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Creating a Resource Efficient India

Resource Flows in Indian Cities

City Profile of the Construction Sector in Ahmedabad

June 2020

Development Alternatives

ifu hamburg
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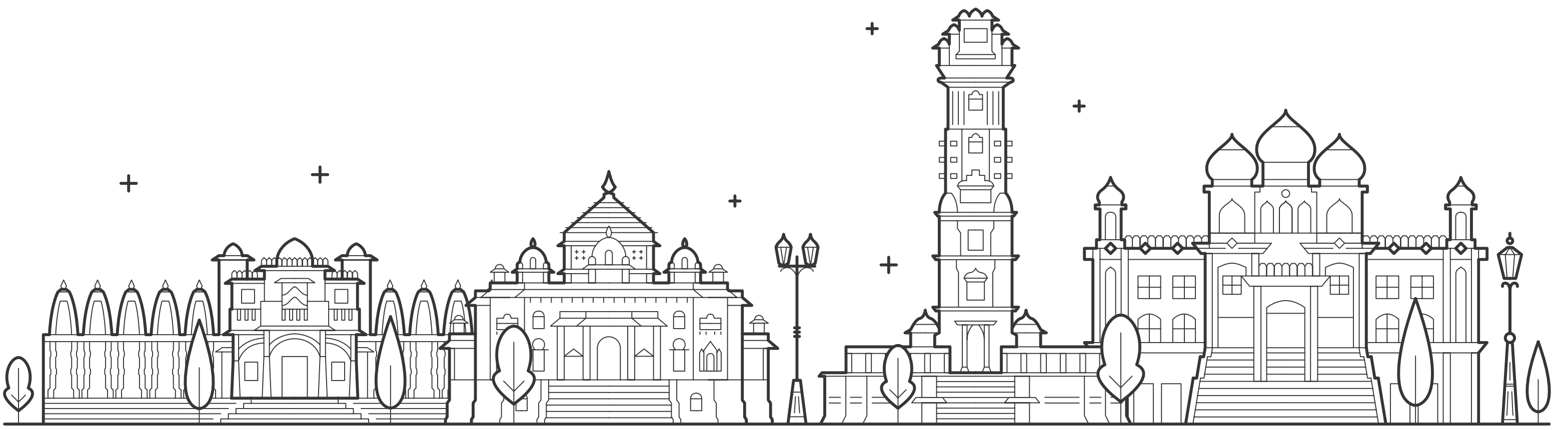

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Abbreviations and Acronyms

AAC	Autoclaved Aerated Concrete
AMC	Ahmedabad Municipal Corporation
AUA	Ahmedabad Urban Agglomeration
AUDA	Ahmedabad Urban Development Authority
BRTS	Bus Rapid Transport System
BSUP	Basic Services for Urban Poor Programme
BUA	Built Up Area
CAGR	Compound Annual Growth Rate
CEPT	Centre for Environmental Planning and Technology
CREDAI	Confederation of Real Estate Developers Association of India
DP	Development Planning
FSI	Floor Space Index
GGBS	Granulated Ground Blast Furnace Slag
GIHED	Gujarat Institute of Housing and Estate Developers
GTPUDA	Gujarat Town Planning and Urban Development Act, 1976
LCA	Life Cycle Analysis
LCI	Life Cycle Inventory
MCFA	Material Flow Cost Accounting
MFA	Material Flow Analysis
MoUD	Ministry of Urban Development
MRTS	Metro Rapid Transport System
NID	National Institute of Design
PMAY	Pradhan Mantri Awas Yojana
RAY	Rajiv Awas Yojana
RMC	Ready Mix Concrete
TPS	Town Planning Schemes
UA	Urban Agglomeration
ULB	Urban Local Body

EXECUTIVE SUMMARY

This city report is the result of a research-based study on Material Flow Analysis of the construction sector in Ahmedabad, with a focus on the housing sector. The study is part of the European Union's Resource Efficiency Initiative (EU-REI) for India and aims to support India in the implementation of the United Nations Global Sustainable Consumption and Production (SCP) agenda by way of adapting international standards and best practices on resource efficiency and fostering the sustainable use of resources. The report encapsulates the findings of Material Flow Analysis (MFA) of the housing sector in Ahmedabad and its environmental footprint (CO_2 emissions- equivalent) and identifies the measures that can be undertaken to enhance resource efficiency and utilisation of secondary raw materials.

