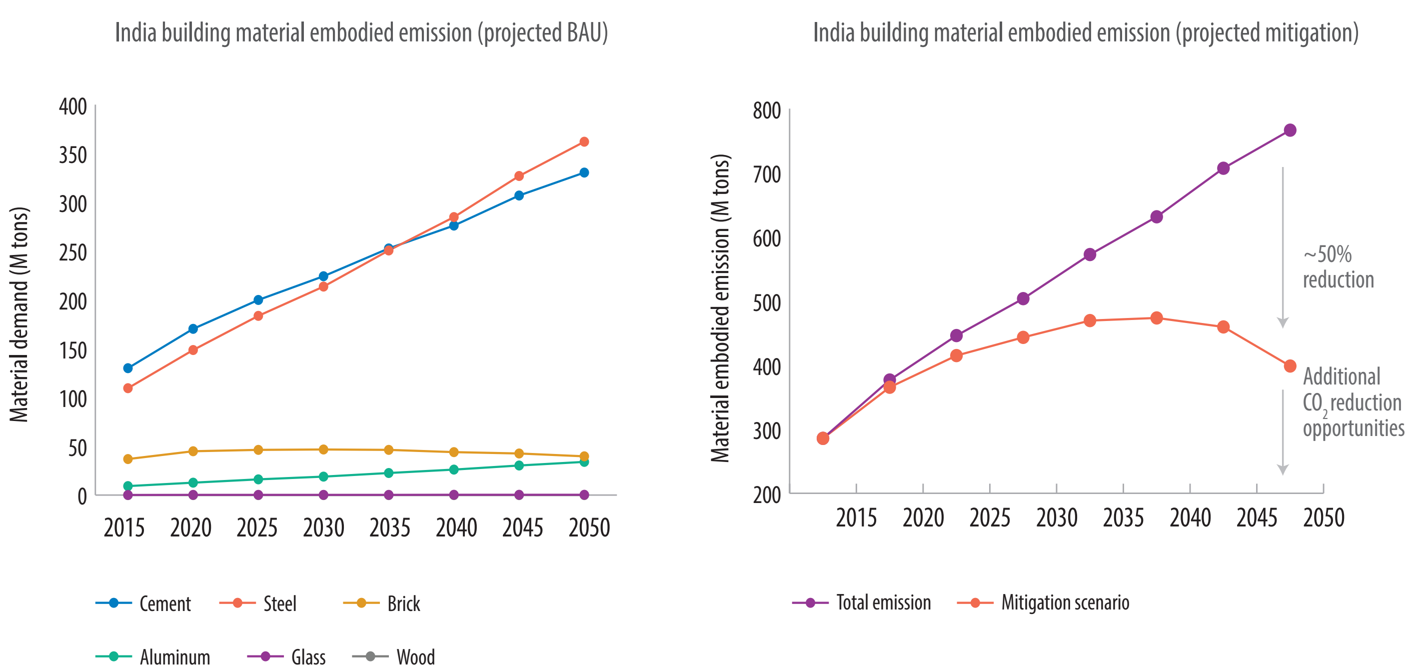
1. Reduction in Embodied Carbon

Embodied carbon refers to the manufacture, distribution, and transportation, assembly/ commissioning and dismantling/ end-of-life of building materials. i.e. the carbon footprint and emissions connected with the creation of buildings. India is projected to become the world's largest producer of embodied carbon emissions from buildings by 2050, given the significant volume of new construction using high embodied carbon materials such as cement and steel. Currently 50% of building related emissions are derived from embodied carbon, and 50% from operational carbon (Fig. 7 (a) & (b)). It is worth noting that upfront emissions contribute approximately half of the entire carbon footprint of that building through its long life of several decades – even if left unoccupied.

Solutions to reduce embodied carbon rely on standards, labeling and green procurement of low carbon materials, integrating accessible and affordable low-carbon materials, methods, and building assemblies as follows:

- Locally sourced and re-utilized/ up-cycled materials: This approach can extend innovative low-embodied carbon vernacular

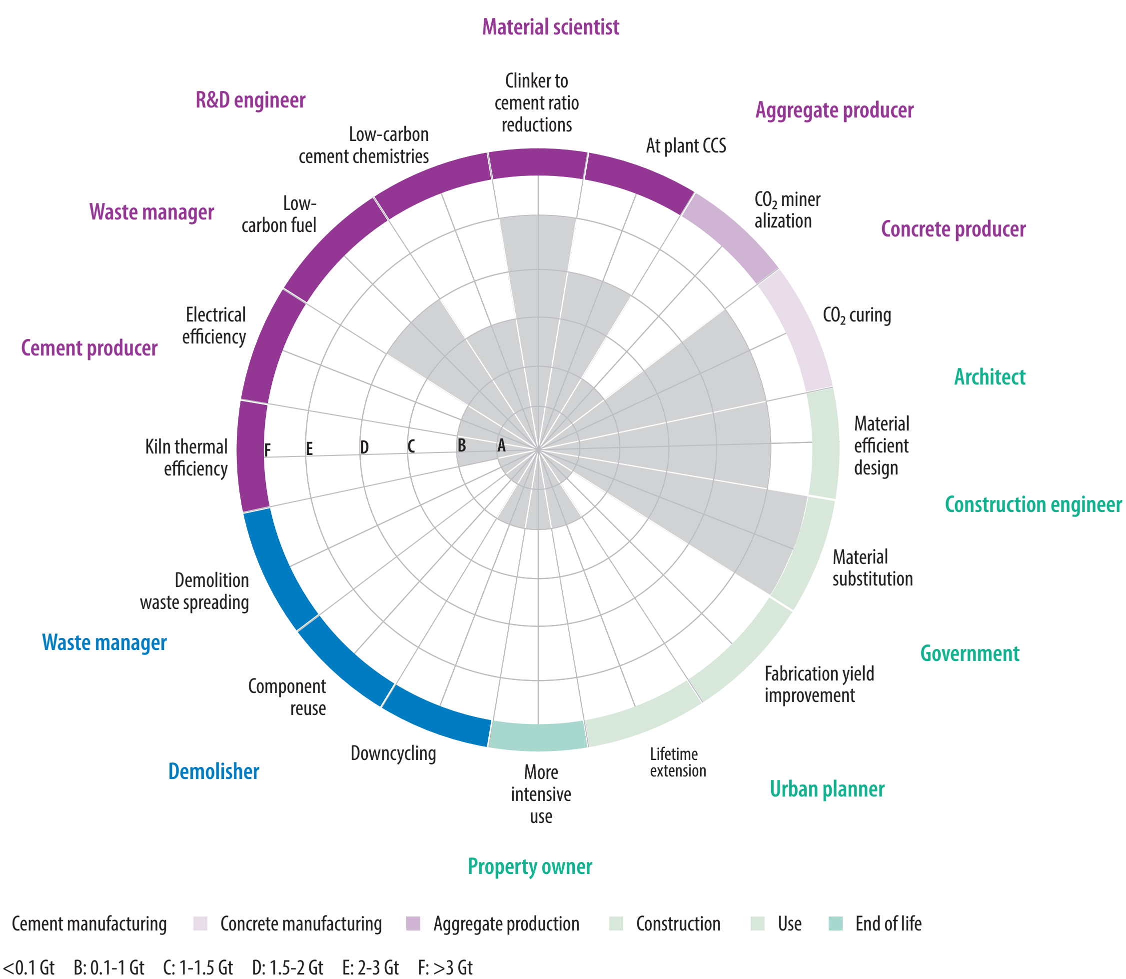
Figure 7 Building materials embodied carbon. (a) Projected Business as Usual (BAU) and (b) potential mitigation from recommended approaches[5]



architecture strategies into commercial, residential and institutional buildings. This may include decentralized modular prefabrication/manufacturing of building materials co-located with availability of local and waste/ demolition materials, e.g. fly ash bricks co-located with petroleum refineries, iron ore tailing as sand substitute, use of demolition waste as site backfill, etc.

- Biogenic resources: The use of biogenic building materials e.g. purpose-grown crops, biomass/ agro-waste from rice husk ash, sugarcane bagasse ash, mushroom (mycelium-strengthened) bricks, luffa-gourd strengthened wall panels, bamboo and timber composites and laminates, coconut fiber wall insulation, etc. have opened up alternative architectural opportunities. These biogenic building materials are biodegradable, rapidly renewable, and potentially remedial for indoor air quality. They can be sourced and used regionally, shortening the supply chain, reducing transportation and embodied carbon contributing to circularity. These could be supported by tax credit or payment programs to incentivize landowners for tree restoration and regenerative agriculture in degraded, non-arable areas.
- Structural alternatives: Better building design can potentially reduce 10-20% material demand. Retrofits to avoid premature demolition, better material choices to avoid over-design, pre-fabrication and 3D printing of building components could provide affordable locally alternatives. Appropriate decarbonizing assemblies, for instance, mass timber, ferrocrete rather than reinforced cement concrete (RCC), jack arches and corbels instead of concrete lintels, load bearing lime-mud blocks could lower the use of high-embodied steel, fired bricks, and cement.
- Decarbonize energy-intensive steel and cement manufacturing: Aggressive multistakeholder decarbonisation in the difficult-to-abate cement (see Figure 8) and steel[43] industries, encourage and explore the use of different

Figure 8: Strategic pathways for deep decarbonization in the cement sector involving multiple stakeholders [43]



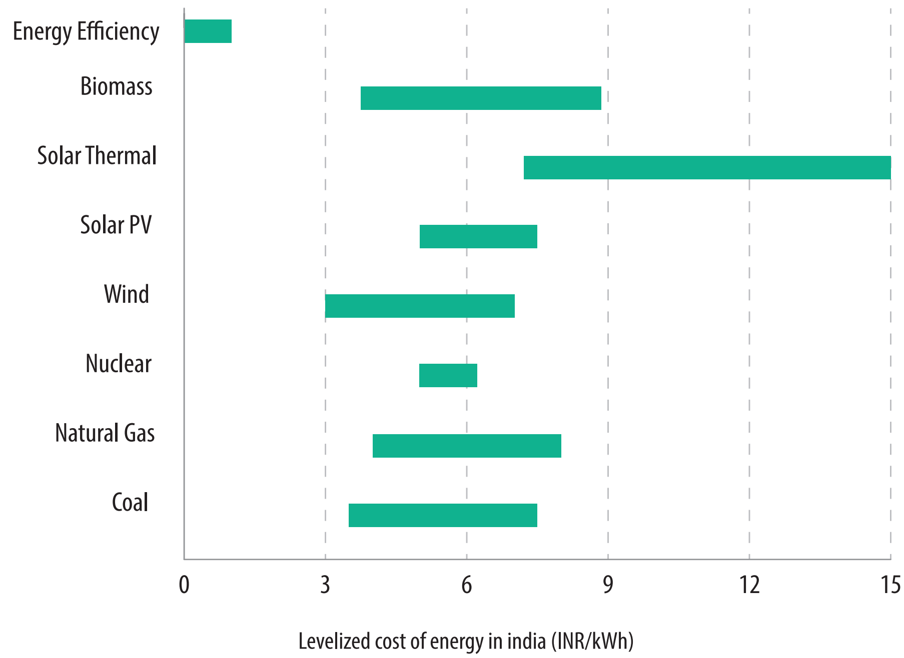
raw materials and mixes to reduce process-related CO_2 emission, recycle construction and demolition concrete and steel waste, renewable energy adoption (concentrated solar power, wind, solar, green hydrogen etc. Emissions pertaining to on-site equipment and their operations also need scrutiny and regulation.

- Carbon capture, utilization and storage (CCUS) at cement plants and carbon storage potential in buildings: Buildings hold significant carbon-negative opportunities, by being carbon stores. Buildings can sequester carbon at a gigaton-scale.[44] This includes state-of-the art technologies such as injecting CO_2 into concrete, 3D printing with organic phase change materials integrated into rapid construction of plug-and-play, modular, flexible spaces such as housing clusters, school classrooms, office pods. Low-embodied materials, and novel biogenic building materials are available on the market today, however there are challenges in their valuation and scaled up adoption.[45]

2. Reduction in Operational Carbon

Operational carbon is the term used to describe carbon or equivalent attributed to the in-use operation of a building. Buildings are typically being operated at suboptimal levels creating negative impacts on both environmental and societal health. For instance, it is not uncommon for buildings to waste 30-50% of their energy use due to misplaced design intent, notably large unshaded glazed facades leading to significant solar heat gain and air conditioning loads, and mismanaged active systems- air conditioning, ventilation, lighting etc. as well as the use of dirty diesel generators at peak times.

Figure 9: Levelized cost of energy[46]

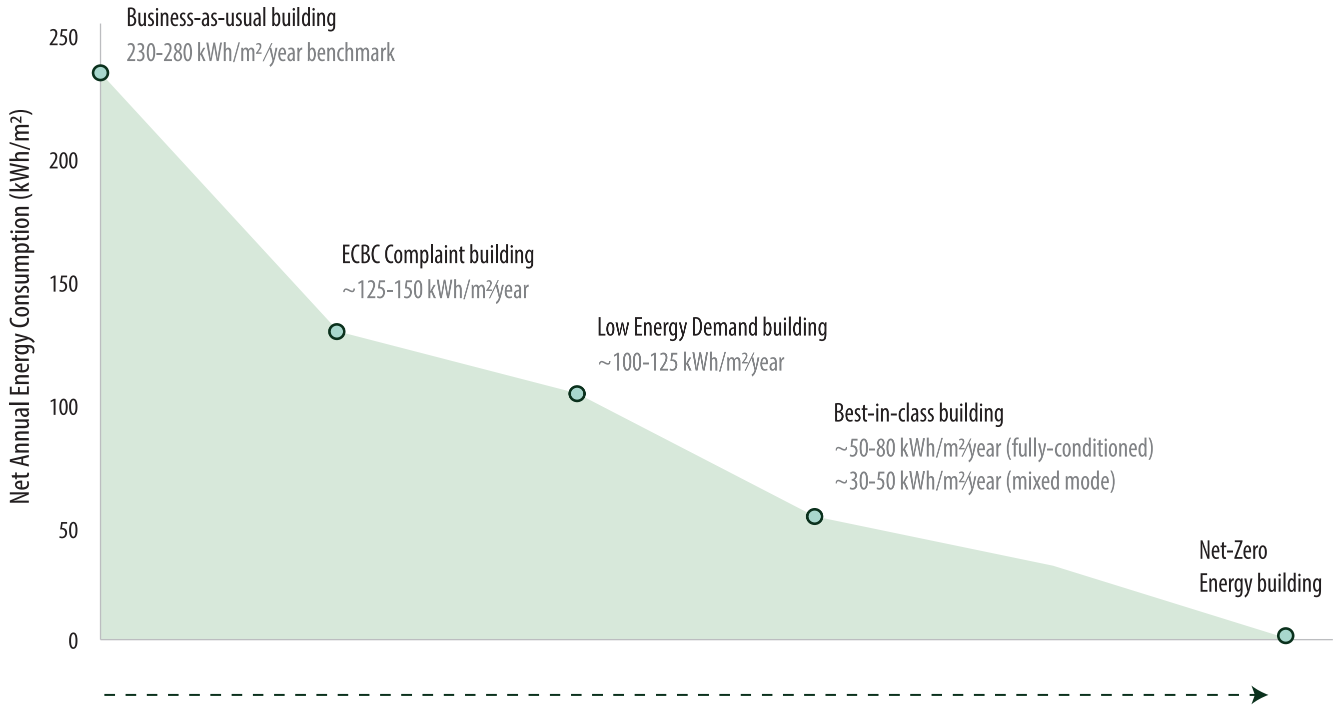


Persistent decarbonization addresses not only initial technology selection, design, and construction, but also ongoing, operational resource effectiveness for buildings. Energy efficiency is often called the first fuel, the cheapest, cleanest, most abundant source of energy (Figure 9). It may take half the cost to save a Watt than to produce it.

