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UPSCALING THE APPLICATION OF LOW CARBON AND RESOURCE EFFICIENT TECHNOLOGIES IN INDIA

Key Messages

- The Indian construction sector has a high ecological and carbon footprint.
- Low carbon and resource efficient technologies exist, and could substantially reduce the ecological footprint of the sector.
- Policy makers need to streamline the policies and develop guidelines that include the green mandate.
- Implementation process and mechanisms should be strengthened, which include technical capacity building of government officials.
- Knowledge dissemination on the benefits of these technologies is essential.

Development Alternatives

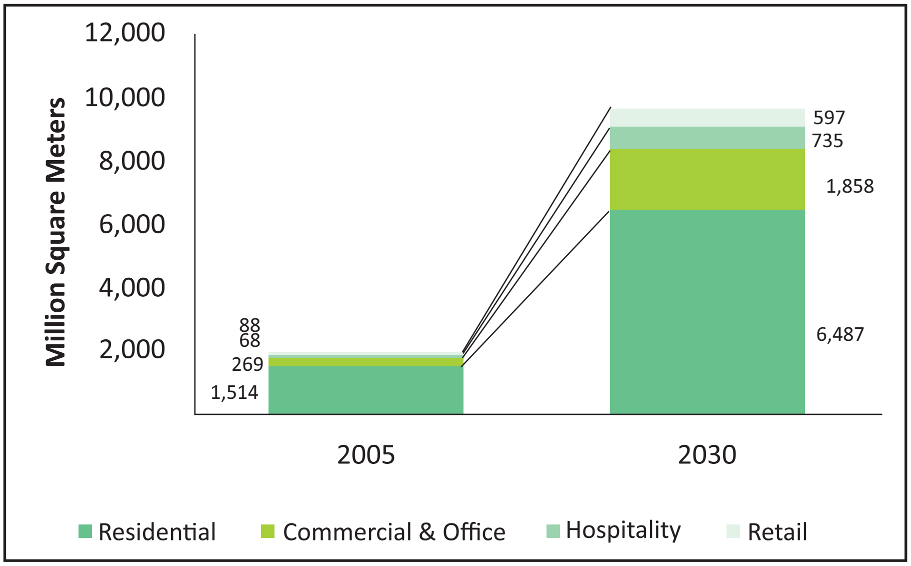
Contents

1. The Construction Sector of India

The Construction sector is considered to be one of the major contributors to economic growth, and thereby a measure for development of a country. It contributes significantly to employment generation, offering job opportunities to millions of unskilled, semi-skilled and skilled work force. According to the Global Construction 2020 Report, the sector will account for 13.2 percent of the world's GDP by 2020,and is estimated to grow by 67 percent from $7.2 trillion in 2010 to $12 trillion in 2020 (Global Construction Perspectives and Oxford Economics, 2011). Of this, China, India and the US will generate 54 percent of the $4.8 trillion increase in global construction output.

The Indian construction industry grew at a Compounded Annual Growth Rate (CAGR) of 9.42 percent between 2003-04 and 2012-13 and contributed to 8.2 percent of the Indian GDP (NSDC, 2012). It employed 41 million people in 2011 and is the second largest employer after agriculture (Planning Commission, 2013). The growth in the sector is fuelled by the rapid transformation of the country from a predominantly rural to an urban society, which houses 377 million people in urban settlements i.e., 31.16 percent of the total population (Census of India, 2011). Small cities and towns are to be the primary locus of this growth, with the number of towns increasing from 2,774 to 7,935 between 2001 and 2011(Census of India, 2011).

Figure : Projected Growth in Built-up Area by 2030



Source: Climate Works Foundation, 2010

Looking at the projected growth trends of built-up area, major growth in constructed area will be seen in the residential and commercial sectors. An increase of 4,973 million m^2 of residential area in 2030 from 2005 has been predicted. The demand for commercial property will also increase to meet the business needs via offices, warehouses, factories and other buildings for industry. The growth rates in hospitality and retail sector are also high although their total area remains relatively small (Parikh K. , 2011).

The current affordable housing shortage in Urban India (2012-2018) stands at 18.78 million dwelling units (Ministry of Housing and Urban Poverty Alleviation, 2012). This is expected to increase to 44-48 million units by 2022 (KPMG, 2014). Apart from the housing shortage, reconstruction due to disasters and extreme weather events along with renovation and aerial expansion of buildings will result in increased demand for materials from the construction sector. A number of Government programmes like Housing for All, Smart Cities Mission and the

Atal Mission for Urban Rejuvenation and Urban Transformation have been launched to meet this urban housing shortage demand and are thus likely to give a further boost to the construction sector.

1.1. Potential for Change

The construction sector is highly resource and energy intensive. In this regard, heat island effect and other environment impacts as a consequence of unsustainable urbanisation are high on the global sustainability agenda. The sector accounts for 30 percent of national electricity consumption and 23.6 percent of national greenhouse gas emissions (Parikh K. , 2011). For example, the brick sector alone generates 24 million tonnes of CO_2 annually and uses 20-30 tonnes of coal and 350 tonnes of top soil[1]. Production of materials like cement, bricks, steel and lime is responsible for 80 percent of the emissions (Reddy, 2003). The construction sector is also estimated to roughly use 40–45 percent of steel, 85 percent of paint, 65–70 percent of glass, and considerable amounts of output from automotive, mining and excavation equipment industries.

Worldwide, the construction sector accounts for over 30-40 percent of the material flows. This holds true for India as well. It is one of the largest consumers of material resources in India. Majority of the resources used in construction are utilised to manufacture bricks, cement and steel. These resources are finite and take longer to replenish. With over 70 percent of the construction by 2030 yet to be built, demand and pressure on limited stocks of these materials are expected to increase exponentially. Increasing conflicts over natural resources to satisfy these demands is already becoming the norm.

Considering the scale of the impact on the environment, it is imperative that the construction sector embeds the concept of sustainability and green growth in its development trajectory. The pathways to sustainability in construction do exist. Cleaner and alternate technologies have been developed that can substantially reduce the ecological footprint of the sector. In the brick sector, the use of fly ash and Hybrid Hoffman Kilns and Vertical Shaft brick kilns can considerably increase resource efficiency. In the steel industry, coke dry quenching technique, DC Arc technology, top pressure turbine and (TPT) and pulverized coal injection (PCI) significantly improve resource-efficiency. Cement production can also be made less resource-intensive thanks to vertical roller mill technology; fluidized bed cements fired kiln system, and the use of mineralisers.

The concrete industry of India has made some advances in lowering emissions as a result of research and development that has been carried out across the world. Additionally, alternative building materials, like micro-concrete roofing tiles, stabilized concrete earth blocks and prefabricated roofing elements are also available as alternatives to materials with a higher carbon footprint which are commonly used. The use of alternate technologies

1 Development Alternatives, 2012

like rat-trap bonds, ferro-cement channels, slabs and cavity walls have been estimated to reduce the resource consumption by 25-30percent (DA and CDKN, 2013).