Resource Efficiency (RE) is recognised today as an important path towards achieving sustainable development. Given its objective of creating greater value with less input and utilising the secondary raw materials thereby minimising environmental impact, RE has important implications for continued resource availability for enterprise and industry, for the conservation of limited virgin resources, and also social benefits such as job creation including in the recycling sector. Construction sector is one of the biggest consumers of virgin abiotic resources - such as soil, limestone and iron, and therefore offers significant opportunities for enhancing resource efficiency with the potential for replacing virgin resources with secondary waste-based resources.

Ahmedabad has been one of the most rapidly growing cities in India in the last decade. Demand for affordable housing - as represented by the "Housing for All" programme and the demands for an adequate transport infrastructure have driven the construction sector in the city. In future, redevelopment of 30-50 year old housing societies is poised to emerge as a significant trend, and will generate massive amount of secondary resource in the form of demolition waste. Based on data of construction permits collected from municipal authorities and predominant construction specifications in Ahmedabad, MFA of the housing sector was carried out using Umberto LCA+ software. MFA generates a scenario of the quantum scale of consumption of key materials – cement, aggregates, bricks, steel and aluminium. Ready mix concrete, river sand, cement, masonry and Construction and Demolition (C&D) waste - are the key levers for enhancing the resource efficiency of the sector. Concrete as a material, being the largest consumer of virgin resources, has significant potential in reducing the overall environmental footprint of the construction sector. The replacement of natural aggregates used in concrete with recycled aggregates from both C&D waste and the industrial waste from the ceramic industry is an area that needs immediate attention.

The findings of the study point towards the need for specific policy action to enable incorporation of secondary resources in the sector. A data-driven approach with a robust methodology anchored at the city administration level for estimating and utilising C&D waste, part replacement of natural aggregates such as river sand with secondary resources, and a more informed approach towards new developments such as increased use of prefabricated concrete are some of the key areas which will benefit from actions.

1 INTRODUCTION - AHMEDABAD

Ahmedabad is the largest city of state of Gujarat in India. It is the seventh largest metropolis in the country and also one of the fastest growing cities in a rapidly urbanising state – Gujarat is 42.6% urbanised as compared to an all-India urbanisation average of 31.2% (Census, 2011). Between 2012-2018, Gujarat was the second fastest growing state in India with 10% GSDP growth rate[1] (at 2011-12 prices) and 10.12% growth of per capita Net State Domestic Product. Many aspects of this rapid growth - population growth, employment growth, housing and infrastructure augmentation are reflected in the development of Ahmedabad. Since mid-19th century, economic growth of Ahmedabad has been underpinned by industry. After the boom of textile mills from 1950-80 chemical and pharmaceutical industry flourished after the liberalisation of economy in early 1990s. In the last two decades – the tertiary 'services' sector has dominated the economy - including business and commerce, transport, communication, construction and information technology. 66% of the total workers in Ahmedabad are employed in this sector[2]. Ahmedabad is also known for its leading educational institutions such as the Centre for Environmental Planning and Technology (CEPT), the Indian Institute of Management and the National Institute of Design (NID) - this strengthen the city's potential in research and design of innovative solutions to challenges in urban development.

The population of Ahmedabad has grown at a steady rate in the last one decade. Between 2001 and 2011, the population increased by 23%, by an average of 2.1% a year. After crossing the 1 million mark in 1960, the city grew to 5.6 million (6.35 million in Ahmedabad Urban Agglomeration - AUA) by 2011 (Census, 2011) - this growth rate has been higher than the average growth rate witnessed in both Gujarat and India. The peripheral areas of the city have registered higher population growth rate than the central parts as expected and hence, the Compound Annual Growth Rate (CAGR) of the AUA area has tended to be generally higher than that of the AMC (Ahmedabad Municipal Corporation) area except in the years when the latter's boundary was last extended in 2010 to cover an area of 466 sq.km. As per AUDA (2011) estimates, the population residing in urban areas is 50%. If the present trends continue, the population in the AUDA region will increase up to 8.8 million by 2021 and 11 million by the year 2031.