Operational energy reduction requires action through a progressive approach (Figure 10), that has been shown to provide ~75% reduction in the use of active energy in high-performing commercial buildings (Table 1). This progressive approach enables deep reductions in capital expenses in renewables required to deliver net zero energy, and entails the following:

- Use passive design to reduce active energy demand for space cooling, lighting, and appliances (whole building scale): Urban heat and pollution mitigation that directly impacts cooling, ventilation, and air quality control at the building-to-community scale. Optimal building orientation and glazing ratio design, a thermally-efficient envelope, hybrid lighting, and plug load reductions help to achieve this goal
- Improve energy equipment, monitoring and controls to reduce energy demand and waste: Low energy HVAC (e.g. low-energy hybrid ventilation, dedicated outdoor air systems (DOAS), hydronic (radiant, chilled beams/floors), super-high efficiency cooling systems, demand controlled ventilation, etc. Digital strategies include building climate sensing and control, daylighting, and smart energy management systems.
- Address the reduced energy demand using decarbonized sources, and implement flexible building-to-grid management: Renewables/recovery systems based electrification, passive thermal energy storage such as thick/dense walls/floors, embedded phase change materials, mixed DC power distribution, etc.

Figure 10: Progressive approach to achieve energy savings potential of ~75 % [23]



1. Use passive design to reduce active energy demand for space cooling, lighting, appliances
2. Improve energy equipment, monitoring and controls to further reduce the energy demand and waste
3. Address reduced energy demand through fuel switching ,electrification, and distributed renewable energy sources

Table 1: Whole-Building Metrics, benchmarked and simulated per climate zone. Depicts 75% savings through energy efficiency from business-as-usual baselines. The metrics use measured data from best-practice commercial buildings and modeled data from building energy simulations per climate zone.[23]

Whole-Building Metric		Benchmarked (Measured)	Simulated, per climate zone			
			Temperate (Bangalore)	Hot Dry (Jaipur)	Warm Humid (Mumbai)	Composite (New Delhi)
Annual energy use EPI [kWh/m2/year]	Standard	242	232	280	253	268
	Better	140	125	146	144	146
	Best	65(30)*	53	78	69	80
	Savings	**74%**	**77%**	**72%**	**73%**	**70%**
Peak energy use [W/m2]	Standard	90	100	123	95	110
	Better	40	39	56	45	56
	Best	19	16	29	22	30
Annual energy use/ occupant [kWh/ person/year]	Standard	2,250	2,320	2,800	2,530	2,680
	Better	1,460	1,250	1,460	1,440	1,460
	Best	620	540	780	690	800

* An EPI of 30 is the best practice target achievable in mixed-mode buildings

The goal is grid-interactive net-zero energy buildings with distributed renewable energy, storage and flexible load management. (Fig 11)

Multi-pronged approaches to reducing energy intensity in both residential and commercial building operations can provide progressive mitigation benefits (Fig. 12). These dramatic reductions in operational energy use deliver commensurate cost reductions (Tables 2 (a) and (b)).

3. Circularity

Circularity may be defined as a 'regenerative system in which resource input and waste, emission and energy leakage are realigned to be close-looped involving multiple stakeholders. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing and recycling',[48] in addition to carbon negative interventions. In a circular economy, resource use is decoupled from economic growth, no longer relying on current unsustainable linear consumption patterns.[49] The world economy is only 8.6% circular,[50] which makes a compelling case for restructured investments. It is paramount to integrate the natural environment as a critical stakeholder for circularity to be effective in achieving goals of decarbonisation and wellness.

Construction and demolition waste represents one of the largest waste fractions by volume, of which only one per cent is recycled in India. Concrete, bricks and metal waste from construction are choking water bodies, green areas and public spaces. Toxic dust particles from the debris are adding to air pollution when cities are to reduce their particulate pollution by 20-30% by 2024, under the ongoing National Clean Air Programme.[51] Building materials are

Figure 11: Grid-integrated energy-efficient buildings can play a key role in promoting greater affordability, resilience, environmental performance, and reliability[47]

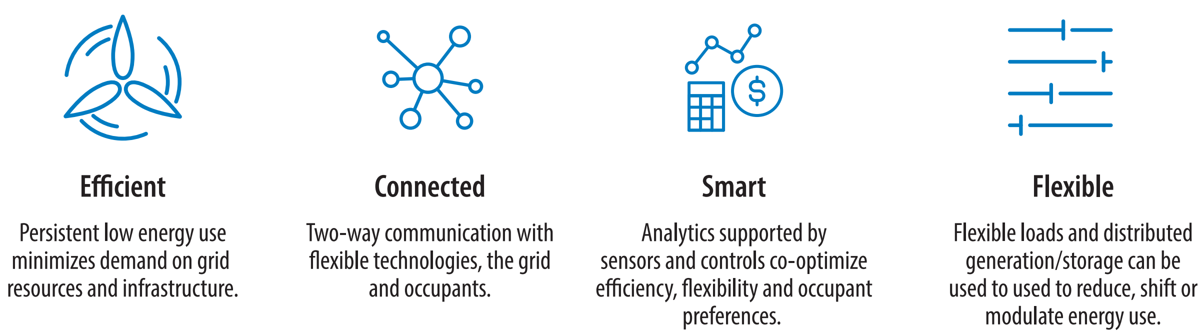
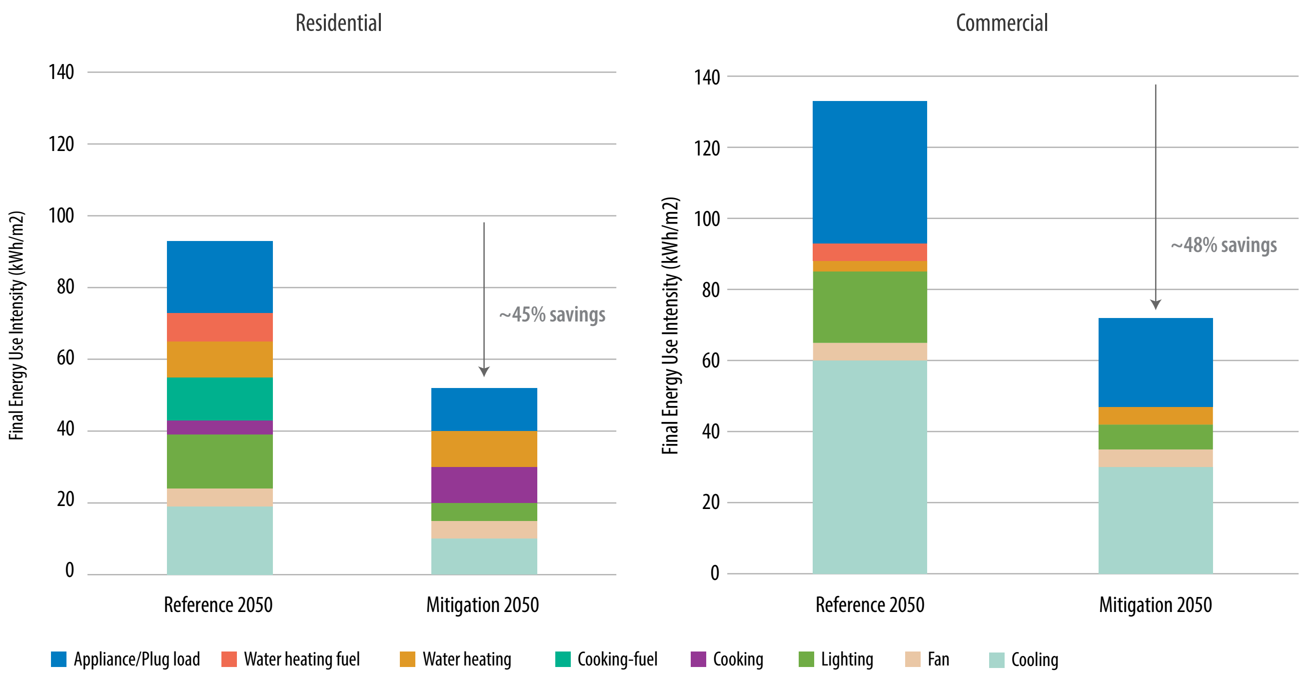


Figure 12: 2050 Mitigation potential for energy use intensity in residential and commercial buildings stock[5]



Tables 2 (a) and (b): Operational resource use leads to dramatic cost-effectiveness

	Performance metric	Standard design	Infosys design	%Reduction
1	Building energy consumption	250kWh/m2/year	75kWh/m2/year	70%
3	Air-conditioning design (Reduction in heat load)	300sqft per TR	750sqft per TR	60%
4	Total building electrical design	6 W/sqft	3.5 W/sqft	56%
5	Water (Office Spaces)	45 liters/person	25 liters/person	45%

Type of building	Business as usual			High-performing			Cost Savings
	Annual energy use	Monthly Cost (INR/ sqft/ month)	Normalized (per employee/ bed/ hotel room))	Annual energy use	Monthly Cost (INR/ sqft/ month)	Normalized (per employee/ bed/hotel room))	
Class A Office	250 kWh/sqm/year	14	1400 INR/ employee/month	60 kWh/sqm/ year	3.25 INR/ sqft/ month	325 INR/ employee/ month	
Hospitals	300 kWh/sqm/year 15000 kWh/bed/ year	16	8500 INR/bed/ month 300 INR/bed/day	150 kWh/sqm/ year 7600 kWh/bed/ year	8 INR/sqft/ month 150 INR/ bed/day	4300 INR/ bed/ month	INR 1 lakh per month for a 100-bed hospital
Hotels	400+ kWh/sqm/ year	23	16000 INR/room/ month	200 kWh/sqm/ year	11 INR/ sqft/ month	9600 INR/ room/month	INR 1.5 lakh per month for a 100-room hotel

Sources: 2a Infosys. 2b Superhuman Race[46] an enormous untapped potential for a circular economy. The Construction and Demolition Waste Rules and Regulations encourage recycling waste.[52] In the built environment the construction-material inputs accumulating in buildings can be accounted as stock.[53]

A paradigm shift in our consumption, disposal, and reutilisation patterns is required for circularity[54] and some interventions are as follows:

- Closed loop energy and water systems: If buildings can generate their own energy on site, this supports the move towards zero energy, and eventually negative emissions buildings. Waste heat from HVAC systems can be captured for chiller/boiler systems. Water efficient fixtures and fittings, capturing rainwater, using grey water recycling systems can support overall reductions in the use of water, particularly, in the current wasteful use of potable water for non-potable purposes.
- Buildings envisioned as material banks: Materials reuse after the useful life of the building ensures recycling of building materials, and reduction/elimination in the use of virgin materials. Therefore, transparency of material composition is a fundamental shift that needs to occur in standard building and construction practices, as well as standardized tagging to promote traceability and transparency in supply chains.
- Recycling of construction/ agricultural/industrial waste: Innovative approaches where discarded materials from one sector can be redirected into the buildings and construction sector, e.g. rice husks as binder and thermal insulation. Other alternatives to clay fired bricks are autoclaved concrete blocks (AAC), recycled aggregates in place of conventional aggregates: sand and gravel, and Portland cement to be replaced by blended cement using recycled fly ash or slag.[55]
- Life Cycle Carbon Assessment (LCA) and Life Cycle Costing (LCC):56 A Life Cycle Carbon Assessment (LCA) highlights trade-offs of material selection and their interaction and energy performance to identify an appropriate balance between the two, to reduce overall environmental impacts, higher upfront cost of high thermal mass that can reduce a building's peak energy demand. LCA takes into account a wide range of impacts such as global warming potential, stratospheric ozone depletion, acidification of land and water sources, eutrophication, and depletion of non-renewable energy sources to name a few. Life Cycle Costing (LCC) is best performed early to leverage the design phase and ensure a reduction in life-cycle costs.

3.1.4 Benefits of Decarbonization

Decarbonization strategies have the highest potential for reduced operational expenses, climate change adaptation and mitigation, environmental remediation and stewardship that translates to gains along all three aspects of the triple bottom line, as follows:

For Prosperity, i.e. economic consideration: At the macro level, the economic benefits can include enhanced energy security, macroeconomic development and industrial productivity; fostering climate-tech innovation, creation of future-ready businesses, serving the deprived, marginalized and vulnerable communities for local resilience, as well as creating potentially higher-paying jobs and asset values. At the building level, the benefits include reduced operations and maintenance costs and avoided/deferred capital costs due to equipment retrofits, leveraging revenue-generation opportunities from utility incentive programs, and potentially tradable certificates due to reduced GHG emissions for an organization/ neighborhood/ campus.

For the Planet, i.e. environmental consideration: Environmental sustainability, reduction in GHG emissions and air pollution, enhanced resource management, biodiversity enhancement and restoration of the natural habitat.

For People, i.e. inclusive diversity and equity consideration: At the macro-level, the benefits include human health and well-being due to decreased pollution with a shift away from fossil fuels, economic development through better employment/upskilling opportunities from green jobs, and poverty alleviation through distributed energy access. At the building level, energy conservation-based measures and retrofits can be integrated with fire and safety upgrades, asbestos and lead removal, and indoor humidity control and air quality improvements. Policies need to leverage geographical and cultural diversity in local material and building typologies to meet growing demands for housing and infrastructure.

Figure 13 shows triple bottom-line calculations based on including facilities cost savings, carbon credits, and human health and productivity benefits from an example of facade energy efficiency measures. It demonstrates that the payback period reduces to less than a year, and return on investment jumps to over 500% if decision makers move beyond first -costs to triple bottom line decision making to support investments in high performance, decarbonization technologies.[57]

A circular economy keeps resources in use, extracts maximum value, recovers and regenerates towards a zero-impact built environment (energy, water, waste), and significantly reduces lifecycle emissions. The benefits include creating jobs in the housing and construction sector that is one of the largest sources of employment in India accounting for 60% of the working population, application of circular principles supports resilience, reduces resource use and lowers overall emissions.

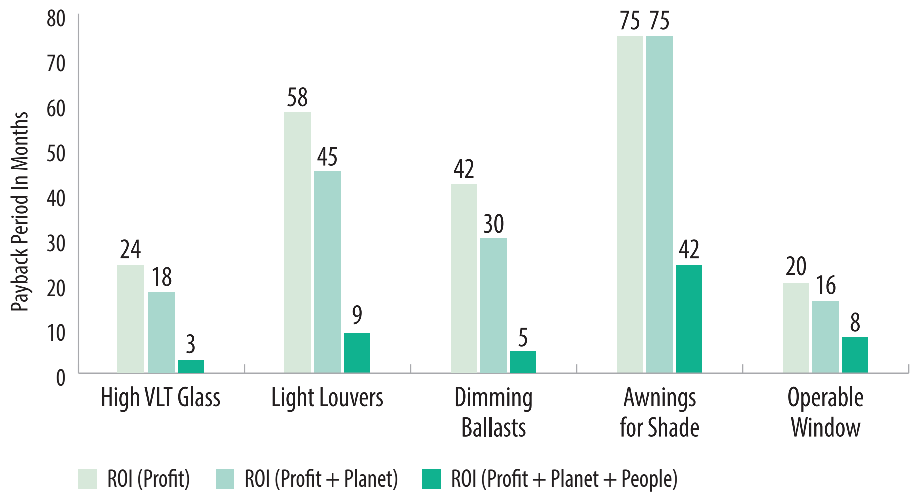
Decarbonization is projected to become a big market opportunity. According to Navigant Research,[58] the global market for energy efficient building technologies is expected to grow to nearly $360.6 billion in 2026.

3.2 Democratize for human wellness

How can communities access affordable climate responsive development with a combination of innovation and wisdom to ensure resilience and wellness in the living environment?