Another alternative building material that is traditionally used and is slowly gaining commercial importance in the building sector is Bamboo. It is an extremely lightweight material and does not require the use of cranes and other heavy equipment in construction work. Bamboo is an apt example for the use of local construction material, thereby making it an economically viable option especially in regions where it is cultivated.

Thus there are several good construction practices which take into account the embodied energy of construction materials in association with environmental implications of resource depletion and GHG emissions. However, in order to translate the opportunities for the use these materials, to tangible benefits, several interventions in the form of public policies, awareness generation, capacity building and skill development, and appropriate financial tools are imperative.

2. Construction Materials and Technologies

Interestingly, construction sector has been identified nationally and internationally as a sector where large savings in energy emissions and resource consumption is possible. To tap into this opportunity, knowledge on the range of technologies that can be used across different pockets of the country is essential. In this regard, an exhaustive mapping and profiling exercise of construction technology and materials was undertaken at the country level. The exercise comprised of identifying good practices of traditional, conventional and alternate/ indigenous/hybrids production technologies in the sector.

The section below gives a detailed overview of the available technologies and construction materials that meet the criteria of resource efficiency and low carbon intensity.

Construction materials and technologies can be classified according to the components in a building:

- Walling materials and technologies
- Roofing materials and technologies
- Flooring materials and technologies
- Construction and structural systems

2.1. Walling materials and technologies

The most commonly used material for construction of walls is red brick. The extraction of this material has an adverse impact on the natural resources as well as on agricultural yield (i.e., exerting pressure on food security) due to conflicting uses of fertile top soil between agriculture and brick making. The traditional brick kiln units occupy considerable land which is subjected to high temperatures that make the land unfit for agricultural use, post the abandonment of the site. Other commonly used materials include stone, reconstructed stone, cast concrete, and wood which further cause large scale environmental degradation from aggregate mining and sand dredging of rivers for concrete, mortars and plasters.

Figure 2 : Perforated clay bricks

As stated above, the production of conventional materials are resource intensive. However, there are energy efficient technologies that are applied in construction using the same conventional construction materials. One such technology is Cavity walling. It consists of two 'skins' (i.e., a brick or a concrete block) separated by a hollow space (cavity). This method of construction results in good insulation and can reduce the dependence of energy consumption on heating and cooling apparatus. Other methods of construction of walls which are similar to cavity walling are Rat-Trap Bond and English Bond. Rat- Trap Bond is a masonry technique in which the bricks are laid in such a manner that a discontinuous cavity is formed between two faces of the wall. This method has proved to reduce 20 percent brick usage, 30 percent saving in mortar and 25 percent of the overall cost of the wall, in additional to reduction in CO_2 emissions and good insulation. Another energy efficient masonry technique is perforated or hollow burnt clay bricks. These bricks save the amount of clay used, and provide better thermal insulation due to the presence of air cavities. While these bricks can be fired in conventional brick kilns; however, further research and development as well as policy support is required for investment in this technology and its diffusion in the Indian market.

Figure 3: A typical Dhajji Walls

Further, there are cleaner brick technologies that not only save fuel and reduce pollution levels during brick production, but also result in high quality bricks along with lesser breakage percentage. Vertical Shaft Brick Kiln (VSBK)/Hybrid Hoffman Kiln (HHK)/ Tunnel Red Bricks are examples of cleaner technologies for fired clay brick production. VSBK consists of one or more rectangular vertical shafts within the kiln structure. The technology relies on the principle of counter-current heat exchange between the upward moving hot air and the downward moving green bricks in order to achieve high thermal efficiency, thereby reduction in the total fuel use. On the other hand, HHK technology improves energy efficiency through internal combustion of injected fuel through the application of heat.

Some of the traditional walling systems that use local materials like mud, stone, straw, timber/bamboo, sand etc., are Dhajji wall/Koti Banal, wattle and daub and Cob walls. These walling systems are both earthquake resistant and have high thermal properties. The walls are made of timber frames within-fills of light thin panels made by close packaging of mud, stone, sand, straw and water. This combination and use the of local materials acts as an excellent thermal mass, and has low embodied energy and CO_2 emissions, thus resulting in least environmental impacts. Hence, these walling systems are excellent examples of vernacular building construction technology which are suitable to hilly regions and seismic risk zone.

Figure 4: Fly-ash bricks

Other construction materials that are sourced locally are laterite blocks and Compressed Earth blocks. Laterite blocks are made from the extraction of laterite after which it is cut into brick like shapes and used in walling units. These bricks have lower embodied energy and high recyclability factor and are used mainly in the coastal regions and are a good alternative in regions where sand is a scare material. Compressed Earth blocks on the other hand are formed of compressed earth/soil. This earth based construction is best suited for regions where the appropriate soil is available and there is trained manpower with a good understanding of the soil properties. Apart from Himachal Pradesh where earth based techniques have been in use traditionally, these blocks are suitable also for semi-arid region.

Apart from the above construction materials, there has been significant research and development as well as marketing of alternative construction materials that enable reduction in the overall use of virgin materials. Fly ash brick is one such example of an alternate material that uses fly-ash, which is a waste product of thermal power plants. These bricks are manufactured from a mix of fly ash, lime and calcite gypsum. They have proven to reduce the embodied energy of building envelopes, and due to the non-firing process during the production process, consume very low energy. In the past few years, the manufacture and use of fly-ash bricks has received high acceptability in the construction sector, especially due to targeted promotional activities conducted by the government as a mandatory material to be adopted, at least in a 100km radius of a thermal power plant.

Another alternative construction material is sand lime bricks which are produced using a mix of finely ground sand and lime and in some cases also incorporates fly-ash in the mix. Like the fly-ash bricks, the advantage of using sand-lime bricks is their low embodied energy value as compared to clay bricks. However, these bricks require a capital intensive production infrastructure and therefore can be used only where the same can be facilitated. It is thus preferable to use them in regions where fly ash is available which can then be used in their production. This technology is presently in the incubation stage and similar promotional as well as regulatory mandates will be required for mainstreaming their use in the construction sector.

The walling material component is one of the most crucial components of a building structure and thus research and development of materials and technologies that are resource efficient and of low carbon intensity continues to be of high priority. Jute-coir composites and Geopolymer waste building block are walling materials that are being developed that use a considerable proportion of waste material, rather than virgin material. While jute-coir reinforced composites are boards made of coir, rubber and jute; geopolymer waste building blocks are formed by the pressure moulding process where fly ash, steel stag, pulverized blast furnace slag, sand and an activator are put together.

2.2. Roofing materials and technologies

As far as technologies for roofing are concerned, reinforced cement is the most commonly used material along with the use of steel or clay bricks. Trusses, space frame truss and Reinforced Cement Concrete (RCC) slabs are resource intensive and require large amounts of steel. RCC slabs is an example of a highly carbon intensive technique which is also the most common technique for constructing the roof/floor in India. It is a monolithic element which consists of cement concrete which encases within itself a matrix of steel rods called 'reinforcement'. It uses the unique property of concrete to quickly harden into a rigid mass after being laid in different forms and thicknesses. However, concrete, which is most efficient in resisting compressive loads, is very poor in resisting tension which develops when it bends. So, the performance of concrete is further enhanced by placing reinforcement rods in the concrete which allows the concrete to resist the bending which would result in a thin RCC slab spanning between two supports.