1 Ministry of Statistics and Programme Implementation. (2019, October 8). *Indian States by GDP growth*. Retrieved from Statistics Times: http://statisticstimes.com/economy/gdp-growth-of-indian-states.php

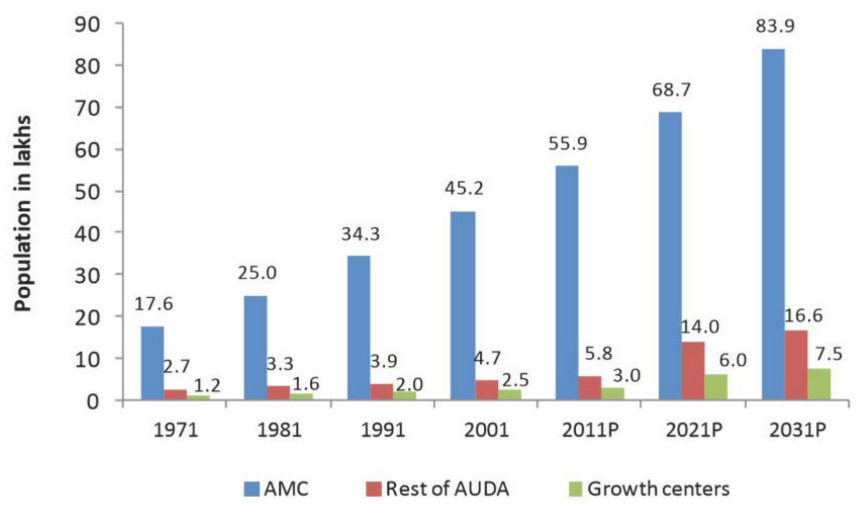
2 Mahadevia, D., Desai, R., & Suchita, V. (2014). *City Profile: Ahmedabad.* Ahmedabad: Centre for Urban Equity.

Table 1: Demographic profile – Ahmedabad

Total Population, *2011 census* *Population 2019*	5.6 Million – Ahmedabad city 6.35 million – Ahmedabad Urban start from: line under Ahmedabad 7.9 Million** - AUA
Area*	468.92 sq.km – 2011, AMC 1866 sq.km – 2011, AUA
Share of ULB population in District Urban population	92%
Population Growth Rate (AEGR) 2001-11	4.60
Slum population (notified slums)* Slum and *challis* population	4.49% 1.88 Million, 33.8% of the AMC 2011 population[3]
Density of population *	890 persons per sq.km, 2011

*Sources: * (Census, 2011)*
*** (World Population Review, 2020)*

Figure 1: Population projection in AUDA area (2021-2031)



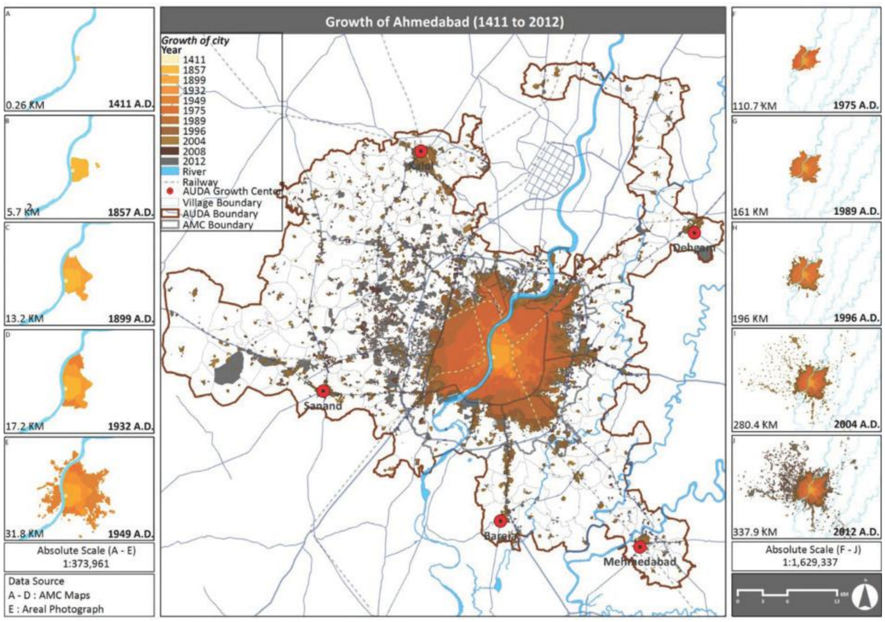
Source (Census, 2011), (AUDA, 2015)