- Low-energy solutions that are responsive to regional and cultural diversity are critical for achieving human health and wellness in the built environment
- Inequity and marginalization needs special attention given the fact that impacts of climate change would impact the poorest economies and communities the worst
- Country-specific constitutional rights and universal Sustainable Development Goals (SDGs) are becoming more relevant in addition to global attitudinal change, particularly amongst the youth

Figure 13: Triple bottom line framework utilized to show value from illustrative energy efficiency measures[57]



3.2.1 Context of Democratization in the Built Environment

Sustainability and wellness are intrinsically linked with two dimensions, generational and geographical. Generational sustainability deals with intra and inter-generational capacity, i.e. the current generation sustaining itself to give rise to a healthy second generation. Geographical sustainability determines the ability of a location to sustain life (biodiversity/ ecosystem services, water and civilizations).[59] Diversity is fundamental to sustainability,[60] however prevalent ideologies of development in the built environment are predominantly characterised by standardization.

The groundbreaking Brundtland Report[61] highlighted the inclusiveness of diversity for sustainable development. However it was only through the Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development, ratified by world leaders in September 2015, did the world officially converge on this shared perspective. The SDGs are 17 interlinked global goals designed to be a "blueprint to achieve a better and more sustainable future for all by 2030".[62] It is undeniable today that the vitality of the natural environment has to be reinstated to achieve well-being in modern human society.[63] However, the pandemic has completely derailed SDG targets,[64] particularly those aimed at alleviating marginalisation, deprivation and vulnerability, that relied on sustained economic growth and globalisation[65] implying that communities must develop decentralized resilience relying on local resources.

The immense diversity in cultures, biodiversity and geographies is reflected in the living environments across the globe, and is also evident in India. Traditional settlements have a much greater resilience to withstand climate change[29] and could provide solutions for adaptations.[66] Nature-based solutions are more effective in realizing a drastic drop in carbon emissions (Figure 14).[60] However, wide spread transitions to modern buildings and even energy-efficient appliances is yielding counterintuitive rebound effects, leading to increased energy consumption, waste and GHG emissions.[10, 67] This can be attributed to increased affordability and increase in lifestyle intensity and population.

Unrelenting consumerism, pursuit of lowering (manufacturing, resources,

labour) costs and increasing sales, and human conscience shadowed by the insatiable targets of maximising profits is unfolding into a conundrum of climate-change, mass species extinctions, unprecedented biodiversity loss and forest-fires, famine, sea-level rise, inequality[68] and pandemics. Unprecedented as it is, humankind is not only faced with the nearly unabating pandemic and climate-change, but also the emerging evidence of forever chemicals, micro/ nano plastics and endocrine disrupting chemicals (EDCs) that can now be found in the placenta of newborns,[69] fruits and vegetables[70] and marine life (including seafood).[71] These can be traced to the insatiable reliance on single-use synthetics in our living environment. In India, nearly 77% of India's population is exposed to air pollution levels above the National Ambient Air Quality Standards safe limits, leading to cardiac distress and diseases such as asthma and cancer. Construction is a major source of finer SPM 10 and SPM 2.5 pollution, which could enter deeper into the lungs. Worsening air pollution not only impacts human health, but also reduces crop yields, alters rain fall patterns and affects climate change.[72]

Human health is an indicator of the state of the living environment, and approaches to wellness often work best if root causes of ill health are traced and eliminated in the living environment.[73] Never before in history has 'wellness' been so emphatically on the global forefront, with emerging clarity and opportunity on what it implies both for the built and the natural environment.

The infamous retreat of migrant workers during the 2020 pandemic in India (Figure 15 (a)),[74] a large share from the construction sector, to their native villages has also instilled a sense of enquiry on the possibility of dignified jobs, livelihood and social cohesiveness back home. This could not only reconfigure and regulate the rural-urban migration through self-sustaining work opportunities, but also promote decentralized, but connected, rural economies and consequently lead to urban decongestion. Time is indeed right to support the PURA[75] initiative with renewed vigour. The void of skilled and semi-skilled labour left behind in urban areas and the additional skills required to build and maintain the connected (smart) rural-urban infrastructure opens up much-needed jobs for India. In terms of human capital, unemployment and

Figure 14: Nature-based solutions could provide much of the mitigation required to restrain global warming

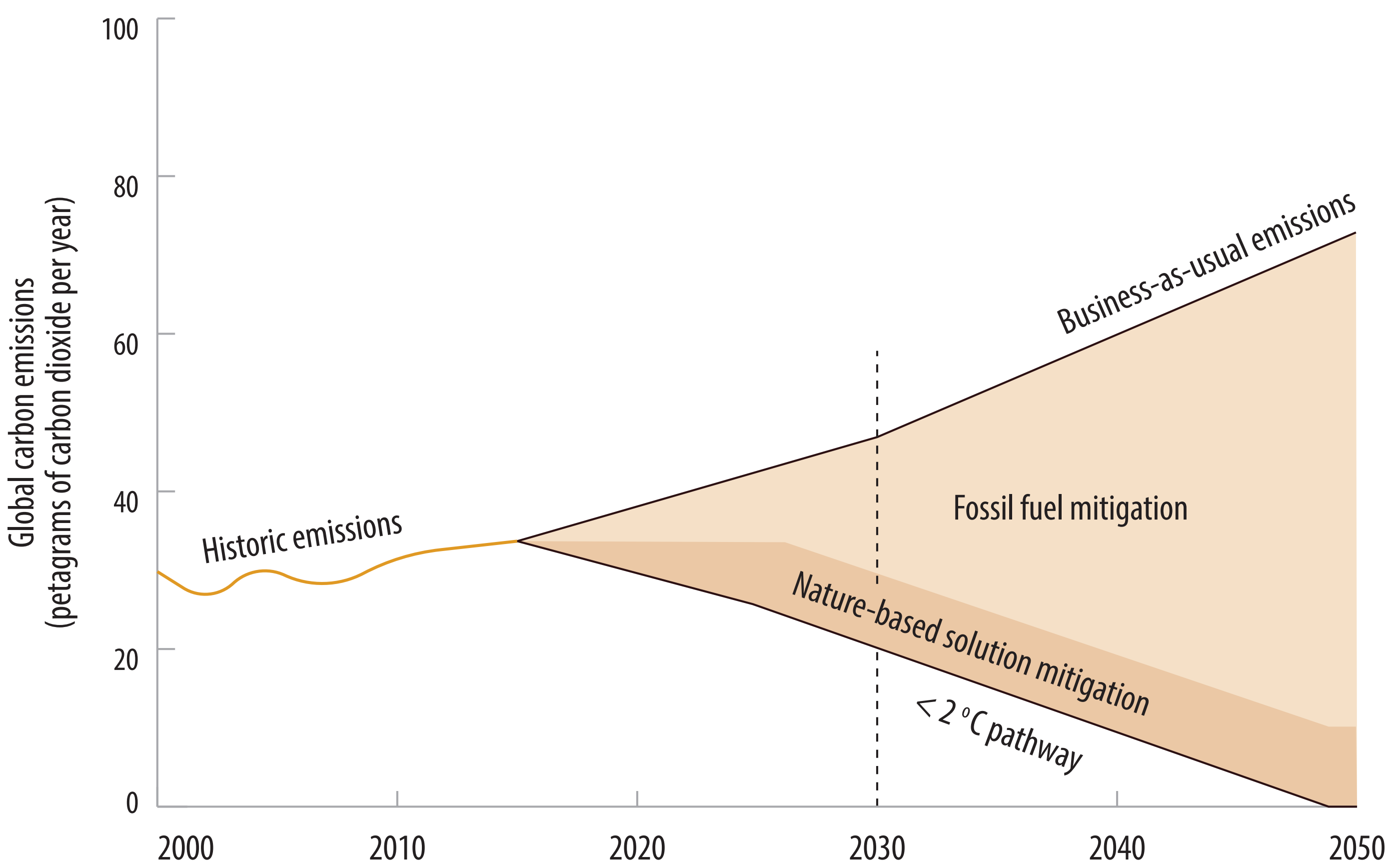


Figure 15 (a): Reverse migration - rural and urban jobs

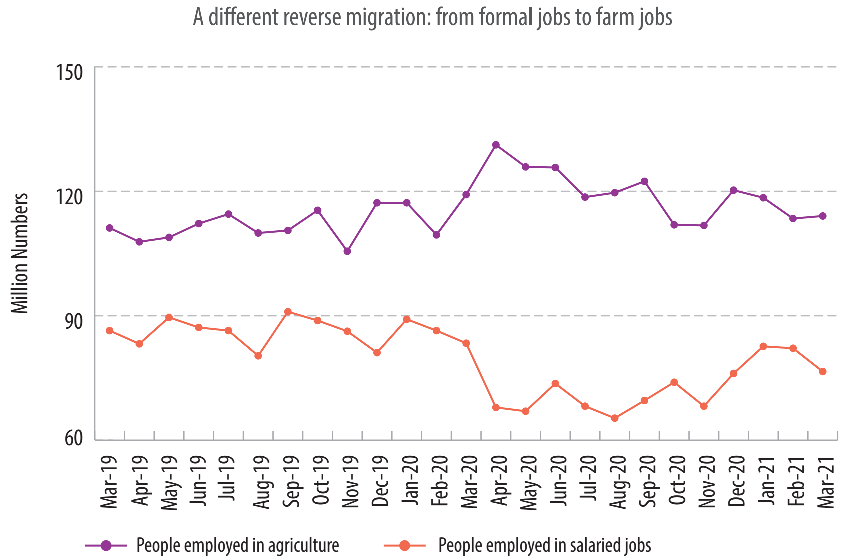
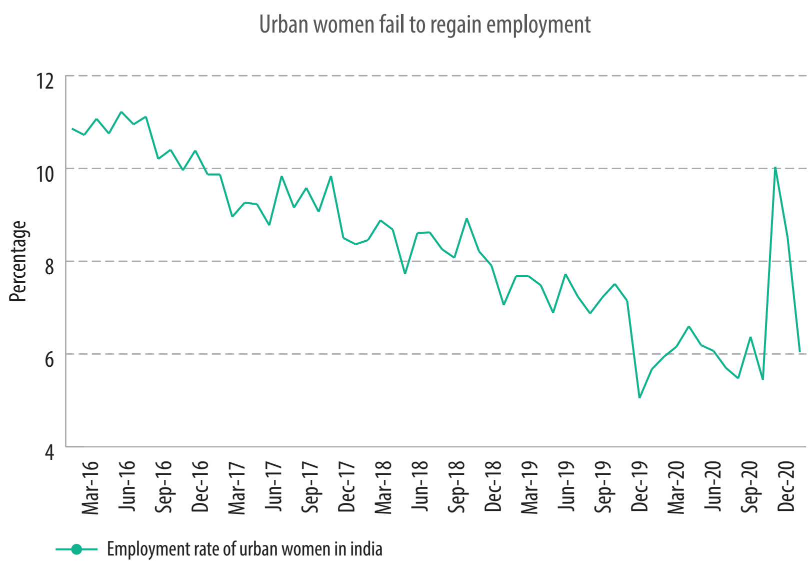


Figure 15 (b): Urban female labor participation rate after lockdown



disillusionment amongst the youth is unprecedented, with disparity in engaging the potential of women in urban areas and a drastic drop in urban female labour participation rate (FLPR)[76] (Fig 15 (b)).

In urban India, work from home is resulting in burnouts and hitherto unforeseen family stresses. A recent study in India has found 29% burnout in workforce.[77] Unbridled dependence on digital platforms and social media during the lockdown has adversely impacted sleep patterns and mental health amongst adults, and increased depressive symptoms among the youth, particularly students. Children too have had to face domestic stress and also restrain their joy of playing with friends outdoors. The Indian Psychiatric Society reports a 20% increase in mental illness.[78]

These evidently are impacts in urban habitations, with rural habitations remaining reasonably insulated to negative mental illnesses attributed to long indoor confinements and social isolation (this is not to undermine the economic distress in rural habitations). This draws attention to human-sensitive design and functioning of urban settlements, which are increasingly polluted, highly congested and lack social conduciveness.

Democratizing fundamentally aims to provide a built environment conducive to wellness, productivity and social equity/harmony, accommodating diversity in geographies, cultures and local resources satisfying both inter and intra generational aspirations. If wellness were to be directly interpreted as a healthy living environment integral to human survival and well-being, then the 1972 Stockholm Declaration recognizes the right to a healthy environment as constitutional. Article 51A (part 4A) of the Indian constitution states that it is the fundamental duty of every Indian citizen to value and preserve our composite (diverse) culture, to protect and improve the natural environment, while developing scientific temper, and strive for excellence in all spheres of individual and collective activity. Among the most explicit and unambiguous constitutional recognition of a right to clean environment, Article 110 (b) of the Constitution of Norway states "Every person has a right to an environment that is conducive to health and to natural surroundings whose productivity and diversity are preserved. Natural resources should be made use of on the basis of comprehensive long term considerations whereby this right will be safeguarded for future generations as well".[79] These constitutional stipulations imply that every single person is entitled to wellness by committing to preserving and protecting the natural environment.

3.2.2 Challenges and Opportunities for Democratization

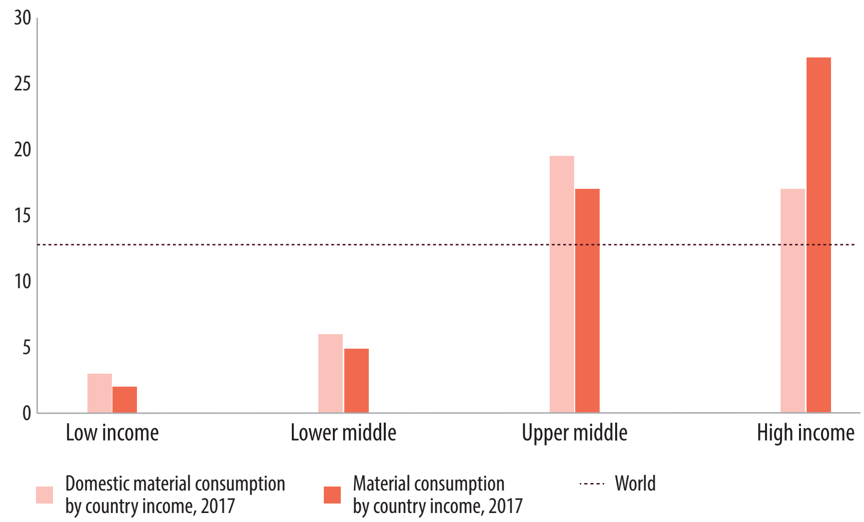
Besides environmental disruption and decimated biodiversity, salient challenges to democratization include marginalization (inequity, deprivation, unemployment, gender disparity), increasing aspirational discontent amongst youth (particularly rural), disillusionment particularly amongst skilled artisans/workforce, stigmatized diversity, rapidly disappearing vocational (livelihood options) diversity and inequitable access to wellness, and vulnerability to climate-change and pandemics.

While healthy competition is crucial to innovation and affordability, it has not ensured equitable access to resources and opportunities, and inclusiveness amidst diversity in society.[63] Being affluent has necessarily not translated to a meaningful life nor attaining a sense of happiness.[80] As ironic it may sound, being contented was seen as a hindrance to increasing consumption and growth of the modern economy. Marginalised and undeveloped sections of society have not only faced disruption of the ecosystem services and traditions they sustained on, buy have become vulnerable sinks for urban waste.[81] But now, diversity (geography, culture, ethnicity) which was once perceived as a voiceless hindrance to development, is proving to be the magic wand for decentralised models for ecologically inclusive low-energy habitations.

In all of the ongoing global conundrum comprising climate change, environmental disruption, biodiversity loss and the pandemic, wellness is emerging as an unifying concept in nearly all aspects of the built environment. For instance, the pandemic's 2 meter/6 feet rule for social distancing is but a proxy for providing equitable space and clean air for all, irrespective of who they are. Health is thus the great equalizer. Wellness is a broad level 'performance' indicator of the living environment and the functioning of its occupants and ecosystem services. There are a few critical market, policy and societal factors that act as barriers to achieve democratization of wellness.