Figure 5: Pre-cast arch roof panel

While they have a high commercial application, they use large quantities of both cement and steel.

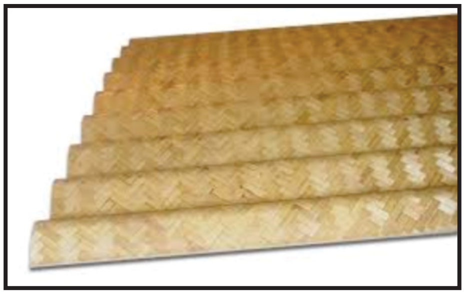
However, there are some conventional technologies that have lower embodied energy and are cost effective due to reduction in the use of steel. Some of these technologies include Plank and Joist, stone patti roofing and pre-cast Arch panel roofs. Plank and Joist is a building system, in which pre-cast RCC slabs-planks- are supported over pre-cast RCC beams, i.e., joists that are placed across walls. This technique can easily be adapted by masons who are familiar with similar techniques of placing stone slabs on girders to construct roofs. This technique is suited to semi-arid regions, where similar flat roofs of stone slab roofs are constructed.

A similar roofing system is the Stone Patti roofing in which sandstone slabs are made to rest over beams. The beam can be of steel or slender RCC/Ferro-cement section. Apart from have low embodied energy, this roofing system provides good insulation as the stone slabs are laid over with terracing which allows for rain water drainage. This system is suited to semi-arid regions where sandstone slabs are easily available. Pre-cast Arch panel roofs are also similar. The only difference being that the pre-cast panels are made with burnt clay tiles that are placed on pre-cast reinforced concrete beams. This technique is recommended for areas where burnt clay products are commonly used in both semi- arid and coastal areas.

Alternative technologies like Brick Jack Arches over RCC joists, micro concrete roofing and filler slabs use local waste material like burnt clay tiles, bricks, coconut shells, stone pieces, terracotta pots etc., thus reducing the need for virgin materials such as steel and cement. The Brick Jack Arches over RCC joists is a roofing technique which consists of shallow (low rise) vaults with compression materials like burnt bricks or compressed earth blocks, supported on intermediate supports in the form of beams. Unlike regular arches, jack arches are not semi-circular but have the profile of a segmental arch. In the case of micro concrete roofing, funicular shells and filler slabs, concrete is partly used along with waste materials. Steel is only utilized in pockets where reinforcement is required, thereby reducing cement and steel consumption. These materials have low embodied energy and are of high durability. These roofing techniques can be applied to low cost housing, institutional buildings etc., especially in regions where these waste materials are easily available.

Apart from the above technologies there are new technologies being developed. Some of these include Bamboo based corrugated roofing sheets and Cellular Concrete. Bamboo corrugated roof sheets are excellent alternatives to corrugated metal, plastic or asbestos roofing sheets. These sheets provide for a cheaper, more durable, and better thermal and sound isolation, roofing option. They are ideally used to cover homes, storage facilities, animal pens and other temporary and permanent structures. On the other hand, Cellular concrete is a low density fill material which is primarily used in geotechnical applications. It is made by the injection (or blending) of a pre-formed stable foam into a cement based slurry. These technologies although developed to a large extent, continue to require institutional support for the commercial applicability of these materials.

Figure 6: Bamboo corrugated roof sheets



2.3. Flooring materials and technologies

Figure 7: Different types of terrazzo floors

The commonly used materials in flooring are concrete, stone chips, ply wood etc. Terrazzo In-situ flooring and tiles consists of a topping of stone chips which are fixed with a binder which is most commonly cementitious. The tile is highly durable in nature and has a low maintenance cost. Terrazzo flooring is suitable for areas where waste stone is readily available and can be recycled into the floor. Ceramic tiles have a similar mortar mix which consists of sand, cement and a latex additive.

Another cost effective material is polished concrete flooring. It is concrete slab that has been treated with a chemical densifier and ground with progressively finer grinding tools. This type of flooring is considered a good sustainable design flooring option because it makes use of materials that are already present. Polishing of the existing concrete slab eliminates the energy and material consumed by applying a floor covering. Other materials that are extensively used for flooring are marble and granite.

Traditionally, wooden flooring used to be a common flooring option especially in hilly regions. It is a natural and low carbon option and the composition of the material can vary from 100 percent wood to composite wood floorings which include various reconstituted wood or other lignocelluloses material based products, such as medium or high density fibre with laminate or veneer. Interestingly, reclaimed or salvaged wood that is used for flooring provides a more durable floor than using freshly harvested wood. This is one of the best options for low carbon construction, however, procuring of the same from other building sites is not a mainstream activity and needs to be organised such that recycling of used wooden elements can be practiced more commonly.

Additionally, Bamboo flooring is also commonly used in the coastal and hilly regions (Assam, Meghalaya, and Kerala) since it is sourced locally with an assurance of quality due to its harvesting cycle. The National Mission on Bamboo Application (NMBA) is a premiere agency at the forefront of developing and standardizing new bamboo based value added products and has stabilized the bamboo flooring technology which is available for commercial production.

A similar low carbon flooring option that is being developed is cork flooring. The cork is obtained by peeling off the bark of the cork tree thus resulting in negligible environmental impacts.

2.4. Construction and structural technologies

The overall construction system is time, money, material and energy dependent. Therefore, developing technologies that enable savings in these components is crucial. Timber framed constructions as well as bamboo structures are traditional building practices of constructing light-weight structures which incorporate a range of infill materials like bricks, stone, and earth. These structures can be promoted as alternatives to the use of high-energy intensive steel structures. Local availability of both timber and bamboo and their high recyclability factor make them cost-effective construction materials to use in earthquake prone areas. There is a great need for providing technological support to building professionals and local building artisans to promote and up-scale these construction materials.

A technology that is fast picking up commercially is Mascon construction. The technology enables the concrete that is used in the construction of the building as well as in the walls, floors, slabs, balconies, staircases, lift shafts, window hoods, curved and decorative features to be cast monolithically, and thereby eliminating joints. This technique is proven to drastically reduce both time and energy that is utilized in the construction system.

Random rubble is a classic example of an affordable and durable foundation construction where cost plays a crucial role. As a result of utilisation of locally available stone and the use of less mortar and no use of reinforcement at all, the technology is highly efficient and is ideal for use in earthquake prone regions.

Another technology that is rapidly gaining commercial applicability is prefabricated construction materials. 'Prefabrication' is an industrialised construction method whereby mass-produced components are assembled into buildings. Prefabricated structural components made of concrete are referred to as 'precast units'. This means that they are cast in advance and given time to harden and acquire strength before being taken to the actual construction site for installation, making it a cost effective as well energy and time saving construction technology. High level of recycle materials (fly ash, slag, and silica fume, which would otherwise go to landfills) are used to develop prefab concrete products. These materials are used in concrete as cement replacements thus reducing the amount of cement used by up to 60 percent. Further, Precast concrete has high thermal and acoustic insulation properties that can result in significant savings by up to 25 percent on heating and cooling costs. This technology has proven to be cost effective and time and energy savings for the construction of low income housing in sub urban regions of metro cities. For example, a pilot project for this technology was applied in EWS and LIG housing in Boisar, Maharashtra, based on in situ prefab components.