3 Annez, P., Bertaud, A., Bertaud, M.-A., Bhatt, B., Bhatt, C., Patel, B., & Phatak, V. (2012). Ahmedabad: More but Diverent Government for “Slum Free” and Livable Cities. The World Bank Sustainable Development Network. Finance Economics and Urban Department.

OVERVIEW OF URBAN DEVELOPMENT

The Sabarmati river is an important differentiator of the different forms of urban development in Ahmedabad. The three major divisions within the city are the old walled city - located on the eastern bank of the Sabarmati, the eastern industrial section to the east of the walled city and western Ahmedabad, to the west of the river. The walled city was organised in pols or residential streets, on the basis of religion, caste and community. This part of the city forms the core of the cultural heritage of Ahmedabad and is the most restricted zone for new development, to preserve its architectural character. The 1970s and part of 1980s witnessed rapid growth of small-scale industries in Gujarat in the form of industrial estates developed by the Gujarat Industrial Development Corporation (GIDC). This also led to the expansion of Ahmedabad's industrial base resulting in rapid development of slums and housing for workers and low-income groups along the eastern periphery of the city. The western section developed as the residential zone for economically upwardly-mobile business families and was characterised by bungalow type housing. It was in 1990s that the western periphery experienced sprawl when the Indian economy was liberalised. This sprawl was through the high-rise development along the Sarkhej-Gandhinagar (SG) highway. By the end of 1990s, AUDA permitted development beyond the SG highway, though regulated by Floor Space Index (FSI)[4] restrictions which resulted in the development of high-end residential complexes in low-density gated communities.

Figure 2: Growth of Ahmedabad



source: AUDA 2012

4 Floor Space Index (FSI) is a ratio of total built-up area divided by the land plot area. If the FSI is 1 then the built-up area is equal to the area of the plot. The relationship of population density (persons per unit area of land) and FSI is through per capita space use. If the per capita space use is low, which is the case in low-income situations, the population density will be high at low FSI. In high income areas, because of high per-capita space use, the population density will be low even at high FSI.

According to Mahadevia (2014), after the year 2000, the growth of Ahmedabad in the peripheral areas under the jurisdiction of AUDA have been larger than the central parts of the city under the jurisdiction of AMC (Figure 1). While over the last decade, there was a boom in the western part of the city, currently, the expansion is along the south-eastern side of Ahmedabad. A major reason for this suburban growth is the higher housing prices in the central parts of the city vis-à-vis the peripheral areas. There are five distinct growth clusters – Kalol, Dehgam, Sanand, Bareja and Mahmudabad – which have also emerged as important nodes of low-income housing projects developed by the city administration. The fragmentated form of urbanisation in the western part of the city became more prominent in the 2000-2012 period, in contrast with the relative compactness in the east. The western segment of the city is relatively low-density development with higher real estate prices whereas the eastern segment of the city is relatively high-density with low real estate prices. The higher income households in the western part which can better afford the transport costs linked to the dispersion and the large number of TP (Town Planning) schemes are both reasons for this dispersion.