Market factors include a lack of investment in technology/R&D value chains. The state of the built environment is an indicator of

Fig 16 Disparity in world global material consumption and footprint (SDG Target 12.2 on sustainable natural resource management, and SDG 8.4 on resource efficiency).[63]



the occupants, their preferences, ideologies and health. However, urban built environments tend to become speculative, isolationist, and non-inclusive. Building byelaws are culturally sidelined, with lakes, gardens/lung spaces, pedestrian/social/play areas encroached upon. Reliance on conventional high-energy industrialised building materials contributes heavily to the building carbon footprint. Investments into R&D to promote industry-academia collaboration is crucial to scientifically arrive at novel building materials/typologies, identify climate change mitigation measures, assess environmental toxicity and revitalisation options. Scientific scrutiny into traditional building practices, such as lime plaster,[82] clay-mineral paints, earthen construction, adobe, etc. could invigorate modern interpretation and adoption. These materials have been found to be more durable, environmentally benign, contribute to a healthier indoor environment quality[83, 84, 85] and are energy efficient.[86] They are also geographically more distributed, accessible and could pave the way for affordable housing.

Market mechanisms could evolve locally attuned strategies, relying on local materials, technologies and skill, which could potentially promote viable businesses, involving local stakeholders, for affordable and dignified housing. Markets need a paradigm shift to clean open spaces for greenery, walkability, social inclusiveness and recreation, which could fundamentally humanize the built environment. Resilience to climate change, extreme weather events and pandemics also needs to be accommodated through adaptable/buffer spaces (vehicular parking, stadiums, etc.), emergency shelters and backup utilities for connectivity, power, water and sanitation. Community spaces such as shopping arcades/malls, community halls should be designed as community resilience hubs for adaptive use during emergencies.

Policy and regulatory factors are also barriers. Policies must explicitly and effectively curb exploitation and marginalization arising from upper middle class consumerism (see Figure 16). Affordable housing and equitable access to built-environment services, could be explored by leveraging on designs and technologies relying on local resources and skill. Emphasis can also be placed on scalability and customisation of building codes characteristic to local geography and climate. Climate-change vulnerability assessment and identification and adoption of appropriate mitigation measures also needs priority.

Policies need to be sensitive to rural youth, their aspirations for modernity, and should be aimed at reinstilling dignity in rural employment/vocations for livelihood enhancement. Urban settlements require interventions aimed at decongestion, pollution reduction, social inclusiveness and humanising its scale and functioning. Peri-urban spaces could provide the cultural setting for rural-urban transition/buffer spaces. Access to modern infrastructure, mobility and digital transformations needs to be ubiquitous across rural and urban habitations. Rural habitations need to be perceived as decentralised economic centres with a seamless connectivity and access to national economic activities.

Societal saliency is an important factor. Built environments evolve as theaters for diverse societal activities and reflect prevalent attitudes, economic preferences, lifestyles, and environmental sensitivity. An emerging attitude of environmental empathy, particularly amongst the youth across the world, is also recognising the imminent risk and uncertainty attributed to climate change. Seventeen countries from the Middle-east, South Asia and North Africa face the risk of extreme high water stress (India ranked 13 on the list).[87] Inclusiveness needs to emerge through citizen science and ownership, comprising diversity in cultures and geographies, vocations, businesses and aspirations. This would foster decentralized economic models and instill a sense of dignity and livelihood in jobs leveraging traditional material use and skill. Given the particularly motivated youth who want to revitalise and enhance the quality of the living environment, market forces are also following suit, with environmental sensitivity, operational energy neutrality and sustainable manufacturing practices being projected as value the consumers pay for. The pandemic has also unified global perspectives on the need for bolstered health-care infrastructure to face similar eventualities. However, policies in favor of wellness need to be either aligned or disengaged from political priorities, and can in fact build on well defined constitutional rights to a clean living environment.

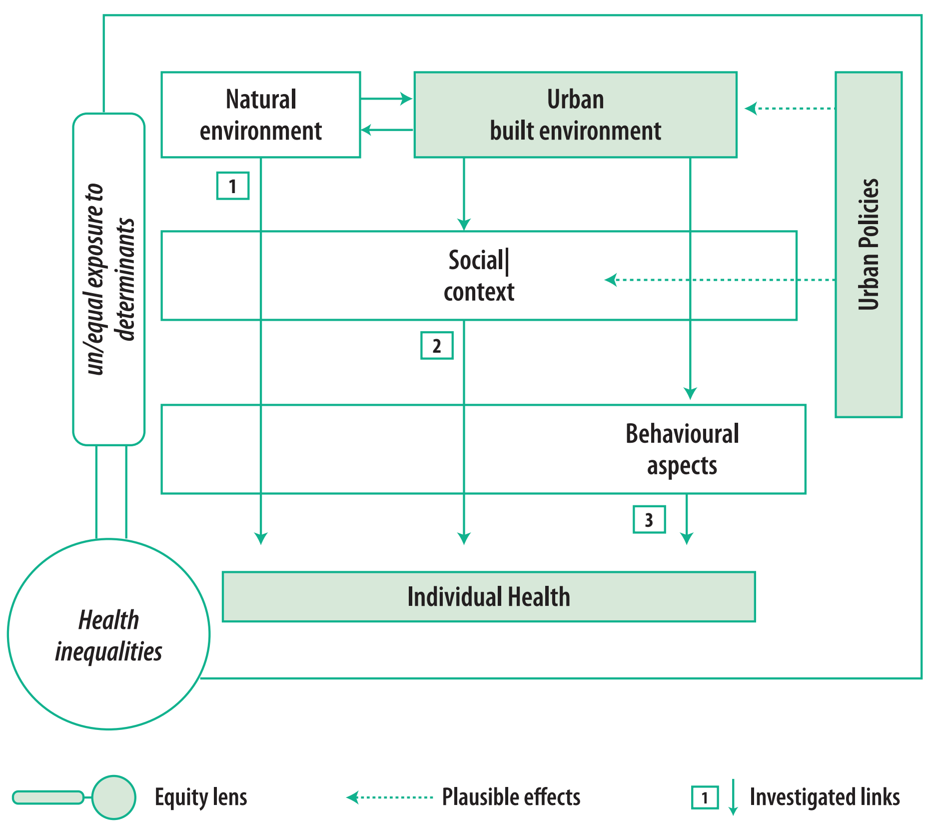
3.2.3 Approaches for Democratization

Democratization requires an enhanced inclusiveness amidst cultural and environmental diversity, augmented with a societal transformation towards wellness and resilience in the living environment, embracing the all pervasive digital technology. Sustainability operates in the intersect between the natural and the built environment, with societal attitude playing a critical determinant in terms of how the built environment operates and integrates within the larger natural ecosystem.[88] Three linkages in the living environment are crucial to improve equitable access to health (Fig. 17),[89] viz., [1] The city-nature linkage influencing health, addressing the built form and natural environment, [2] The city-society linkage addressing societal diversity, and [3] The city-individual linkage addressing behavior design manifestations in the living environment.

In order to achieve the democratization of the built environment, we suggest the following approaches:

(1) Inclusive, healthier built environments and communities

Fig. 17: Addressing health inequalities in the built (urban) environment



(2) Resilience of people, communities, and organizations to unprecedented health and climate risks

(3) Reinforce positive behaviors.

These are described below.

(1) Inclusive, healthier built environments and communities

Given that a larger share of our time (> 80%) is spent indoors, the impact of indoor environment quality on health is paramount. This is most evident during the ongoing pandemic, where not only are the design and quality of spaces being put to the test, but also access to services amidst social isolation testing our resilience to maintain sanity. A deliberate focus on individual happiness could translate to spaces conducive to relaxation and vocational leisure, with societal mechanisms geared to identify emerging problems such as depression, anxiety and stress. Empowering people with disabilities, to contribute to wellness, would require their needs to be intertwined seamlessly within the living environment. With a large aging population and increasing loneliness and social isolation, the built environment (and families) need to revalue their role in the mental health and wellbeing of children,[90] with the win-win situation of maintaining a cheerful and active daily routine for the aged resulting in lowered depression and other aging severities.[91] Smart geriatric care also needs an empathetic inclusion and concern.

In the industrial/office setup, the shift to an impact metric such as value on investment (VOI) is a broad measure of all the benefits conferred through employee health and wellness programs. VOI benefits go beyond lower health care expenses and include metrics as productivity, employee morale, retention and satisfaction, all of which impact an organization's bottom line.[92]

Indoor air quality and hygiene are directly determined by outdoor environmental quality and indoor space-material configurations. The ongoing pandemic has emphasised the importance of fresh air, improved ventilation[93] and sunlight, the lack of which is clearly evident in numerous urban dwellings. Further, its paramount to address exposures in the indoor environment such as disrupted circadian rhythm and stress due to bright-white LED luminaires,[94] VOC's, aerosols,[95] pathogens,[96] endocrine disrupting chemicals,[97] plastics[98] electromagnetic radiations, etc., that are increasingly contributing to chronic morbidities. A cohesive approach across all societal stakeholders, viz., residence, agriculture, administration, industry and commerce, education and research, infrastructure services, transport and communication,[59] could go a long way in ensuring indoor health and wellness.

We are undergoing an existential moment in our relationship to the built environment around us, that the built space around us is no longer a shelter but a threat to health and wellness. While hospitals are intended for disease control, the apartments, offices, classrooms, restaurants, shops, and cinemas halls that we live, work and play in are not designed to manage disease transfer. We should take into serious consideration the design and operations of built spaces as potentially improving our comfort and wellness. For instance, using computer models to study aerosols emitted by an infected person in different configurations of room air distribution and identifying scenarios where infectious doses could potentially occur in various building types.

Similarly, another important facet is the deep linkage between HVAC and COVID. The conventional notion that a building's tightness is directly proportional to energy efficiency is under challenge as part of the larger conversation around infection control. However, energy efficiency and greater fresh airflow (up to 100% outside air/100% exhaust) are achievable via control systems that keep CO2 within acceptable limits while balancing the amounts of outside air and energy.

(2) Resilience of people, communities, and organizations to unprecedented health and climate risks

Just as much as wellness in the built environment is crucial, so is the mental resilience of the inhabitants. Buildings serve to stimulate our senses of the environment, and have a direct bearing on our cognitive function. Time amidst vegetation/nature significantly lowers stress levels and provides unparalleled sensory stimuli.[99] The largest epidemiological study linking green spaces and mental health reveals that exposure and upbringing of children amidst green spaces significantly reduces risk of numerous psychiatric disorders later in life.[100] Emphasis on dwelling and work spaces integrated with open and green spaces is paramount to mental health and productivity.

The recent pandemic has revealed that current spaces need to be reimagined[101] to be reconfigurable for humanitarian emergency requirements eg., housing migrants and those stranded without access to basic amenities, rapid deployments for patients, operation theaters, storage of relief material, etc.

With regard to climate change, the past two decades have also seen an unprecedented number and frequency of extreme events. Climate-related disasters have jumped 83% and storms by 40%, with 321 disasters reported in India between 2000-2019.[102] With rapid climate change, diverse building typologies and climatic zones need to be scrutinized for their adaptive resilience to withstand extreme climate events.[103] Vernacular dwellings reveal the largest resilience to withstand climatic variations in maintaining indoor comfort (without intervention or depence on air conditioners)[29,] or expensive concrete/steel construction.

Reliable energy access is also crucial, with decentralized and distributed energy generation, storage and backup, with a mix of renewables (biomass, PV, wind, etc.) providing varying degrees of resilience to disruptions.

(3) Reinforce positive behaviors

Tweaking societal habits and corporate behavior, to achieve decarbonization, is probably the single-most potent intervention, more effective than technological interventions[104,105]. Prevalent attitude that underlies societal behavior and actions is a fundamental determinant of sustainability,[88] and is often overlooked in achieving building performance goals and resource conservation. High-performance technologies thus often fail to achieve intended performance expectations.[106] India has a culture of resource conservation, frugal innovation, and spirituality associated with the environment. On the individual scale, behavior change strategies sensitive to the natural environment, combined with appropriate technologies can lower impact on the living environment[107] and prove to be cost-effective rather than replacing technology.[108] It is crucial to leverage on this inherent approach to transform the built environment, and then appropriately adopt modern green technologies.

According to the International Energy Agency (IEA) and the latest Intergovernmental Panel on Climate Change (IPCC), Working Group I, the world can reach net-zero energy by 2050 and limiting global warming to 1.5°C[109,110]. Notably, nearly two-thirds of the energy reduction needed to reach the net-zero goal will require people to change their behavior and enthusiastically embrace more-efficient and healthier practices for the planet and themselves. As the IEA puts it, "It is ultimately people who drive demand for energy-related goods and services, and societal norms and personal choices will play a pivotal role in steering the energy system onto a sustainable path." Behavioral change could be viewed as a wheel comprising three layers viz., sources of behavior, intervention functions and policy strategies, to identify change interventions.[111]

There are three main strategies for changing behavior: Regulations and mandates such as augmenting appliances and whole building standards, with penalties and fines ('sticks'); Market-based instruments such as peak pricing, mandatory carbon labeling, and incentives ('carrots'); and Information and awareness ('sermons') such as product labeling/public awareness campaigns, and comparison information and feedback for reducing excessive resource use.

3.2.4 Benefits of Democratization

Fundamentally, democratization carries the potential to moderate opulence and dramatically reduce per capita resource-energy footprint. Democratization can unify humanity at large, to rise up, recognize, and respond to the inequitable geographical distribution of vulnerability, deprivation and environmental disruption attributed to over-exploitation of resources, climate change and extreme weather events. Democratization would create equitable opportunity and access to housing, energy, wellness, technology, communication and mobility to accommodate emerging aspirations, while reinforcing faith and dignity in regional identity and uniqueness. The fundamental benefit achieved is a culturally and ecologically inclusive living environment that promotes health, safety, resilience and social harmony across all the diverse societal activities/sectors.

3.3 Digitalize

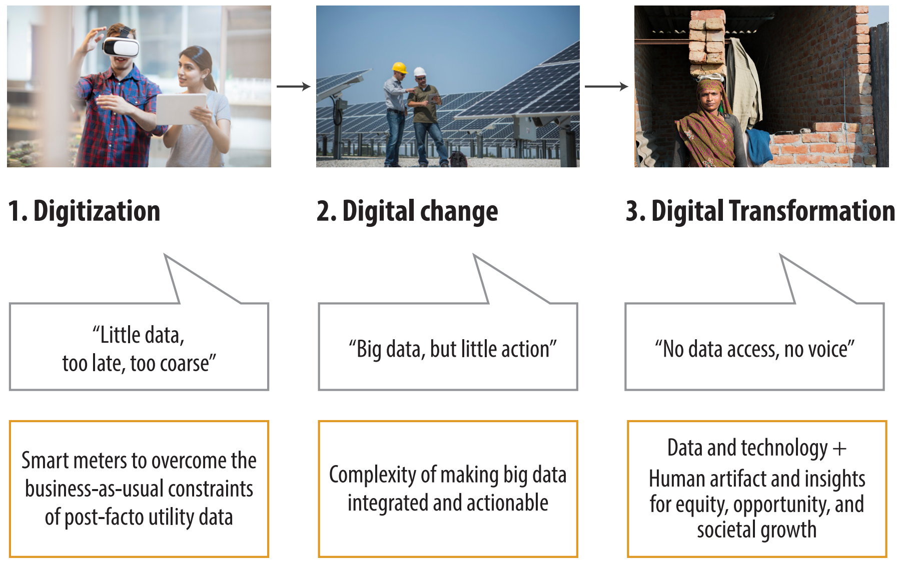
How can digital transformation provide an integrative platform for effective energy and resource utilization and conservation in buildings, revitalize ecosystem services and biodiversity for equitable social harmony, health and resilience?