2.5. Insulation

Thermal efficiency of a building is the determining factor of the extent to which additional heating and cooling applicants are required. Maximum ingress of solar heat in tropical climates is from the roof. Covering flat roofs with inverted earthen pots is an easy and cost effective method to reduce solar gain, placed abutting each other and the intervening space is filled with cement/lime mortar and finished with the terracing material. These pots increase the insulating value of the roof by virtue of the air gap created by them. Pots made with earth are recyclable and regionally available. Mud Phuska is also a traditional insulation technique for flat roofs where high thermal mass of mud is used to insulate the roof.

Figure 8: Inverted Earth insulation

Another cost effective material for insulation, is the use of broken china mosaic for terracing. It is a post-consumer product, as it is used as a cost effective external roof finish to reflect the incident solar radiation. It is thus a low energy cool roofing technique, thereby reducing the demand of cooling appliances in the buildings.

A trend that is seen in the recent years has been the transition from the use of less intensive materials like timber/stone/mud to more energy intensive materials, like clay fired bricks, to RCC slabs and finally moving to the increasing use of steel products.

In this light, the study aims to identify construction materials that are resource efficient and of low carbon intensity and to understand the drivers and barriers that may enable or hinder the up scaling of the use of such materials and technologies.

3. The Enabling Environment

The global discourse on sustainability has progressively intensified over the years. Considering the scales of the impact on the environment, it is imperative that the construction sector embeds the concept of sustainability in its development trajectory. Examples of cleaner and more resource efficient materials and technology have been described above, however, the usage of these products continue to remain marginal due to a series of barriers. These include lack of coordinated efforts by the various government agencies and other stakeholders in initiating change towards more sustainable practices, lack of norms and regulatory systems, and unfriendly financing systems.

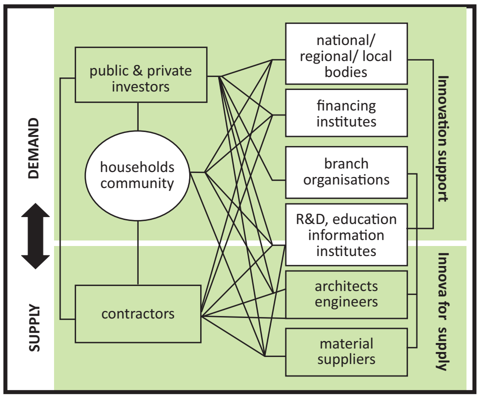


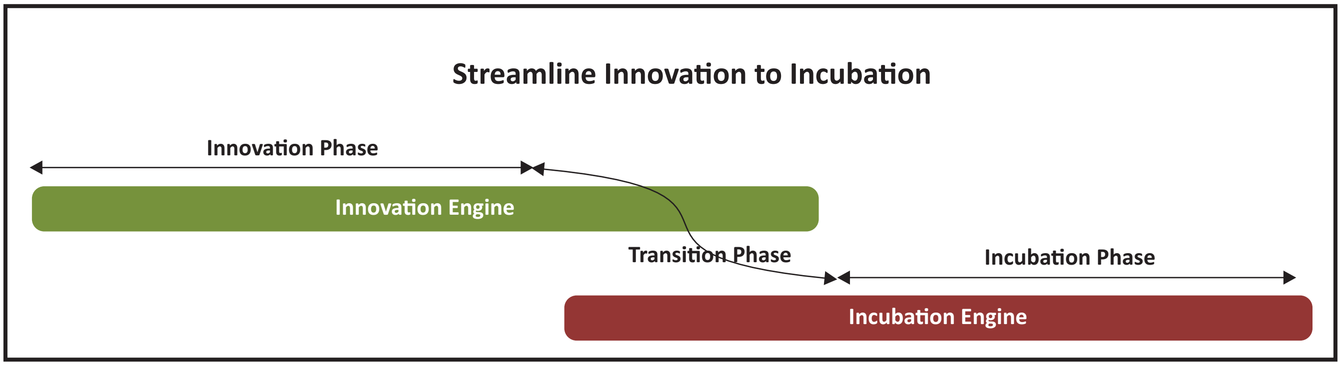
Figure 9: Actors in the process of technology diffusion

Region specific case studies on particular construction materials and technologies within India have helped in analysing economic, technological, and regulatory and policy frames on successful mainstreaming of low carbon options both within the sector. The case studies selected from India are fly-ash bricks, bamboo as an alternate construction material and cast in place construction styles i.e. prefabricated concrete slabs.

3.1. Technology Diffusion

Over a decade and a half, globalisation and trade liberalization have offered opportunities to industries and countries to 'catch-up' on development by adopting innovative technologies from across the globe. 'Innovation,' is a cyclic process that encompasses the development, diffusion and implementation of new competitive technologies. The social and economic context that revolves around the innovation is called the innovation system. It provides the framework within which markets as well as governments form and implement policies to influence the innovation process. The case where a new technology is introduced into an innovation system from outside the system, the change in the system emerges out of socio-technical experiments, such as pilot projects. In these pilot projects, the technology is applied through collaboration by various actors in exchange of information, knowledge and experience, resulting in the facilitation of the incubation process of the new technology.

Figure 10: Development Alternatives- Innovation-Incubation engine 2015



The incubation process is followed by the diffusion of the technology which is accomplished through human interactions and communications between the practitioners. By 'practitioners', we mean the actor network which comprise a network of interrelated individuals, organisations and enterprises who share a common field of knowledge and interest with regard to the particular innovation.

The figure below depicts an ecosystem where a multi-stakeholder approach is applied to the commercialization of eco-solutions through partners and experts at different stages and levels. While co-innovators, academic institutions and the household communities ensure a steady flow of market-oriented ideas and innovation, it is the financial institutions that provide the catalytic fund for the development of innovations, and their launch into the market. Further it is the National/regional/local bodies and other stakeholders like architects and engineers who form the network for implementation of the business model on ground. Such an enabling ecosystem, is not linear but rather interconnected, where each functional unit of the system impact the other.

The UNEP (2009) envisions Sustainability in the Building and Construction Sector as an active process where policies and incentives are provided by the government support to Sustainable building and construction practices. In addition, investors, insurance companies, property developers and buyers/tenants of buildings are aware of sustainability considerations and take active role in encouraging sustainable building and construction practice (Hakinen & Belloni, 2011).

With this regard, the present study has identified case studies of good practice applications and an attempt has been made to evaluate the drivers and barriers that have helped in the mainstreaming of these applications in the construction sector.

3.1.1 India: Case Study Briefs

Waste to Wealth- Fly Ash Bricks

Fly ash is one of the major wastes generated during combustion of coal in thermal power plants. It refers to the fine powder that is formed from the mineral matter in coal during its combustion, consisting of the non-combustible matter plus a small amount of carbon that remains from incomplete combustion. As a result of the increased energy requirements of the country, fly ash generation in the country has increased massively. Inadequate management of this waste product and its appropriate disposal o has been of great concern.