REGULATORY AND ADMINISTRATIVE FRAMEWORK

The Ahmedabad Urban Agglomeration (AUA) 5 includes 4 towns and 103 villages (besides the municipal area), leading to a multitude of local governments (both rural and urban) and fragmented structure of governance. Ahmedabad Municipal Corporation (AMC) is the local government body responsible for infrastructure planning, design and implementation of services in its 6 administrative zones - Central, North, South, East, West and New West covering 466 sq.km area. Spatial and land-use planning of the AUA, covering an area of 1866 sq.km is undertaken by the Ahmedabad Urban Development Authority (AUDA), which is set up under the Gujarat Town Planning and Urban Development (GTPUD) Act of 1976.

The land use planning of the entire city as well as outskirts is done by AUDA. The major planning interventions in Ahmedabad are currently designed, planned and implemented through Town Planning Schemes (TPS)[5]. The TPS works in conjunction with the Development Plan (DP), which is a long-term (10-year) plan that identifies growth areas and plans city-level infrastructure. The Development Plan is prepared for the entire AUDA area (of which the AMC is a part) and which is divided into 480 TPS areas. Till 2010, AUDA and AMC had implemented 103 and 101 TP schemes, covering an area of 153 and 148 sq.km respectively. The TP schemes have shown promise for transformative outcome such as the construction of 80,000 low-income dwelling units (since 2007) under various social housing schemes. The TP schemes have also improved the road network in Ahmedabad – an average 24% land was covered by roads from 2000-2013- ensuring average trip lengths of 7-8 km, which

5 The TPS is a land pooling and readjustment mechanism that allows the city to appropriate land from private landowners for public purposes, such as roads, open spaces, low-income housing, underlying utility infrastructure, and other health, education, and community services. Private land owners get compensated for the land acquired (after deducting infrastructure costs) and benefit from rise in land prices after the planning authority invests in trunk infrastructure.

is significantly less than other comparably sized cities[6] (Mahadevia, Pai, & Mahendra, 2018).

Gujarat is one of the few states to have implemented the Real Estate (Regulation and Development) Act 2016 (RERA). All real estate projects are mandated to register with the regulatory body – project detail including drawings, estimated costs and completion timeframes are put in the public domain through the RERA website[7]. The Act is meant to favour buyers of real estate by holding private developers accountable for timely completion of projects. The RERA website, which currently has close to 7000 registered projects is a valuable database of the type of real estate - housing commercial, mixed and plotted development - being developed in the city.