3.3.1 Context of Digitalization in the Indian Built Environment

- Digitalization connecting buildings and communities across the lifecycle can be transformative in achieving decarbonization and democratization
- The shift from industrial age to information age is already occuring. The unique regional context of India must be considered to unlock digitalization opportunities

The pandemic has effortlessly dismantled normal life, and how we work, travel, communicate, dwell and operate in buildings. The digital network has prevented a total socio-economic collapse, and enabled a semblance of normalcy. Digitalization has allowed us to go from isolation

Figure 18: Process of Digitalization



to inclusion. Access to mobile and internet communications has rapidly amalgamated businesses to coordinate and maintain operations. 94% of micro, small, and medium enterprises (MSMEs) have relied on information technology (IT) during the COVID lockdown.[112]

Digitalization even in normal times can enable transformative effectiveness in the built environment, viz. the value chain, resource consumption and CO2 emissions, and in the process create broad individual, organizational, and societal value. Digitalization in the built environment is a transformation that encompasses (Figure 18):

- **Digitization,** i.e acquiring data, at varying levels of granularity and frequency, from smart devices at the right volume and velocity, e.g. from advanced metering infrastructure, electric vehicle charging, renewable energy generation, weather stations etc., augmented with occupant feedback/surveys.
- **Digital change,** i.e. deriving intelligence through analysis, visualization, and enabling actionability, e.g. benchmarking and anomaly detection to enable energy efficiency or decarbonize energy supply.
- **Digital transformation** i.e. digital access to equitably unlock social and business value, particularly in the Indian informal and fragmented construction sector. This could seamlessly ensure income and livelihood enhancement, e.g. mobile based cash transactions for services (skilled/semi-skilled) availed, as well as unlock upskilling opportunities.

It is worth noting that in today's connected and digitized world, cybersecurity has become a strategic criticality due to the sophistication of

"The digital transformation of programs, processes and practices has become a proven accelerator in value creation and business/ implementation performance. In the corporate world, digitalization of Environmental, Social and Corporate Governance (ESG) management enables greater organizational transparency in business practices, integration of a broad range of data types and complexity, much beyond the spreadsheets of the past".[113]

cybercrime. Digital businesses require complex and distributed interactions among people, applications and data - on premise, off premise, on mobile devices and on the cloud, increasing cyber-vulnerability. As data flows from facilities, operations are becoming extant, the potential convergence with enterprise data and their provenance (origin and tracing of data) needs to be carefully considered. As the boundary between information technology (IT) and operational technology (OT) is getting blurred and the internet of things (IoT) is expanding, security requirements are increasing by an order of magnitude. The risk level is also commensurately increasing, to manage the massively distributed fleet of autonomous devices that make decisions that affect people, equipment and their interaction with the built environment. Securing business and people requires securing the physical perimeters, device edges, users, and data.

3.3.2 Challenges and Opportunities for Digitalization

There are several challenges and opportunities, based on three factors as follows:

Market factors include economic investments in digital technology value chains. The building industry is globally fragmented,[14] with inadequate digital infrastructure, lack of collaboration between suppliers and contractors, and siloed procurement across technologies. Data acquisition is often ad hoc, with a significant cost of change from legacy infrastructure. There is also a lack of integration between existing technology platforms and public datasets, and often insufficient knowledge transfer across projects and platforms. Investment opportunities must promote data synchronicity, ubiquity and equity by leveraging national initiatives for grid modernization and deployment of smart meters for system reliability, energy cost and theft reduction. Additionally, the smart meter rollout on the distribution grid should be mirrored with a rollout of "behind the meter" devices, i.e. smart meters on buildings and electric vehicle chargers for demand-side management. Investments must be made in materials and energy supply chains and procurement.

Policy and institutional factors include the implementation of standards for gateways, IoT devices, communications protocols, cybersecurity, data privacy, data provenance and ownership. Other key issues are the lack of standardization of data formats, i.e. metadata dictionaries, schemas, and models, and the lack of comprehensive energy data acquisition with clear goals and use-cases. Robust policies and regulations to trigger data acquisition and visibility across energy sectors and scales of communities e.g. building, campus or city monitoring, benchmarking, and reporting are important opportunities.

Societal saliency is hindered by the lack of data, visibility, and tangible evidence of benefits across decision-makers. There is also a lack of capacity to translate data into action and derive benefit. The opportunity lies in leveraging new digital services, such as smart metering and societal initiatives to also support the informal sector through mobile wallets to connect participants and upskill them for improved livelihood.

3.3.3 Approaches for Digitalization

In order to achieve the digitalization of the built environment, we suggest the following approaches:

(1) Digitalize the building lifecycle

(2) Develop community resource operations and planning systems

(3) Unlock digital transformations unique to the Indian context.

These are described below.

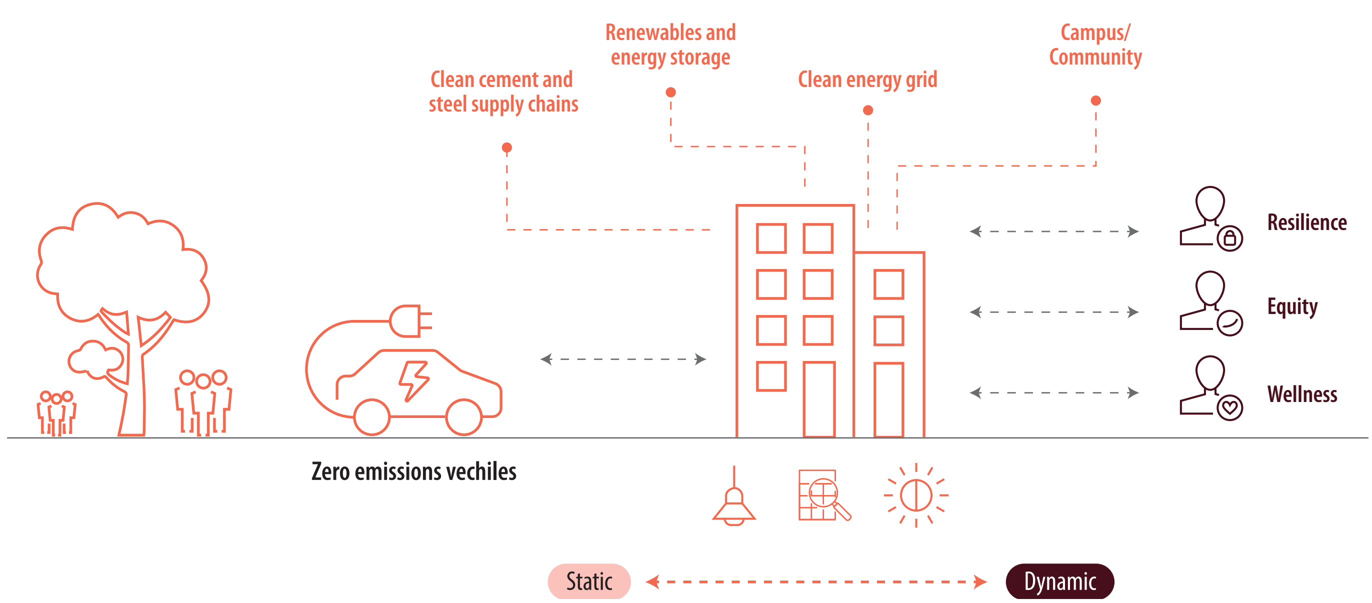
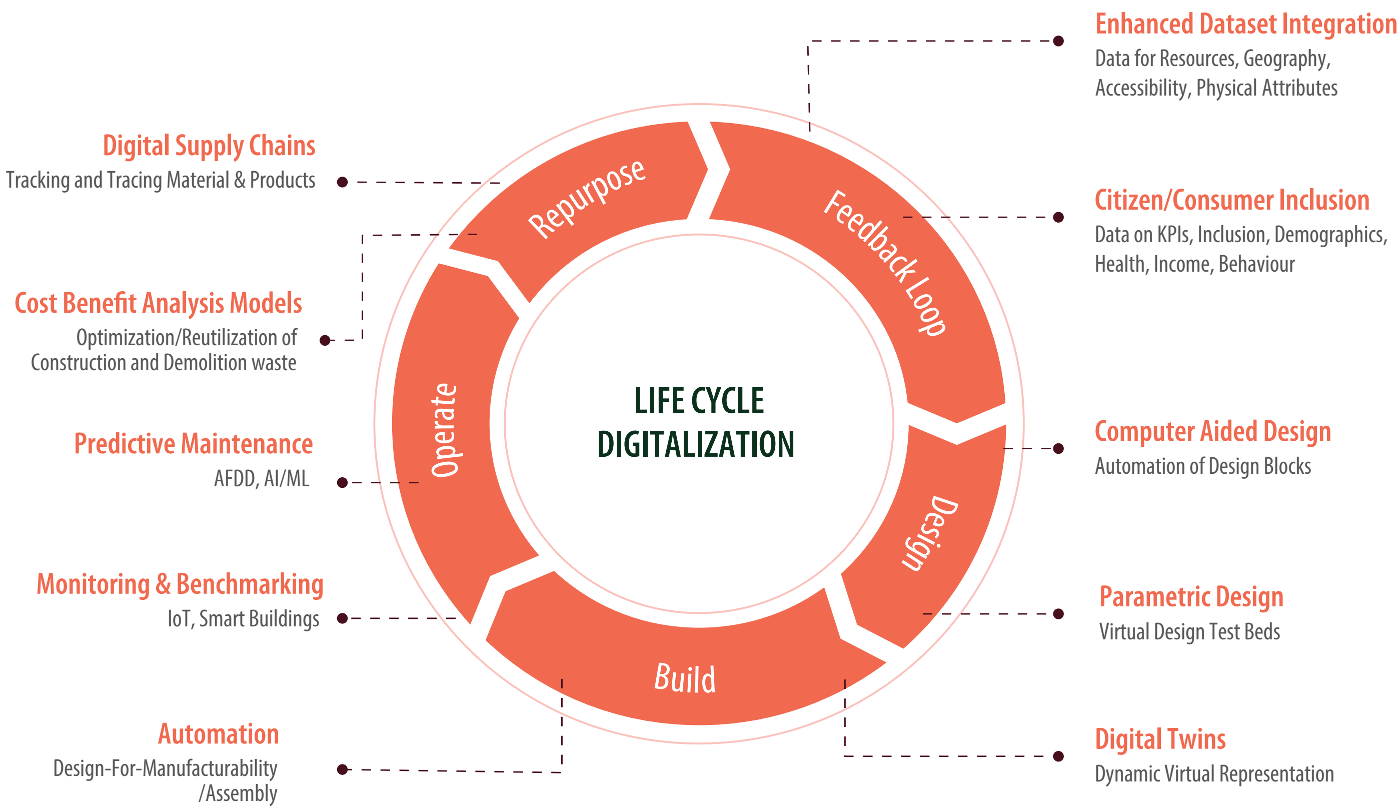


Figure 19: Depiction of various digital tools that can enable transformation of the built-environment life cycle[116]



Digitalize the building lifecycle

Building lifecycle management from design, construction, operations, retrofit, and end of life, including reuse and recycle through circularity[113] is critical. Digitalization offers measurement, quantification, and potentially greater insight, leading to smarter decisions, and ensuring value.

At the design stage, performing building modeling computer aided design (CAD) and parametric simulation enables site relevance, code compliance, and resource-use forecasting. State-of-the-art digitalization technologies include the Building Information Modelling (BIM) to create digital twins of the physical building. Digital twins are models that focus on a building's design, construction, and operations stages.

At the build stage, BIM aids design-for-manufacturability of modular, prefabricated, or unitized buildings that can enable rapid construction using decarbonized, low-embodied energy, circular materials.

At the operations stage, integrating meters, sensors and controls to track and adjust real-time performance is vital to ensure that resource-use is commensurate with the design intent. As mentioned in the Decarbonize segment, operational monitoring and controls overlaid on climate responsive design can enable upto 50-75% energy use reduction in new construction compared to business-as-usual buildings, and 25-40% in retrofits, with 2-3 year payback period.[23] Emerging artificial intelligence/machine learning (AI/ML) methods including predictive analytics and model predictive control[114] (Figure 19) open up the promise of optimization of the building, on-site energy generation and storage, essential to avoid energy costs, emissions, renewable energy capital expenses, requirements, reserves, ancillary services, and transmission and distribution (T&D) infrastructure investments. Strategies that help with avoided energy use and/or costs, capacity, operational expenses and emissions should also be explored.

In-person building audits may have lower first costs, however they only provide a one-time snapshot and manual diagnosis of the building's energy performance. Two digital solutions are available commercially: building management systems (BMS) that focus on ongoing building automation and controls and energy management and information systems (EMIS) that help automate the process of monitoring and benchmarking with real-time data. The EMIS family of tools consist of three types: Energy information systems (EIS) that help find energy waste using smart meter data, Fault Detection and Diagnosis (FDD) that detect and prioritize HVAC system faults; and Automated system optimization (ASO) that include control algorithms to minimize energy use across systems.[115] EMIS track energy use and waste at the whole building and sub-metered level, provide anomaly-detection leading to operational strategies (schedule, control) and retrofits (equipment, envelope), longitudinal benchmarking compared to past performance to ensure the persistence of savings, and cross-sectional benchmarking against peer buildings and real estate portfolios. EIS dashboards provide useful information to building owners, occupants, and operators about a building and its energy use, identifying cost-effective interventions, and enabling positive behaviors.

As the boundaries between the building, mobility, energy generation and storage become blurred, Internet of things (IoT) makes use of edge devices for communication between these systems in the field and the cloud, and enables crucial low-latency real-time monitoring in the built environment. An example of an IoT-enabled system at the whole building level is an integrated command and control center (ICCC, Figure 20) is an integrated platform for managing multiple building systems (HVAC, power, lighting, UPS, sewage treatment plants, and water meters). Enhanced data integration

Figure 20: An integrated command and control center with its features and capabilities.