While this material is considered waste for the thermal power plants, it is a valuable resource for building materials and the construction of roads, embankments, dams and dykes. Its prime use is in the use of Portland Pozzolana cement. Apart from this it used in the manufacture of fly ash bricks which is an excellent alternative to red bricks. Currently, only 9.94% of the total fly ash produced is utilised in the production of building materials like bricks/ blocks/ tiles. According to calculations, around 2800 fly ash units are present in the country producing 6.65 billion bricks annually, with a market share of only 3 percent as compared to red brick production.

A few of the states that have successfully adopted fly ash brick technology are Maharashtra, Chhattisgarh, West Bengal, Andhra Pradesh, Tamil Nadu, Delhi, Odisha and Bihar. The success of this can be credited to regulations and incentives by the central and state governments. The notification numbered S.O. 763 (E) of Ministry of Environment, Forests and Climate Change and the Fly Ash Mission of Department of Science And Technology have played a crucial role in the uptake of the technology, through technology demonstration, easy access to fly ash and mandatory use of fly ash bricks in construction. Initiatives by the state government include incentives for fly ash units under their industrial policies and preferential procurement of fly ash bricks for public construction. Fly ash is supplied to the entrepreneurs by both public and private coal based power plants. Other stakeholders include support agencies like research institutes, banks and financial institutes and civil society organisations, technology service providers and consumers including private builders and government departments.

While states can only incentivize entrepreneurs to set up more units, it is the markets that play a crucial role in facilitating a shift from the conventional resource inefficient technologies to fly ash brick technology. Increasing brick demand presents an opportunity to shift towards low carbon and energy efficient fly ash brick technology. Reduced profit margins of red bricks due to increased coal prices aid this transition. Other drivers include heightened awareness among the entrepreneurs as well as consumers, ease of access of technology and the active engagement of civil society organizations in promoting the technology. It is thus a combination of effective policies, a market demand, access to finance and strong quality control regulations that have together led to the success of the uptake of fly ash technology in some states of India (e.g. Odisha, Bihar) and these should be replicated in other parts as well.
A few examples of successful utilization of fly ash are cited below:

- Construction of houses by private parties in cities like Vishakhapatnam, Pune etc.
- NTPC townships in Simhadri in Andhra Pradesh, Sipat in Chhattisgarh, Faridabad in Haryana and Talchar-Kaniha in Odisha have been constructed exclusively with fly ash bricks
- NTPC, Kahalgaon, Bihar uses fly ash bricks for their own construction
- American Embassy has used fly ash bricks in some of its construction

The main driver in Odisha is the market demand. The state is host to various power plants like National Thermal Power Corporation (NTPC), Orissa Power Generation Corporation (NTPC), Hindalco, Jindal and many others. On the other hand, the seeding of fly ash bricks in Bihar is policy driven. The scope of fly ash utilization in the state of Bihar is limited to the regions around power plants. Currently, only NTPC plant at Kahalgaon is producing fly ash. However, the government of Bihar is actively involved in the promotion of fly ash brick technology in the state. An Inter Departmental Task Force on Accelerating Cleaner Production Systems in the Building Materials Sector in Bihar has been set up. The Mandate of the Task Force is to recommend, monitor and advise on accelerating production, availability, acceptability and use of low-carbon technologies and building materials in Bihar.

Bamboo as an alternate construction material for the future

Bamboo is a low-cost construction material, which was used traditionally as well as perceived as a basic construction material to be used by the underprivileged and the poor. In recent times it is being used as a decorative material. Further, case studies have shown that there continues to be shift in bamboo usage from the purpose of interior decoration to a construction material.In Kerala bamboo reinforced columns and beams are being used to replace steel in the conventional framed structure. In Assam the *Nyishi* (indigenous tribe of Arunachal Pradesh) have replaced their indigenous homes made of Thatched Chinese palm leaves and jungle banana leaves with bamboo wall panels and bamboo CGS sheets for roofing.

The proliferation of the use of bamboo as a construction material, especially in the urban setting is still weak. However, there are some examples of buildings that have extensively used bamboo in their construction.

For example:

- Inspiration's office complex, Cochin
- Hotel Sarovaram, Ernakulam
- Whispering Palms' Holiday resort for Abad group at Kumarakom
- Administration Building for Socio Economic Unit Foundation, Alleppy

Bamboo products (bamboo boards, bamboo veneers, bamboo mat corrugated roofing sheets, etc.) due to their physical and mechanical performance in terms of hardness, stability and strength are gaining attention with large opportunities in emerging market. Moreover, bamboo has the capability of mitigating climate change as it restores degraded land, act as carbon sequesters and protects from soil erosion. Technology advancement and initiatives taken up by the central and state government has helped in the development of bamboo in construction and structural applications. National Bamboo Mission and National Mission on Bamboo Application are playing major role both at central and state level. These missions are supporting the activities taken up at state level for bamboo development in construction. State level missions have been set up in order to enhance the bamboo sector in the respective states.

Cast in Place Construction Style – Prefab Concrete slabs

In the recent years prefabrication is a practice that has enabled reduction in both time and energy in building constructions. It is a practice of assembling components of a structure in a factory or other manufacturing sites, and transporting complete assemblies or sub-assemblies to the construction site where the structure is to be located. Globally, precast technology can be used in various fields which range from agricultural products (bunker silos, cattle feed bunks agricultural fencing etc.), building and site amenities to sanitary and storm water components (vaults, catch basins and manholes). In this case study the focus has been on the construction and structural uses of precast concrete in India which include building components like walls, beams, floors, columns, precast concrete tiles etc.

Prefabrication technology has been getting support from various stakeholders including Government, private sector, research institutes and financial institutes. Promotion and regulation of the use of prefabricated concrete in construction have helped in creating the market for these products. Policies like National Urban Housing and Habitat Policy, 2007 and Housing for All are playing a major role in promoting the use of prefabricated products in construction of affordable housing. Bureau of Indian Standards has formulated technical standards for prefabricated components for their use in construction.

The role of manufacturers and private developers in the promotion and the utilisation of prefabricated concrete products have been evident in construction of residential buildings. Moreover, increase in Institutional partnership has also led to the increased use of prefabricated concrete products.For example, the EWS houses constructed by the Ahmedabad Municipal Corporation and the township projects and residential apartments constructed by Larsen and Toubro and Tata Housing to name a few, have all used precast concrete elements of wall panels, slabs, stairs cases, balconies etc., in their building structures.

3.2. Analysis Frame

From the selected case studies of good practice applications and of conventional applications in India, a detailed evaluation was done to identify the drivers and the barriers that have helped in the mainstreaming of these practices. The table below provides a structured framework on the areas that need to be identified and analysed within each case study and to thus identify the drivers for change within the institutional mechanisms, financing systems, incentives and partnership arrangements. Such drivers are critical in helping to define the eco-system for the promotion of low carbon development pathways. Similarly it is essential to identify the barriers with respect to technology know-how, regulatory mechanisms, and capacities of stakeholders and market solutions so as to develop effective strategies for sustainable delivery of low carbon solutions for sustainable development.