ZONING AND DEVELOPMENT REGULATIONS

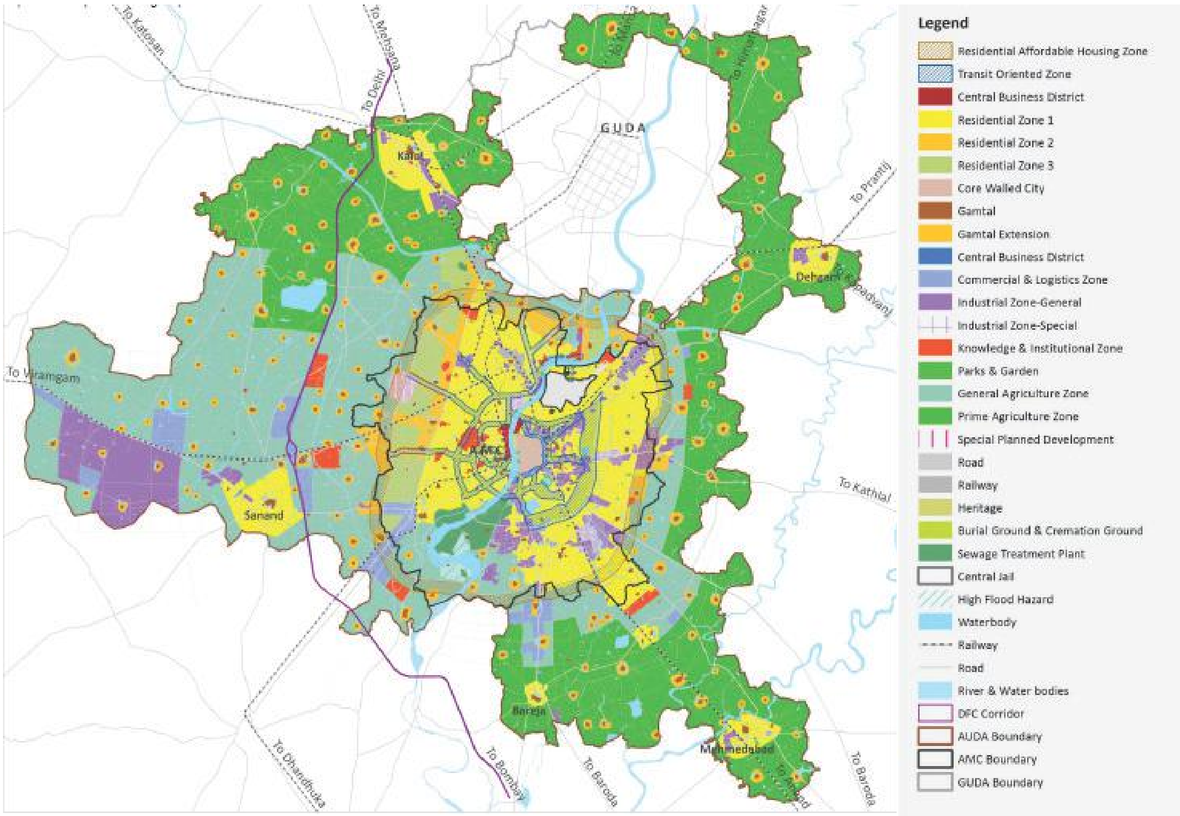
A Comprehensive Development Plan (CDP) 2021 and its General Development Control Regulations (GDCR) have been developed by AUDA to guide the urban development of Ahmedabad. Zoning of the city is one of the key tools and legal framework to manage growth, regulate built density and organise land-use in the urban area. Combined with the GDCR, it determines the supply of land available for development to accommodate the increasing population of the city. The total area under zoning in Ahmedabad UA as per AUDA 2021 is 1866 sq.km. The Residential zone covers an area of 334 sq.km, accounting for 18% of the total area. (See Figure 2 and 3). The Floor Space Index (FSI) stipulations in the GDCR are an important determinant of the built-form, which in turn influences the structural design of the buildings and, in particular, the quantum of concrete that is consumed in construction. Two residential zones (central R1 and Affordable Housing RAH), Transit Oriented Zone (TZ) and Central Business District– are zones of maximum permissible FSI of 2.7, 4 and 5.4 respectively. The FSI for affordable housing, with a view to encourage mid-high rise (G+7 or higher; 25-30 m height) construction, is responsible for dis-continuation of low-rise vernacular housing approach in favour of multi-storeyed housing with a constrained carpet area/person (See Box 1: Regulations for affordable housing).

Zoning is also a tool for assessing existing supply and future demand for housing in particular and to understand how much additional zoned land will be required to accommodate population growth in the coming decades. AUDA (2015) estimates that the expected population of nearly 1.1 Million by 2031, which translates into 30 Lakh additional people (beyond 2020), will need about 135 million sq.m of built space and about 120 sq. km of additional zoned land. At present, Ahmedabad has 373 sq.km of zoned area, of which 137 sq.km is still vacant and can absorb a part of this growth. The remaining demand will need to be met with developing new areas- much of this development will take place in the four growth clusters located close to the corners of the AUDA boundary.

6 Mahadevia, D., Pai, M., & Mahendra, A. (2018). Towards a more equal city. Ahmedabad: Town Planning Schemes for Equitable Development—Glass Half Full or Half Empty? World Resources Institute.