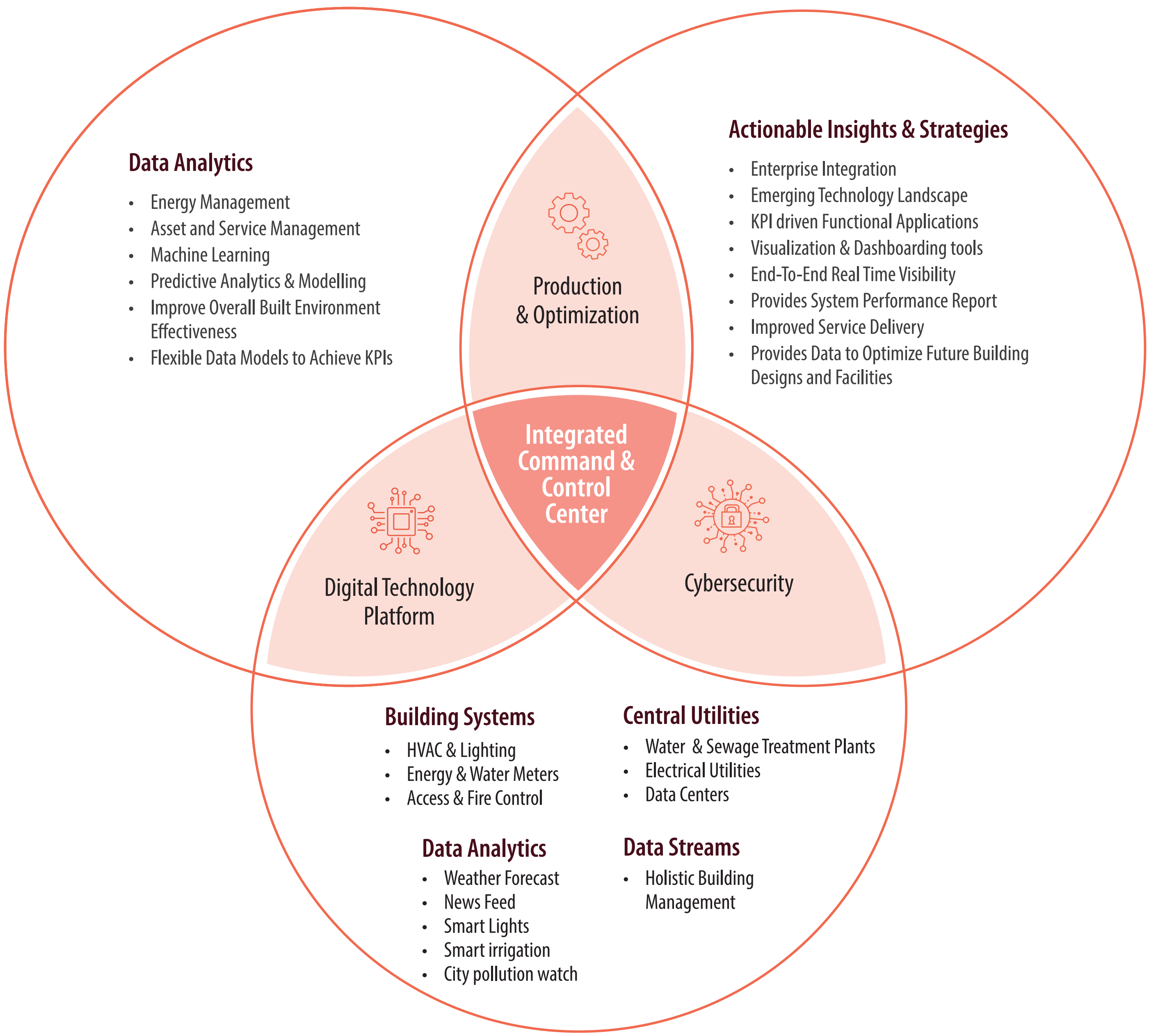
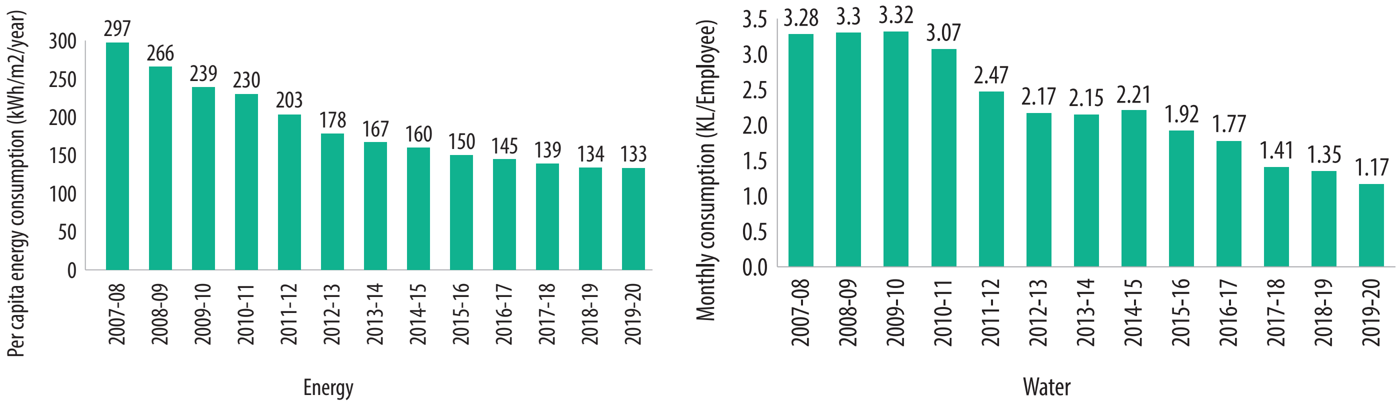


Figure 21(a),(b): Per capita reduction in energy and water consumption (2008-2020) across Infosys campuses



between different subsystems, can help converge siloed aspects of the built environment to identify energy-efficiency pathways. The ICCC can leverage real-time sensors and process data, implement advanced data-driven diagnostics on the cloud to improve equipment operations and lower downtimes. An ICCC can facilitate alarm and incident management for quick and efficient responses, and enable implementation of key performance indicators (KPIs) using role-based dashboards and reports.

Use of bleeding-edge artificial intelligence (AI) and machine learning algorithms integrated with 3D immersive technologies for unified building digital environments, could provide novel solutions that permit efficient building operations through predictive maintenance (Figure 19).

At end-of-life stage, data for building material reuse for recycling/repurposing is essential for decarbonization. Developing decentralized but integrated digital supply chains to track and trace materials and products end-to-end with a goal to deliver them at the lowest cost when and where they are needed.[117] Although challenging, given the informal buildings markets in India, this would provide an impetus to affordable housing, well-paying construction jobs, and enabling a circular economy, as well as environmental policy decision-making and adoption through citizen/customer inclusion.

The digitalization and decarbonization benefits in per capita energy and water consumption across the Infosys campuses with 51 Million square feet real estate foot print is shown in Figure 21(a), (b). While the organization has experienced a 166% increase in total employees, the operational energy has been halved and water use has been reduced by two-thirds per employee.

Community Energy Operations and Planning Systems (Community EOPS)

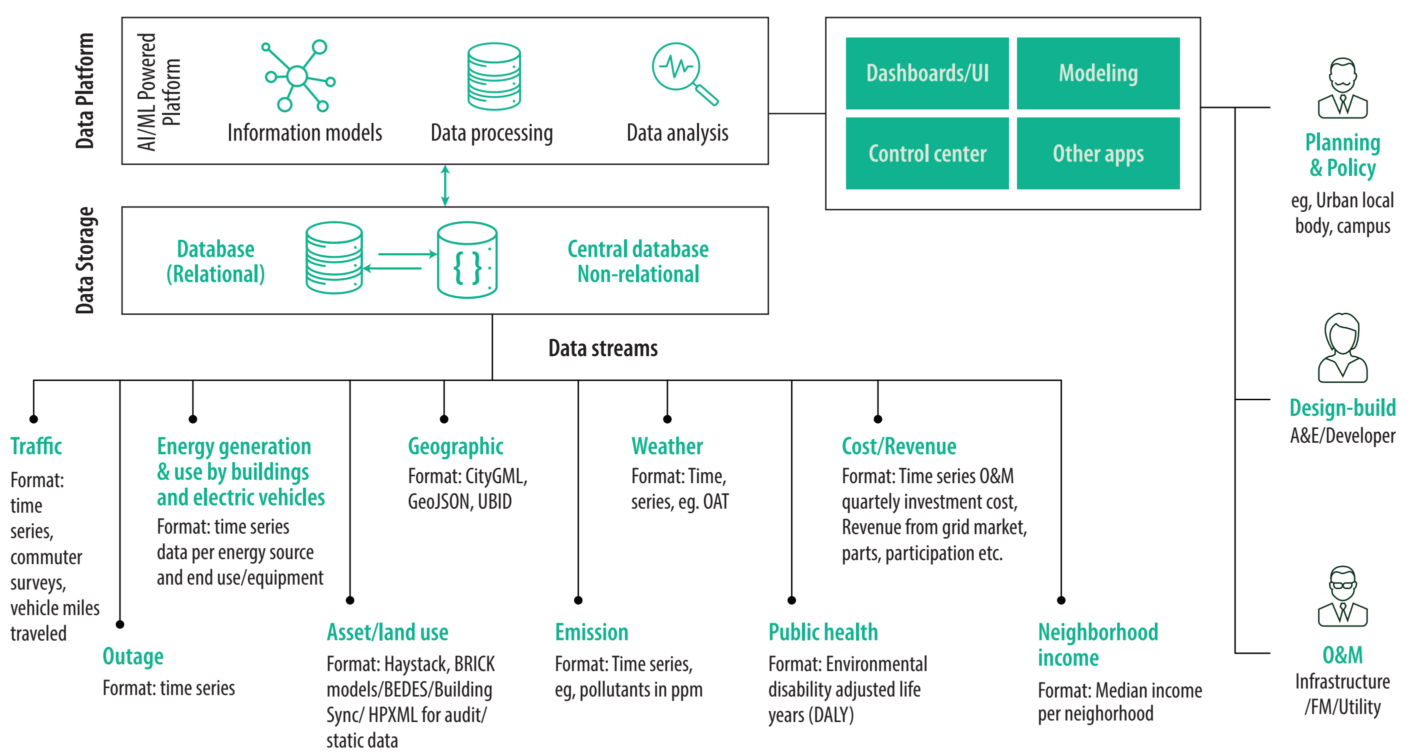
Digital transformation at the building-scale alone is not adequate. There are untapped resource savings opportunities possible only at the multi-building scale. Community-level data acquisition, analysis and action can provide significant benefits.[118] For instance, flexible load management across sectors (e.g.scheduling electric vehicle charging, managing non-coincident building peak loads, district and community energy systems) can reduce operating cost, and enable a resilient and greener fuel mix. Using the community's resources effectively enables economies of scale from shared energy infrastructure, potentially enhanced grid/microgrid integration, and efficiently coordinated operations.[119] For instance, data visibility can help leverage the diversity of loads across building typologies (e.g. 24X7 data centers vs. single shift commercial buildings), as well as harness opportunities to utilize waste heat, district heating and cooling plants and thermal storage, thereby creating community-level closed energy loops.

Early adopter organizations have launched smart platforms, to ensure that their built infrastructure can be resilient, operate efficiently, and help achieve sustainability goals, such as the ICCC (Figure 20). Expanding on ICCC provides the business case for a conceptual Community Energy Operations and Planning System, a data exchange platform for the acquisition and sharing of richer energy and complementary datasets. As shown in Figure 22, the architecture integrates datastreams from energy, water, waste, which when overlaid on attributes such as location/geography, asset and land use, weather, emissions, and social data such as demographics, health, and income enables deeper insights for planning through operations of a campus or community. The Community EOPS with data acquisition and sharing, cross functional integration driven by prioritized use cases, and common metrics and actionable visualizations can provide significant value across planning and operational stakeholders. There is still further research and development required to solve for common semantic data models, interoperable systems, and methods to collect, normalize and integrate data, make it cybersecure, and support decision-making.

The value of such a conceptual platform is for multiple users across the community's life cycle who can have a single pane of glass visibility of integrated data, that may create a multi-fold value, as follows:

- Community planners and Urban Designers: for energy data-integrated land use planning and infrastructure investments in sustainable dwellings, microgrids, storage, district heating and cooling, agriculture/irrigation facilities etc. Data analysis and ML can help improve planning by integrating information for the protection of resources and biodiversity.
- Facility and Energy Operators: for harnessing energy efficiency (leveraging optimizations at community scale) and flexible load management (grid-edge load management to offset, shift and flatten loads). This can enable communities with smart intelligent monitoring and control for enhanced emergency response, detection of energy waste/water leakages, opportunities for solid and liquid waste management and reduced pollution. Note that this platform may be integrated with supervisory controls. Such a platform could integrate with automated e-waste processing and robotics that could eliminate human risk and exposure to toxic contaminants. Such a platform could also provide detailed operations scheduling and supervisory control of existing buildings or distributed energy portfolios on a week-ahead basis, using forecasted loads and weather data. This could reduce time-of-use (TOU) electricity costs, maximize renewable resource utilization, ensure adequate back-up capacity for reliability, and generate revenue from future demand response or ancillary services.
- Policy makers: for enabling triple bottom line benefits, i.e. economic benefits such as cost savings and revenue generation (through participation in grid services), energy and environmental benchmarking and reporting, and social benefits such as community resilience and awareness/behavior change.

Figure 22: Framework for a Community Energy Operations and Planning System that integrates energy and complementary datasets to provide value across various users in the built-environment life-cycle[118]



Unlock unique digital transformation in the Indian context

The Indian built environment provides unique digital transformation opportunities, that may be harnessed through the following approaches:

Pervasive digitization of the built environment with strategic growth of national computing and networking infrastructure[121]

Secure pervasive integration of sensing and control across all buildings can enable community-level data acquisition, analysis, and action. While commercial telecom and computing infrastructure is deployed widely in India, the onus of integration, payment and use of those services falls on the building owner. A key potential area for investment and institutionalization is a national computing and networking resource[120] that can facilitate large-scale IOT data collection from buildings at city-scale. Typically the building sensor data may only be used by the building/facilities manager to optimize its day-to-day operations and occupant comfort. Collecting this at a community or city-scale will leap-frog opportunities to correlate this city-wide consumption view with the regional power grid, distributed renewable energy, energy storage, EV charging etc. creating transformative opportunities for environmental and social benefit. Using machine learning techniques, this data can reveal currently hidden patterns of use and interdependencies across communities, creating further opportunities to predict and mitigate climate or grid related impacts.

This national computing and networking resource could acquire these large amounts of data, through the integration of network capabilities and services across wireless, high-speed cellular and fiber optics, enabling data transport back to the computing centers for processing. With community-scale data acquisition from the energy supply and demand side, the network infrastructure would be designed to reliably handle aggregation of millions of sources of data without overwhelming the consumer and enterprise services being offered over the same infrastructure.

A significant opportunity is to use the data to create community-scale digital twins to explore energy generation and consumption patterns. Digital twins that are possible over a high-performance computing cluster will enable predicting the load on the power grid across regional clusters during a variety of conditions mapped to potential climate change parameters but would also enable early warning and disaster management (preparedness, resilience and response) and also explore the impact of new net-zero technologies and techniques applied to the built environment. This capability can give the national and state government, policy makers, urban local bodies and architects/ builders unique insights that will help both democratize and decarbonize effectively.

The primary concerns from building owners about data privacy, cyber security, and sharing of data to private enterprises for developing efficiencies and insights should be resolved by well-thought through policies and regulations. Anonymization of data can be easily accomplished through any of the existing techniques. Securing the data is a challenge that will require secure design and diligent management of the infrastructure, strong multi-factor authentication, authorization and access protocols, as well as good security auditing capabilities.

International collaboration can enable discovering common challenges across the built environment worldwide, and create the momentum for solving these problems consistently across different climate zones and economic strata. Effective anonymization and secure sharing of data can also enable researchers from different countries to create scalable solutions and insights that can help tackle the environmental impact of buildings.

The data, insights and digital twins can also be used for training the next-generation of building managers, HVAC experts and other operational staff. This upskilling of the staff will create a sustainable impact and is critical for the long-term success of this approach.

The main areas for investment and institutionalization are computing centers, hardware, software to accommodate both supercomputing and data-intensive workloads, and human resources.

Long term investment in digital infrastructure to facilitate high-performance computing (HPC) and data-intensive workloads to run efficiently are key for digital transformation. Setting up national resources in HPC and big data also requires major, sustained investments in hardware. It is recommended that India not embark on the race for flops, but rather focus on well-balanced systems that emphasize compute, memory, storage and networking.

Investing in purchasing and developing software, and more generally being in sync with the broader open source community is highly recommended. Policies must be established for facilities to share data across campuses freely, backed with funding for data management platforms at well-connected strategic computing centers so that the data may be shared without any infrastructure impediment. Loss-free campus networks should be carefully architected and operated for big-data movement. End-to-end application throughput is the most important metric. Providing compute systems, storage systems and networks that are well-matched is important.