Analysis Frame

- Policy guidelines and regulatory frameworks
- Institutional Mechanisms and synergies across institutions
- Partnerships
- Investments/ Financing
- Capacities

3.3 Key Institutions and Stakeholders

The first step to analysing the drivers and barriers of the diffusion of a particular technology (in this case, fly-ash bricks, use of bamboo and prefab in construction) is to identify the institutions that are involved as well as the different stakeholders that play a crucial role in determining the success or failure of technological diffusion and its acceptance in the market.

Public Sector

The public sector in any intervention plays the crucial role of the facilitator as well as the regulator. In the case of application of low carbon and resource efficient building materials, governmental bodies have been involved in the formulation of policies as well as regulation and promotion of the sector.

While the Ministries are mainly involved in the formulation of policies and guidelines, it is the Central Public Works Department that engages in the up gradation of technical knowledge of engineers, by effective training and participation in seminars, workshops etc. The department also monitors architectural, structural design and the construction of

Government institutions involved in the promotion and development of 'green' construction:

- Ministry of Housing and Urban Poverty Alleviation-
- Ministry of Rural Development
- Ministry of Urban Development
- Department of Science and technology
- Central Public Works Department
- Bureau of Indian Standards
- Town and Country Planning Organisation
- Building Material &Technology Promotion Council (BMTPC)
- Housing and Urban Development Corporation (HUDCO)
- National Housing Bank (NHB)
- JNNURM

buildings. As mentioned earlier, the BIS sets the standards as well as provides certification and other promotional activities.

Public financial agencies like HUDCO and NHB provide finances which are targeted towards the use of local building materials, cost effective and innovative construction technologies for their possible utilisation in the housing and building construction.

A combination of policy formulation as well as regulations by various government departments like the Bihar Pollution Control Board, Department of Environment and Forests, Department of Building Construction and other organisations like the National Thermal Power Corporation (NTPC) have enabled the accelerated adoption of Fly Ash Bricks in Bihar. Further, Central as well as State sponsored schemes like the National Bamboo Mission/State Bamboo Mission are examples of targeted promotion activities aimed at encouraging the growth of the bamboo sector.

Private sector

The private sector on the other hand is crucial in enabling the green construction material sector to penetrate into the construction market. This includes the private financial institutions, developers, individual home owners, building material manufacturers etc.

Private Developers: A number of private developers like 3C, DLF, Mahindra Life Space Developers, Jaypee Group, K. Raheja Corp., as well as infrastructure agencies like Tata Realty and Infrastructure, Larsen and Tourbo etc. have begun to develop huge townships and residential apartments where precast concrete elements of wall panels, slabs, stairs cases etc. are being used. Developers like Amrapali and Supertech Ltd. are also involved in setting up their own precast plants.

Manufacturers: They have an important role to play in promoting the use of such green construction materials. Manufacturers like Teemage Precast Ovt. Ltd, Bharathi Concretech, Precast India Infrastructure Pvt. Ltd among others are actively involved in supplying precast concrete products.

Similarly, in the case of fly ash bricks the coal based thermal power plants and captive plants are the major fly ash producers. This resource is then utilised by entrepreneurs in the production and sale of fly-ash bricks. Currently, there are approximately 2800 fly ash brick entrepreneurs in the country. In addition, the

Bamboo House India (BHI)

It is a social enterprise, striving to create chain of bamboo showrooms across the country which shall promote & market all bamboo based products under one roof starting from Bamboo pen to Bamboo Housing Structures. BHI works through a hybrid model, a 'for-profit' component and a 'non-profit' component. "For profit" activities "Bamboo House India" involves sourcing, designing, retailing, exhibiting and developing markets and "not-for-profit" activities are handled by "Bamboo Artisan Welfare Society" involving skill training & up gradation, design development & capacity building. The organization is taking initiative of opening showrooms for bamboo products, artifacts, materials etc. BHI is also encouraging the artisans to come up with bamboo based materials by providing them with interest free-cash in advance for their orders which allows artisan to purchase equipment and raw materials without going into debt by taking out loans with high interest rates.

entrepreneurs are aided in setting up of plants by technology service providers, the services of which include testing of raw materials, layout and design of the site, installation of equipment, training of manpower and troubleshooting services. Some of the major service providers are TARA Machines and Tech Services Pvt Ltd., Jayem Manufacturing, Lakshmi and Co etc.

Financial agencies: Private financial institutions look for creditworthiness in the lender. This is mainly due to the small scale at which the green material construction sector operates. With greater awareness and expansion of technical know-how, the creditability of the sector and more importantly the credibility of the entrepreneurs can be built. At present, some of the possible financial institutions that need to be targeted for providing 'green' loans are DHFL, Micro Finance Corporation Ltd., and Magma Housing Finance Corporation.

Civil Society Organisations

The main role of civil society organisations is of advocacy. Despite the formulation of policies and regulations, the enforcement of these policies are weak. In the case of application of Bamboo in construction as well as the use of fly-ash bricks, policies and regulations alone have been unable to penetrate the construction sector. With respect to fly-ash technology, civil society organisations like INSWAREB (Institute of Solid Waste Research &Ecological Balance) and Development Alternatives (DA) have been instrumental in influencing the policies as well as increasing awareness of the technology through workshops and seminars. With respect to bamboo, Bamboo House India has been one such enterprise that has helped in building networks and partnerships in the bamboo sector for greater knowledge dissemination of bamboo and other bamboo based material products.

Users/Citizens

Finally, the home-owners, which we refer to as the end-users, are the key absorbers of the green products. While policies and regulations aim at the producer end of the chain, attention needs to be paid to increase the awareness among the users. Along with providing an inventory on the low carbon and resource efficient technologies, perceptions on some of the technologies need to be corrected, which tend to remain a huge obstacle in the acceptance and use of such materials. Once awareness is created and the demand increases from the users- end, the demand- supply market take over the production and the consumption of the product in the economy.

4. Policy & Regulation

Successful formulation of policies and regulations are derived from a combination of research and development to the promotion as well as commercialisation of the product/technology. This enables the product/technology to enter the market, which would thereby result in an upscale of the production and consumption of the product/technology.

4.1. Research and Development on Technology

The stage of research and development deals largely with intangible and random or stochastic processes. The outcome of R&D is more often than not uncertain. The R&D processes use as input the resources allocated like budget, number of people assigned or laboratory equipment available. On the other hand, the output is the number of innovations or the patents that are used (Milling & Maier).

Thus to establish a conducive environment where R&D can take place, there is a requirement of systems that encourage and support innovation in a particular sector. Institutes like Council for Scientific and Industrial Research (CSIR), Indian Institute of Technology (IITs), Central Building Research Institute (CBRI) have conducted extensive research to determine the feasibility of use of fly ash as a raw material for the production of various products. Overall these institutes have been instrumental in research and development in the construction and building materials industry, hence providing the validation for the use of such technologies and the speedy adaptation of new methods including precast technology.

Policies with regard to research and development have been through the establishment of the Fly Ash Mission (1994) and the National Mission Bamboo Application. The role of the Government has been majorly focused on the promotion of research and development of technology and the commercial application of the technology in building constructions. The Fly Ash Mission was commissioned in 1994 as a joint activity of Department of Science & Technology (DST), Ministry of Power (MOP) and Ministry of Environment & Forests (MOEF), with Department of Science & Technology as the nodal agency. As mentioned above, The Fly Ash Mission has provided a single platform for the safe management and gainful utilization of fly ash. The main objectives of the mission are:

- Technology development and demonstration
- Facilitation and hand holding for the multiplier effects
- Policy measures for sustainable use

On similar lines, The Department of Agriculture & Cooperation (DAC), Ministry of Agriculture has implemented a centrally sponsored Scheme called Mission for Integrated Development of Horticulture (MIDH) in which National Bamboo Mission (NBM) is being implemented as a sub-scheme.

Under the Mission, steps have been taken to increase the availability of quality planting material by supporting the setting up of new nurseries and strengthening of existing ones. Further, the Mission has taken steps to strengthen the marketing of these bamboo products, especially those of handicraft items. It supports activities for bamboo sector in North East state (Assam, Mizoram, Tripura etc.), Andhra Pradesh, Jharkhand, Gujarat, Kerala, Uttaranchal and Orissa. The aim of the Mission is to support application oriented research and developmental activity for utilising bamboo for constructional applications.

4.2. Technology Promotion

There lies a significant lack of empirical information which is necessary for stakeholders to make informed decisions. A lack of information on the comparison of conventional and green building costs, detailed data on the energy, water and other resource savings from green construction; availability of consultants and providers who offer green building services and products, and investments in financing packages for green buildings have all hindered the growth of this sector.

While policies exist, knowledge about such products and technologies is lacking. Thus awareness generation is a crucial for deriving the success of the policies. Further, capacity building of officials working in the construction as well as sensitizing them to low carbon and resource efficient resources will enable greater acceptance of these technologies. The Indian Bureau of Standards and the Building Materials Technology Promotion Council have been key in promotion as well as setting standards and quality certification of innovative building materials and construction technologies. BMTPC has been promoting development, manufacture and use of alternate materials and technologies through the use of waste products, energy conservation, and development of substitute materials for scarce materials e.g. wood, and disaster resistant construction technologies. Building centres have thus been set up across the country to disseminate the research benefits.

However, these codes and standards are not enforceable and therefore regulation of the efficiency and quality of the building materials that are used remain weak. NGOs and think tanks can play an important role in filling these data gaps, publicising the information, and undertaking awareness generation and policy engagement activities.

4.3. Technology Commercialization and Mainstreaming

With the National Housing Policy advocating the use of alternate technologies and a holistic approach to sustainability, the overall interest in promoting 'green' in the construction sector India has greatly picked up. To mainstream green-building practices, the Government of India has several policy initiatives in the form of regulations and voluntary schemes.

In order to streamline low carbon and resource efficient technologies, an effective policy regulation has been of sustainable public procurement (SSP). In the Indian context, preferential procurement of certain products and services have been introduced through policy measures and guidelines at the central and the state level. A few states in India promote fly ash brick production by giving preference in the purchase of fly ash brick for the use in public construction. State governments like Odisha, Bihar and Jharkhand have made the use of fly ash bricks mandatory in all government buildings located within a radius of 100km from the thermal power plants. For those areas not within the 100 km radius, 50 percent of the brick requirement in government buildings has to be met by the use of fly ash bricks, irrespective of location.

5. Strategies for Change

The concept of low carbon and energy efficient material is of using locally available material that meet the target of minimal use of natural resources i.e., resource efficiency and that which is not carbon intensive. With that regard, good practices of three construction materials which were identified were fly ash bricks, bamboo and prefab technology. While these may seem readily available, there continue to be barriers to attain the maximum utilization of these materials. Below are some of the drivers, that have helped to increase the utilization levels, as well as other barriers, that have prevented in the up-scaling of these technologies.

5.1. Technology and Capacities

Currently the Indian construction sector suffers from lack of appropriate technologies and the support by efficient technology transfer. Innovation of cleaner and environment friendly technologies is essential to transform the construction sector. The absorptive capacity due to lack of information and skill deficit is a major barrier to the growth of technological innovation in the country. Several aspects need to be addressed for the development and transfer of these technologies. Some of them include collaborative research, technology demonstrations, access of information, and capacity building of the workforce.

Successful adoption of these technologies can be seen in small pockets across the country. While these technologies are available, limited information about the benefit of these technologies, its viability in the local context, and the operation processes hinders its growth. Large-scale awareness programmes targeting both entrepreneurs and users is the need of the hour to develop and nurture service providers.

Lack of technical capacities is one of the biggest barriers faced by this sector. In India, about 12 million people join the workforce each year, and only 4 million are skilled workers (FICCI & Ernest and Young, 2012). While several schemes that work towards upgrading the skills of the workers have been launched by the Central and State Governments, they remain woefully inadequate. The technical training of masons and engineers is not organised on a regular basis and it is hard to obtain industry-sponsored apprenticeships.

While technologies are innovated, and awareness of these technologies may exist, without the technical capacity to set-up these technologies and their operation, this technology is rendered useless.

Another major concern is the lack of a definition of green construction. While several green building rating systems like the Leadership in Energy and Environment Design (LEED) and Green Rating Integrated Habitat Assessment (GRIHA) are present, ambiguity in the definition still exists and the multiplicity of these systems adds to the confusion. As a result, many buildings are being marketed as green, which undermine the quality of green construction. The current rating systems focus majorly on energy efficiency. Pilot projects should be undertaken to demonstrate its benefits. Some of the popular rating systems have been adapted from other countries and are not suitable for India. Their suitability in the Indian context in terms of quality and environmental sustainability needs to be assessed, before being implemented. Thus, a common framework defining the parameters of green construction should be developed and implemented across the country

5.2. Policy and Regulation

An economy, is a sum total of various sectors in the country. With the focus on a green economy, a policy push is a key driver that advocates for the use of alternative technologies. Understanding this need, both the 12th Five Year Plan (2013-2017) and the National Action Plan on Climate Change have identified green buildings and construction as focus areas.

However, despite several policy mandates; the translation to plans and schemes has been minimal. Policies and schemes such as Jawaharlal Nehru National Urban Renewal Mission (JNNURM) and Rajiv AwasYojana (RAY) that aimed to provide affordable houses lacked the inclusion of green features in their objective. Schedules of Rates (SoR) do not always include a wide range of green options. To remedy this, guidelines should be developed to include the aspects of green construction in policies and schemes. The scope of SoRs should be expanded to accommodate green building materials. This would enable the government departments to use environment friendly construction techniques and technologies in their construction. Awareness generation should also be an integral aspect of these policies. Capacity building of officials for the proper implementation of these policies should also be within the scope of this framework. Such a stimulating policy framework would help in creating confidence among the stakeholders in environment friendly technologies and green construction.