Investing in developing and growing equitable human resources is vital to the long-term success and sustainability of a national computing initiative. Centers should focus on hiring and retaining the best national and international talent, deep connections with leading academic institutions domestically (e.g. IITs, IISc) and internationally, collaborations with leading industry vendors, and an International Advisory Board to keep them abreast of latest developments and to seek independent evaluation of progress. The quality of operational and research staff at such centers is fundamental to the eventual success of such initiatives. An important aspect is to overcome the digital divide between rural-urban, rich-poor, educated-uneducated. The transformation needs to take into account any uneven distribution in the access to, use of, or impact of information and communications technologies between any number of distinct groups, which can be defined based on social, geographical, or geopolitical criteria. The Centers should align their mission with national priorities."[121]

Digitization, preservation, and retrieval of rich non-digital records and design/construction methodologies

Emerging socio-economic factors enable traditional technologies to be interpreted in new ways.[122] Records , i.e. *patwari* maps,[123] handwritten records, architectural drawings, and traditional sustainable design principles can be revived through digitalization. Digital libraries of innovative regional and vernacular methods such as passive solar architecture, cool and vegetated roofs, lattice *jaalis*, regional architectural materials and assemblies can be scientifically scrutinized for widespread adoption.

Local craftspeople, masons, carpenters and labourers should be engaged for revival of traditional practices and heritage restoration activities as new, respectable jobs.[124] This can be strengthened by creating a database of place-based artisans and developing associated content in Indian languages to increase access to these disappearing craft forms. Innovative digitization tools, in particular building information modeling (BIM), must support architectural heritage conservation involving technology and processes, to raise awareness across the local communities and provide meaningful insights to the larger community of planners, architects, conservationists, builders and facility operators.[125]

Adoption of machine learning on novel sources of data in the built environment.

Advances in machine learning (ML) and computer vision algorithms, combined with increased access to complex unstructured data (e.g., images and text), have created an opportunity for automated extraction of building characteristics. These ML methods can be cost-effective and scalable.[126] For instance, through use of ML on aerial RGB and thermal images, full 3D geometries and thermal maps of buildings and swathes of neighborhoods and campuses can be constructed. This includes automated extraction of building characteristics such as building footprint,[127] height, window to wall ratio, number of floors, and envelope thermal characteristics. Further, non-destructive methods of identifying thermal and moisture anomalies in building envelopes are also possible (Figure 23 (a) (b) (c)). This can be expanded for developing heat maps to study and mitigate urban heat island and local pollution effects through nature based solutions such as planting, shading and microclimate-affecting methods. This is especially beneficial for asset mapping in organically developed built environments where plans and drawings are not available, as well as enable the creation of digital twins for campuses and communities. There is further R&D required to commercialize these methods.

3.3.4 Benefits of Digitalization

Digital transformation facilitates decarbonization and democratization in the built environment through unprecedented value creation to empower stakeholders.

Digitalization co-creates solutions for a zero-carbon future, by addressing the next level of intelligence made possible through information and communications technologies such as sensors, connected devices, networks, and data analytics. On an implementation level, this leads to more effective benchmarking, savings persistence and grid benefits, capital purchasing choices, as well as enabling new markets and financing

Figure. 23 (a): Drone-flight paths for overlapping image capture (Left) and generation of 3D point clouds (right)[126]

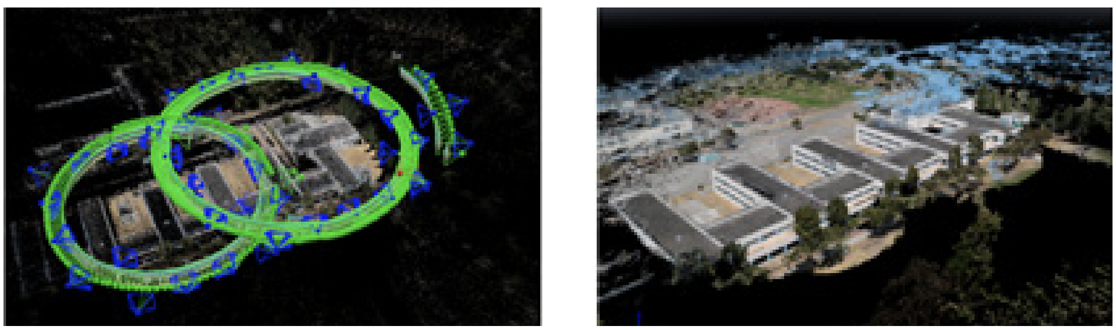


Fig. 23 (b): ML on RGB images for building footprint extraction[127]

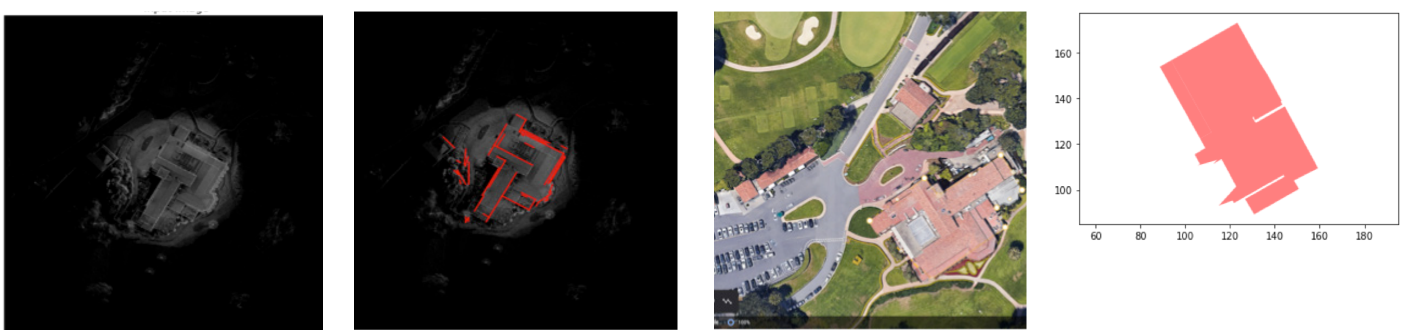
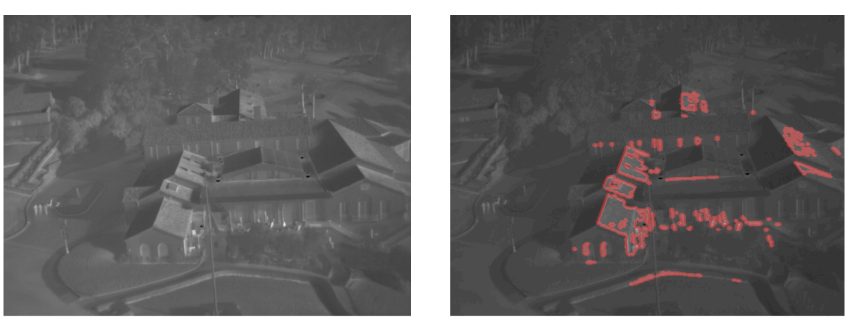


Fig. 23 (c): ML on RGB and thermal images for 3-D building reconstruction and thermal anomaly detection[125]



opportunities. For instance in the electricity sector, an estimated 8.8 billion metric tons of CO_2 emissions could be saved by 2025, creating $418 billion of new value for the economy.[128]

Digitalization can empower democratization through the quantification and potential integration of social, demographic, health, and economic information to effectively plan and implement a data-driven built environment that promotes wellness. The digital transformation encompasses a broad range of societal concerns including health, resource efficiency, security, cybersecurity, and digital inclusivity and enhanced livelihoods. This has already created new roles (e.g. modelers), new types of organizations (e.g. cloud computing providers), and even new sectors of the economy (e.g. digital security and data science). The impact of digitalization has also acted as a catalyst for employment growth in the wider economy. For instance, the World Economic Forum reports that digitalization could create up to 6 million jobs worldwide between 2016 and 2025 in the logistics and electricity industries alone that could offset an estimated 26 billion tonnes of CO_2 emissions between 2016 to 2025.[129]

Unlike any other technological development, the information (digital) age has managed to ubiquitously connect humanity at large, such that geographically diverse communities can revalue (and reconfigure) their role (choice, diversity and aspirations) as rightful stakeholders in modern society. Humanity has started to shed it's inhibitions to reach out to the most deprived and affected. The digital age has also unified all dimensions of modern industry and manufacturing, paving the way to productively integrate distributed and decentralised regional diversity and traditional skills. Nature-based solutions[129] and indigenous wisdom[130] could be enhanced with sophisticated and scalable digital technology advancements to create effective strategies attuned to diverse geographies. It is critical to adopt approaches that are sensitive to the diversity in geography, environment, habitations and cultures to achieve both decarbonization and democratization.

However, evident in the unbridled adoption of any technology (eg. reliance on fossil fuels), the impact of digital transformation on the evolution of modern civilisation, its health, social harmony and environmental consonance requires careful scrutiny and the requisite checks and balances. However, as on date, the benefits of digitalization seem to outweigh the perceived disadvantages as evidenced through the value of remote digital monitoring and assessments especially during the pandemic.

4. Analysis/Results

Modern built environments have evolved to become more sophisticated and complex when compared with simple buildings that provided basic functionalities such as structural stability, protection from the elements, ventilation, shelter and storage. The functional performances expected from modern buildings is a long list comprising regulated indoor comfort, lighting and ventilation, automated HVAC, energy generation, acoustics, fire safety, rapid transport and space travel, ubiquitous internet connectivity, smart sensors and intelligent controls, health and occupant safety monitoring, emergency/disaster (earthquake, floods, landslides, etc.) preparedness/management and in recent years environmental consonance and sustainability. Modern human activities comprise seven sectors, viz., residence, agriculture, administration, industry & commerce, education & research, infrastructure services, transport & communication.[59] Each of these sectors have a characteristic manifestation in the built environment, and corresponding ramifications on the environment, society and economy, which need to be specifically scrutinized for their threats and opportunities for planetary wellness. Fig. 24 provides a comprehensive illustration of a modern living environment. The seamless integration amidst the inter-dependent sectors determines the overall health and functioning of the human settlement and has the potential to revitalise biodiversity and provide equitable access to wellness. Each sector provides unique opportunities to achieve sustainability, leveraging on the 3Ds (Decarbonize, Democratise and Digitalize) in the built environment. Technology transformation and digitalisation provides a unifying platform to support and monitor interoperability between these sectors, in tune with local ecosystems and cultural diversity.

The experts at the BIGathon+ Roundtables discussed specific strategies comprising the three-D's – Decarbonize, Democratize and Digitalize – spanning five levers– R&D, Technology, Human Capital, Regulatory/Policy, and Economic Investment. The white paper attempts to deal with issues and challenges primarily centered on energy and resources in general. However, the specific pain points could be more diverse and complex and need careful scrutiny depending on the sector being examined. The summary of three-Ds recommendations in Table 3 has undergone multiple reviews and iterations, and currently stands generic so that its applicability could be aligned with each of the seven built environment sectors, and derive specific interpretations depending on the geography, building typology and social context.

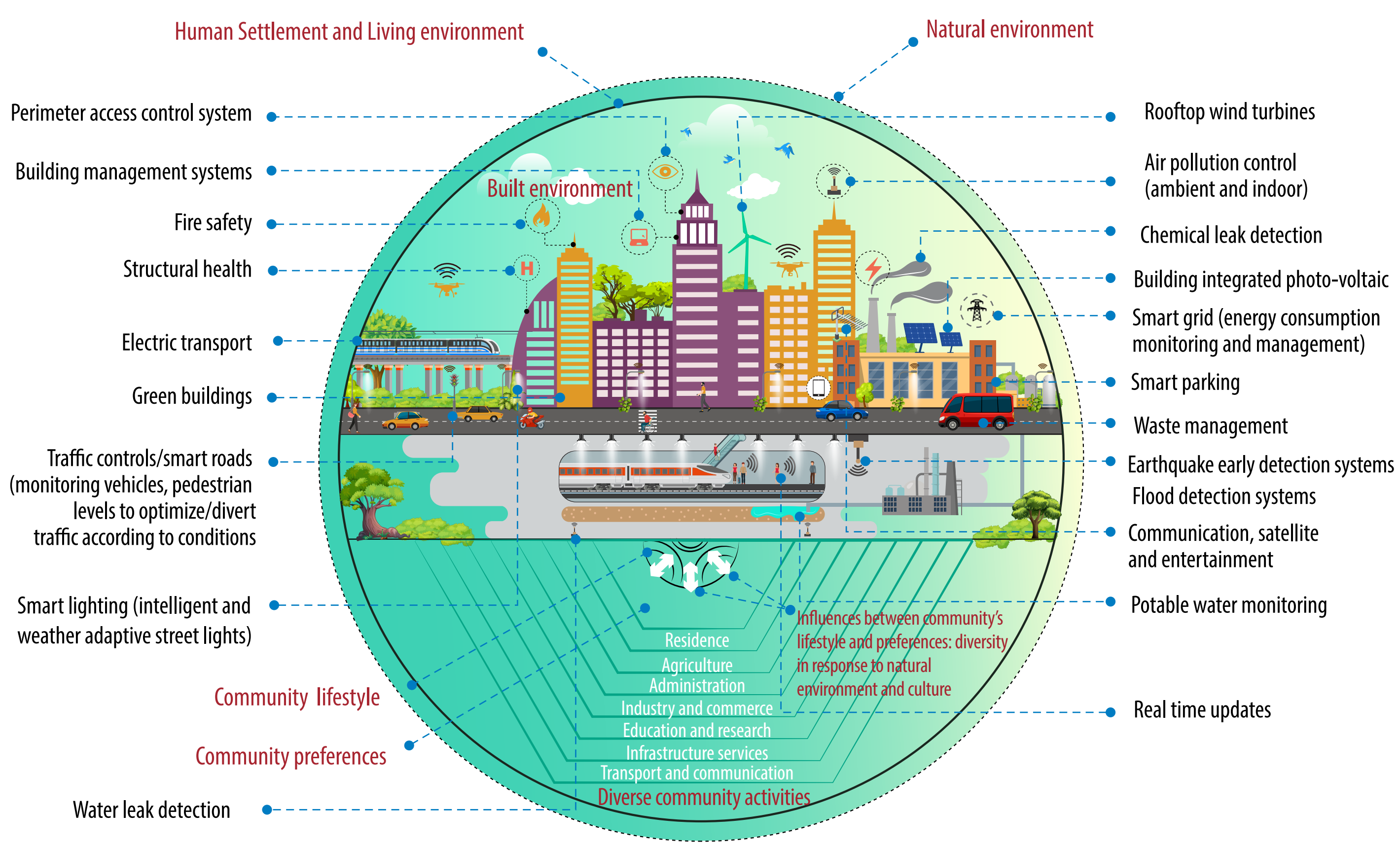
Table 3 provides realistic goals prioritized by the BIGathon+ Roundtables experts that could

serve as a guidestone for each of the stakeholders to identify and prioritize their strategies and targets that collectively contribute to wellness in the built environment. The items in the table are not in intended order/ sequence, but a collation of actionable pathways along the three-Ds at building, community and regional/ national scales. Each of the items listed is intended to provide directions across the three-Ds at the building, community, and regional/national level. The intent is to channelize multiple ideas and diverse action items, depending on the stakeholder's role, expertise/competence, geography of operation, ecological bearing and societal integration in the built environment.

5. Summary

Our vision is a zero carbon built environment to achieve equitable wellness and resilience by 2050. Zero carbon is synonymous with zero emissions and zero energy. The following section summarizes ten key recommendations along the three drivers, Decarbonize, Democratize and Digitalize to enable short-term early wins (2022-2025), medium term (2025-2035) and longer term pathways (2035-2050). Each stakeholder may set and orient early, medium, and long-term goals using their lever of influence: R&D, Technology, Human Capital, Regulatory/Policy, and Economic Investment to achieve the transformative vision.