While the concept of green construction is missing as the basic fabric, the set of codes and standards that regulate the efficiency and quality of the building materials used is rather weak. Where Bureau of Indian Standards (BIS) has set standards for some alternate building materials, however it doesn't have any mandates for enforcing it. A quality control system should be set in place that is in the form of eco-labelling/ rating systems for materials and products. While ensuring quality is essential, it is also crucial to allow flexibility in the design and applicability of these materials. Materials and design should be selected on the basis of local geographical conditions, climate and availability of local materials.

Further, policies and standards are essential to mainstream green construction. For this greater integration and coherence among the government departments and policies is necessary. For example; the responsibility of management

TARA Karigar Mandal

TARA *Karigar Mandal* (TKM) is a social enterprise that builds capacities of masons through dissemination of sustainable eco-friendly construction techniques. Registered as a Mutually Aided Cooperative Society (MACS) with the Madhya Pradesh State Government in India, TKM facilitates creation of eco-houses by acting as a service provider to provide construction services and training masons to fulfill the needs of the people while contributing to low carbon development. The masons under the *Karigar Mandal*, help meet the growing demand for rural housing without harming the Earth.

The availability of skilled masons enables new homeowners to make informed and empowered choices. A frontrunner of green job creation - TKM has supported training of artisans across the state of Madhya Pradesh to service their social housing initiative, The *Karigar Mandal* model has a large potential for replication by skill enhancement and currently six other *Karigar Mandals* are being incubated in the Bundelkhand Region. TKM has been initiated and supported by Development Alternatives.

and utilisation of fly ash lies with the Ministry of Environment, Forests and Climate Change. However, other departments also play a key role in ensuring the efficient usage of the same, like the Department of Science and Technology encourages research and development, and demonstration of ash disposal and utilisation technologies. BIS has developed standards for building materials produced out of fly ash, and further at the state level, the Department of Industries promotes industries based on fly ash through incentives and subsidies. Thus a concerted effort by all the government departments has resulted in an increase in the utilisation of fly ash in the country.

5.3. Market and Finance

The construction sector in India is highly unorganised and informal. For adoption of alternative technologies, aggregation of the construction sector will be imperative. The advantage of economies of scale as well as sharing of technical- know of these technologies will result in the streamlining of these technologies. Micro enterprises can ensure continuous supply of construction materials, which have the advantage of using local materials as well as catering to the local demands and creating local employment opportunities.

A market for adoption of alternate technologies essentially cannot just entail access to the alternative construction material but also a standardised curriculum and a system of certified skills for masons and artisans. This is necessary to ensure quality of construction material as well the method of construction. Despite the availability of the market, the demand for such technologies and practices is low due to the low level of awareness of various stakeholders. As a result, the level acceptance of the end-users is low.

Green Building Centres

TARA Machines and Tech Services Pvt. Ltd, a social enterprise of the Development Alternatives Group, has partnered with ACC and is setting-up TARA-ACC branded "Green Building Centres". These franchises are a one-stop shop for all green building requirements, from design to facilitation of construction. The Green Building Centre is a very attractive social entrepreneurship model with high investment returns.

The setup of the Green Building Centres, co-branded with ACC cements, provides best technology solutions as well as a quality brand name to develop a strong and growing business model for the entrepreneur. Green Building Centres have multiple economic, environmental and social impacts. Other than creating employment and giving a boost to the local economy, they have a huge potential in mitigating climate change impacts through promoting energy and resource efficiency and waste utilisation.

5.4. Institutions and Partnerships

Given the current state of technology in the construction industry, research and development is essential for improving and promoting environment friendly and efficient technologies. While R&D goes on, these technologies remain confined to the research laboratories and institutions, completely inaccessible to common entrepreneurs and developers both in terms of the accessibility and affordability of the technology. This is particularly true of the construction industry. It is thus, essential to strengthen commercialisation of appropriate technologies as and when they are invented or developed. One of the methods to do this is through propagating incubation services

Green Infrastructure Bonds

YES Bank, the 4th largest private sector bank in India has successfully issued India's first Green Infrastructure Bonds raising an amount of INR 1000 crores. The money will be used by YES Bank to finance Green Infrastructure Projects in Renewable Energy including Solar Power, Wind Power, Biomass and Small Hydel Projects. The main challenge in the promotion of green construction is the access to finance for entrepreneurs. In the space of small size loans, the Indian lending system has still under-developed. While incentives should be provided to entrepreneurs for investing in environment friendly techniques and construction, other mechanisms could be in the way of Green bonds for investors or Green Mortgages for home owners. Green mortgages provide retail customers with considerably lower interest rates than market level for clients who purchase new energy efficient homes and/or invest in retrofits, energy efficient appliances or green power. An effort to extend these to housing construction which use green construction materials could be a possibility worth exploring.

that act as intermediary between the laboratories and research institutions, and entrepreneurs. Such pilot demonstrations will generate awareness among the stakeholders. However, the incubation service should not be limited only to technologies. The incubation service can also include other softer aspects of construction like design and processes, capacity building, etc.

With the increasing involvement of private sector in the construction industry, it is vital to promote public-private partnerships (PPP). In such partnerships, the services are delivered by the private sector, while the responsibility of providing service rests with the government. PPP includes all non-government agencies such as the corporate sector, voluntary organisations, self-help groups, partnership firms, individuals and community based organisations. PPPs will not only help in commercialisation of the technologies, they would also play a key role in creating a critical mass of skilled workforce necessary to implement the policies and incorporate green aspects in construction.

The table below summarises key barriers and drivers in the mainstreaming of green construction.

Means of Implementation	Barrier	Driver
Technology	• Absorptive capacity due to lack of information and skill deficit • Lack of technical capacities	• Large-scale awareness programmes for entrepreneurs and users • Technical training of masons and engineers • Eco-labelling system for pilot projects • Common framework defining parameters of green construction

Means of Implementation	Barrier	Driver
Policy and Regulation	• Translation to plans and schemes • Quality control system	• Inclusion of green feature in policy mandates and guidelines • Capacity building of officials • Greater integration and coherence
Market and Finance	• Supply chain of materials and services • Acceptance by the end-users • Access to finance	• Aggregation to construction services and micro-enterprise • Innovative tools taxing and dis-incentivising entrepreneurs who use conventional technologies
Institutions and Partnerships	• Confined to research laboratories	• Propagating incubation services and pilot demonstration • Promoting public-private partnership

6. Conclusion

In conclusion, it is evident that the construction sector is a disaggregated sector with complex interlinks among both the public and private stakeholders. But at the same time, one is able to identify the key agents of change whose cooperation as well as coordination can bring about a paradigm shift in the construction sector from a carbon intensive and resource inefficient sector to a more sustainable construction sector.

On one hand, the government agencies need to work towards streamlining policies to include the 'green' mandate, strengthen the implementation processes and mechanisms and increase coherence and integration among departments. On the other hand, the private sector needs to build partnerships so as to strengthen the supply chain as well as enhance access to finance to provide an impetus to micro-entrepreneurs. Finally, the civil society organisations also have a crucial role to play in generating awareness as well as building capacities towards the use of green construction materials. Thus the coming together of all these stakeholders with a universal goal of mainstreaming the use of low carbon and resource efficient construction materials and technologies will result in the transition to a green and more inclusive economy.

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Published by:

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