Figure 24: Overview of transformations in the built environment for wellness across seven sectors (Adapted from Mani et. al (2015)[59], and Desjardins (2019)[118])



Smart montitors and controls across all aspects of cities and communities are set to transform the urban landscape (Transport : Buildings : Environment : Life : Infrastructure : Utilities.)
These aspects synthesize the three levers of the built environment – Decarbonize, Democratize and Digitalize

Decarbonize

GOAL: Net zero emissions built environment by 2050

- Reduce the embodied carbon emissions from all new construction, and associated materials to 50% by 2035 from current industry standards.
- Achieve a target energy use intensity (EUI) of <50kWh/m^2/yr (up to 66% reduction in energy use from baseline through energy efficiency) and using decarbonized renewable energy to address the remaining 33% energy use to achieve net zero operations.
- Triple annual energy savings and (micro) grid demand flexibility in residential and commercial buildings by 2035, relative to 2020.

1. Breakthrough, low-embodied, robust materials and assemblies adopting aggressive high-performance measures amenable to circularity and planetary ecosystem services.

- **R&D:** Model, develop, and validate innovative low-embodied energy building materials that are vernacular, biogenic, remedial, circular, carbon-sequestering, and provide high-performance alternatives to steel and cement;
- **Technology:** Processes and assemblies for rapid, modularized/ prefab EE construction and envelopes for e.g. façade/glass/ shading/cladding; improved insulation, coatings and sheeting devices; building-integrated photovoltaics, passive and active EE technologies that are durable in hot/humid environments, and disaster-resilient;
- **Human Capital:** Capacity building for advanced manufacturing, as well as design, and construction using low embodied carbon materials and assemblies;
- **Policy:** Develop region-specific materials, equipment and assemblies' performance testing for safety, durability, disaster-proofing, moisture and thermal performance; environmental product declarations to disclose and apply embodied emission information through design, construction, operation and demolition;
- **Investments:** Develop robust supply chains and market-stimulation to pivot from business-as-usual high embodied carbon construction (cement concrete, steel, high demolition waste); avoidance of new construction through adaptive reuse of buildings.

2. Low-carbon, region-specific, durable and disaster-resilient building typologies with cost-effective, integrated passive and active resource efficient technologies

- **R&D:** Develop best practices and an open access digital repository for regionally-relevant building science and technology;
- **Technology:** Develop and deploy cost-effective and energy-efficient community-and-building-scale cooling, filtration, cleaning, and ventilation methods including passive/hybrid ventilation, non-vapor compression-based/low-GHG refrigerant-based air-conditioning and refrigeration, and closed-loop thermal technologies that harness the region's climate, construction, and cultural practices for thermal, visual, acoustic, fresh air, daylight, ventilation performance;
- **Policy:** Develop regional eco-labeling policies, building codes and standards driving minimum energy performance for appliances; identify strategies to nurture and revitalize dependent ecosystem services; increase stringency, and mutual recognition/harmonization amidst regional diversity;
- **Human Capital:** Enhance multi-stakeholder partnerships for training, awareness, deployment of the above technologies through the education and vocational pipelines; upskill for a motivated compliance/enforcement, facilities, sustainability, and energy services workforce;
- **Investment:** Stimulate energy efficiency financing as part of building performance codes and standards.

3. Building-community-grid scale integration with cost-effective distributed energy resources to harness demand flexibility and provide equitable, reliable energy access.

- **R&D:** Develop analysis, planning and operation decision-making tools to integrate Building-community-grid scale energy solutions
- **Technology:** Deploy distributed energy infrastructure architectures (e.g. community microgrids) to harness demand flexibility (diversity of building and AC loads, local energy generation, EV charging, thermal and battery storage) for peak load management and energy resilience while eliminating dirty diesel generators; Develop and deploy direct current (DC) equipment for buildings and EV transport (low, medium, heavy duty vehicles) to harness local renewables and eliminate the large AC/DC conversion losses;
- **Human Capital:** Train a multi-stakeholder pipeline;
- **Policy:** Regionally diversified codes and standards, implement state targets or mandates for building-to-grid community-scale solutions;
- **Investment:** Develop innovative incentive-based programs, green financing models for a circular economy, including energy/water/ materials/equipment closed loops, environmental revitalization and remediation, and biodiversity enhancement.

Democratize

GOAL: Equitable access to wellness for a resilient built environment, that includes clean air, energy, water and sanitation, mobility, biodiversity and open spaces.

4. Resilience to counteract warming and pollution levels and providing equitable access to a clean, remedial, health-promoting built environment.

- **R&D:** Monitor, analyze and recommend methods, including inherently providing environmental comfort outdoors urban heat island countermeasures (cool materials, shading devices) and indoors (thermal, visual, acoustic, fresh air, ventilation, daylight/shade); develop and demonstrate novel energy-efficient cooling/ventilation/filtration/cleaning systems;
- **Technology:** Deploy community-scale closed-loop thermal energy systems; healthy and environmentally safe materials (e.g. low volatile organic compounds, non-endocrine disruptive chemicals); cost-effective, scalable indoor environmental quality technologies to improve health and productivity ;
- **Human Capital:** Develop skilling to provide effective multi-stakeholder services to achieve comfort and wellness for all in the built environment;
- **Policy:** Enforce policies that mitigate pollution, urban heat island, photovoltaic heat island, and manage albedo through nature-based and microclimatic strategies;
- **Investment:** Public-private partnerships to radically improve open space infrastructure, de-densification, urban agriculture, heritage and biodiversity-integrated inclusive, polychronic spaces that may also be adapted as economic-generation spaces.

5. Attitudes and technologies leveraging a culture of resource conservation and restoring environmental vitality.

- **R&D:** Behavioral and sociological research to develop toolkits, software applications and programs to drive resource conservation, wellness and civic sense in the built environment;
- **Technology:** Deploy disaster-resistant (fire, earthquake, flood, cyclone) building typologies and technologies; provide clean energy access to energy constrained communities
- **Human capital:** Provide training in vulnerable communities for self-dependent energy infrastructure;
- **Investment:** Revitalize and transform communities that experience unprecedented, extreme climate events especially the underserved, marginalized and energy-constrained communities.

6. Knowledge management with education, vocational, and workforce training in architecture, engineering, sciences, and sustainability fields through integrated living environment curricula.

- **Human capital:** Develop curriculum/ training/ collaborations for upskilling and revival/ reinterpretation of traditional/ vocational and 21st century skills to deploy best practices and technologies
- **Policy:** Develop productive partnerships with key international partners/communities aligned to national scientific priorities.

Digitalize

GOAL: Scalable, secure solutions to enable dynamic effectiveness of the built environment.

7. Digital tools and modeling frameworks throughout the building life-cycle including digital supply chains, energy modeling, benchmarking, and circularity.

- **R&D:** Develop a systems life-cycle framework/tools/calculator that takes into account the Indian context of fragmented and informal construction markets;
- **Technology:** Develop digital platforms for accessibility, early warning and disaster management (preparedness,resilience and response);
- **Policy:** Adopt wide-scale energy monitoring systems to enable accountability through business models such as energy performance contracting/ efficiency as a service;
- **Investment:** Expand internet and communications infrastructure, national platforms for decentralized governance and energy access.

8. Resource management and information systems that provide data analysis and scientific underpinnings for performance of traditional, passive, and active systems at building and community scales.

- **Technology:** Data acquisition and software platforms to plan and operate integrated infrastructure systems including buildings, mobility load flexibility and services, as well as data from non-energy verticals, e.g. GIS, demographics, health, environment, commute data;
- **Human Capital:** Conceive and implement a comprehensive BOLD (**B**uilt-Environment **O**rganization **L**eadership using **D**igitalization) program engaging public and private sector building owners in technology adoption and scaling across the building stock; Activities include program design, technical and procurement assistance, demonstrations, best-practice dissemination, and policy influence;
- **Policy:** Building/community/ city-level/national benchmarking, disclosure, and quotas for multi-sector built environment metrics e.g. emissions, energy consumption from built environment sectors.

9. Cost-effective, ubiquitous cyber secure, sensors and controls integrating building- to-(micro)grids;

- **Technology:** IoT enabled integrated building controls (facade, HVAC; lighting, plug; model predictive); remote sensing and artificial intelligence based asset characterization and energy efficiency, enable net-positive buildings integrated with community resources (i.e., "connected communities" integrating buildings, EV, grid, renewable, storage), AI/ML overlay for built environment data and renewable energy integration (e.g. geothermal+solar hybrid).

Demonstrate

GOAL: Demonstrate key strategies, tools and technologies to create a net zero community, at the multi-building scale.

10. Design, implement, and operate a net zero carbon community, with a cost-effective, scalable technology suite, human capital development, policy, and investment.

This will showcase a proof-of-concept and potentially trickle down adoption. Examples of potential demonstration projects include: (1) a net zero carbon building/grid-integrated community demonstration showcasing pre-commercial/ pre-competitive technologies and solutions; and/or (2) a net zero carbon, grid-integrated stock/portfolio demonstration focused on showcasing commercially available technologies (integrated/systems-level) and policy/market solutions.

The above ten key recommendations have been more comprehensively addressed in Table 3 considering the five levers and organized based on three scales of intervention in the built environment: building, community, and regional/national.

Table 3: Recommendations/opportunities categorized under the drivers Decarbonize, Democratize and Digitalize, at three scales of intervention in the built environment: building, community, and regional/national.

Decarbonize	Democratize	Digitalize
	Building Level	
Systems approach to life cycle assessment: R&D, tools and calculators (framework/software) Biogenic, innovative vernacular, and remedial building materials and construction, that may be modularized, but customizable and scalable for climate-responsive buildings Investment and R&D in carbon capture, utilization and storage in buildings using alternate building materials and manufacturing with low-carbon cement and steel Circularity of building assemblies and value chains, use of recycled/upcycled waste/end-of-life materials/products Utilization of passive methods to reduce demand for active energy use, e.g. cooling, heating, and artificial lighting, plug and process loads Energy-efficient technologies for a) Lighting, space and water heating & cooling, process equipment b) Domestic/ commercial/ agricultural refrigeration devices Minimum energy performance standards for appliances and equipment, and supply chains that provide technologies at highest performance levels Review building design and monitor operations for code compliance	Strategic energy conservation measures-driven retrofits, and adaptive reuse of existing buildings Technologies for monitoring and improving air quality Passive methods for buildings to inherently provide environmental comfort (thermal, visual, acoustic, fresh air, daylight, ventilation) Innovative active energy thermal, visual, comfort and wellness technologies for health and productivity Materials safety/durability R&D/ testing Re-introduction of innovative vernacular construction	Data analysis and scientific underpinnings for passive and active systems Building management systems: Mechanical, electrical, lighting, computer based control system Energy management and information systems Systems-wide digital monitoring and controls platforms: Integrated and networked command and control centres for operations management Smart, low-energy self-powered switches and sensors

Decarbonize	Democratize	Digitalize
	Community level	
Investments in distributed renewables, thermal/ electrochemical storage, building-to-grid integration technologies Renewable energy forecasting, technologies, and policies for their end-of-life management Market-based instruments e.g. incentives and penalties to encourage zero net energy communities	Develop frameworks to facilitate design/ retrofit for adaptive, inclusive, polychronic spaces Behavioral research/campaigns promoting civic sense and wellness in built environment including open spaces Inclusion through accessibility to housing, barrier-free mobility, clean energy, clean water, clean air, open space and sanitation Invest in fostering and monitoring occupant wellness and environmental quality in outdoor and semi-outdoor spaces and urban heat island countermeasures. Develop economic generation, polychronic spaces within communities e.g. MSME, startups, cottage industries, co-working Upskilling to plan and deploy accessible practices and technologies Invest in hierarchy of heritage - and biodiversity-integrated outdoor community space infrastructure, de-densification, plantation, and urban agriculture	Large-scale investments to develop smart communities Energy data infrastructure, buildings models, and controls EV-to-grid load flexibility and services Data from non-energy verticals, e.g. GIS, demographics, health, environment, commute data Community EOPS data acquisition and software platforms to plan and operate the integrated infrastructure systems that includes • Infrastructure digital twin • Smart meters on the utility side and demand side • Monitoring and tracking of resource state, consumption, patterns of resource use • Technologies for fail-safe communications • Shared connected energy high-performance infrastructure and tech platforms • Flexible load management from community level energy centres, and grid-responsiveness • Community level monitoring and benchmarking

Decarbonize	Democratize	Digitalize
	Regional/National	
Investment in environmental revitalization and remediation (unproductive farmlands, mines, brownfield sites, etc) Augment national level policies suitable for regional diversities, environmental sensitivities (climatic diversities), ecosystem services, occupations and resource availability Policies to mitigate climate change: carbon credits, carbon tax, cap and trade emissions trading programs Technologies for 100% electrification/ renewables of road transport (heavy, medium, and light-duty) railways and shipping	Behavioral research/campaigns for opportunities leveraging inherent local culture for resource conservation Partnerships with key science collaborators/communities aligned to national scientific priorities, e.g. industry-academia-government partnerships A digital literacy and leadership program to empower building designers, operators and sustainability managers	Technologies for AI/ML overlay for built environment data and renewable energy integration (e.g. geothermal solar hybrid) Investments to develop and expand internet and communications infrastructure Invest in development of national blockchain platforms for decentralized governance and resource accessibility Early warning and disaster management (preparedness,resilience and response) digital platforms to maintain accessibility National level benchmarking for built environment metrics e.g. emissions, energy consumption from built environment sectors Open-access digital repository for regionally applicable materials, performance standards, designs

6. Endnote

The BIGathon+ included expert multi-stakeholder dialogue on the built environment to identify and prioritize decarbonizing challenges, to democratize access to wellness sensitive to geographical and cultural pluralism leveraging a unifying digitalized platform. Given climatic disruptions worldwide, besides the pandemic, wellness is emerging as a unifying theme for course correction and large-scale transformations needed in the built environment. There is an imminent need for restoring ecosystem services and enhancing biodiversity. Wellness as a fundamental right permeates all aspects of the living environment. The built environment (urban to be specific) also needs to be reconfigured keeping in mind human scale and socio-temporal sensitivity, eg. open spaces, pedestrian mobility, social inclusiveness, nature and recreation. Clarity needs to emerge on the defintion, measurement and assessment of wellness as it would apply to various activities. In addition to equitable and affordable access to a healthy living environment, meeting aspirational needs (of the youth) is crucial.

Economic growth is seen as fundamental to development, and integrating regional diversity and decentralised economies could provide novel opportunities favoring a digitally networked circular economy amenable to local ecosystem services. Policies and businesses need to frame strategies that respond, inclusively, to regional diversity in lifestyles, cultures, vocations, resources and ecosystems. This would imply promoting rural-urban connected economic growth, with decentralised and distributed job opportunities involving traditional/vocational skills, upskilling for current technological transformations with the aim of integrating rural and urban economies to revitalise local ecosystems and biodiversity. Circular economies could provide the inclusive platform to dignify and recognize the contribution of the semi-skilled/skilled informal sector for their support in the upkeep of built and natural environment services.

Carbon footprint is the universal pain point underlying climate change, disrupted ecosystems and biodiversity loss. Future strategies need to radically cut resource dependency and carbon intensity. Operating and maintaining the built environment carries the single largest carbon footprint and therefore holds the largest opportunity for decarbonisation. Industries and manufacturing processes are nearly reaching their saturation point in terms of efficient operations. For maximizing effectiveness, the built environment thus needs to embrace sustainable strategies that involve geographically smaller (local) resource and energy dependencies, revitalise associated ecosystem services and avoid any disruption, pollution or contamination. There is potential for appropriate intervention/measures to be identified and adopted in every sector of the built environment.

We are currently at a singular inflection point, where digital transformation supports sustainability in the built environment, across all sectors: residence, agriculture, administration, industry & commerce, education & research, infrastructure services, and transport & communication. Digitalization brings opportunities for commonality and integration amidst geographical and cultural diversity in the living environment, helping to align stakeholders on common, shared metrics to manage complex information, enhance data-driven decision making, ensure inclusiveness, transparency and accountability to promote overall wellness, enhancing productivity, social enrichment and environmental revitalization.

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