7 Gujarat Real Estate Regulatory Authority. Government of Gujarat (n.d.). Registered Project List. Retrieved from Gujarat Real Estate Regulatory Authority : https://gujrera.gujarat.gov.in/

Figure 3: Proposed zoning map of Ahmedabad 2021



Source: Comprehensive Development Plan 2021- AUDA (2015)

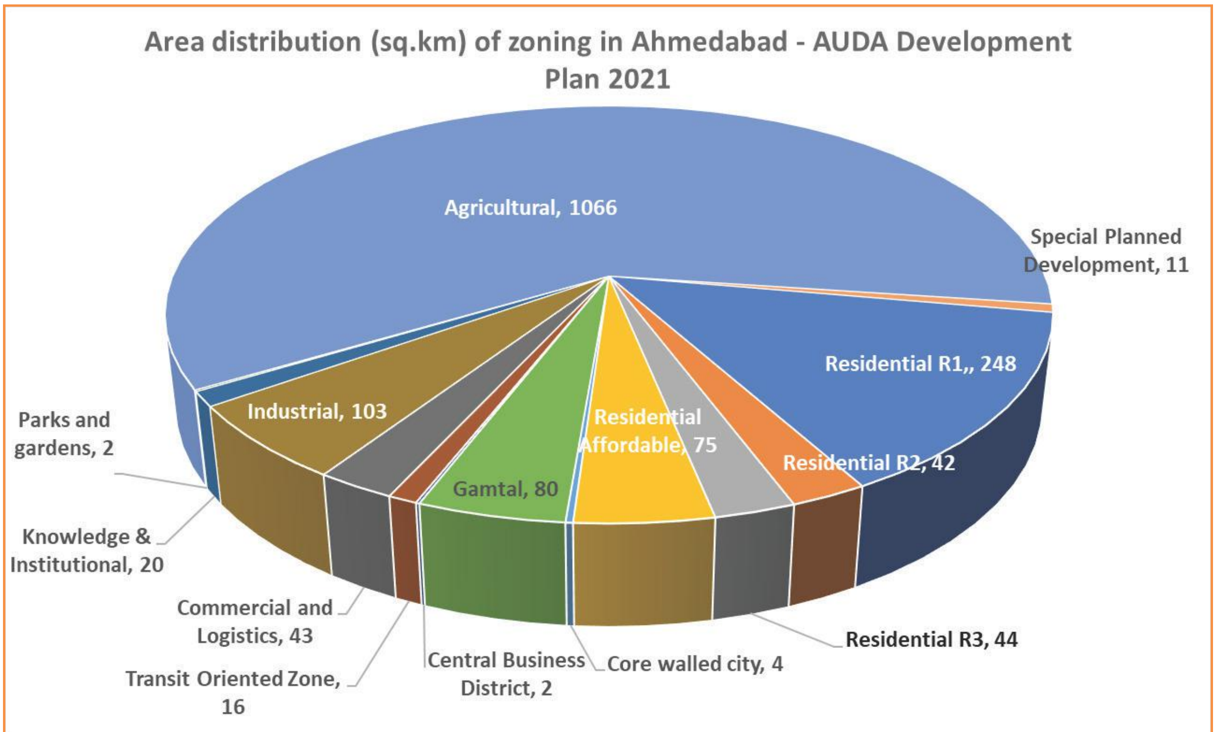


Figure 4: Vernacular style housing in Ahmedabad is no longer allowed by GDCR-2021

The linkage between GDCR and the possibilities of environmental and truly affordable housing is an issue worth considering for the planning authorities. Currently, the combined influence of FSI and land-use requirements (parking, setbacks, ground coverage) makes housing affordable for high income households but more costly by about 23% (cost/unit) while reducing the available living space per person from 7-8.5 m^2 to 5.2-5.5 m^2. A study conducted on housing the slum population of Ahmedabad[8] (Annez, et al., 2012) points out that despite an upward trend in household incomes between 2001 and 2011, during which time, the median income grew 2.7 times to INR 19,500 (USD 256), a large proportion of the population continues to reside in informal slums and challis[9] which, though occupying less than 8% of the total built up area in the city account for more nearly 34% of the city's population. There was negligible change in the proportion of slum-dwelling population from 2001-2011, indicating a densification of existing slums in this period. Vernacular land-use practice creates roughly 50% more housing space using the same piece of land, at the same density as the GDCR model. The essential difference between the two models is ground coverage. The study argues in favour of modified GDCR which allows 4 storeyed walk-up housing with 20% more ground coverage. This form of development allows consumes lesser material resources – particularly concrete and steel - per unit built - up area (see section on Study Findings).

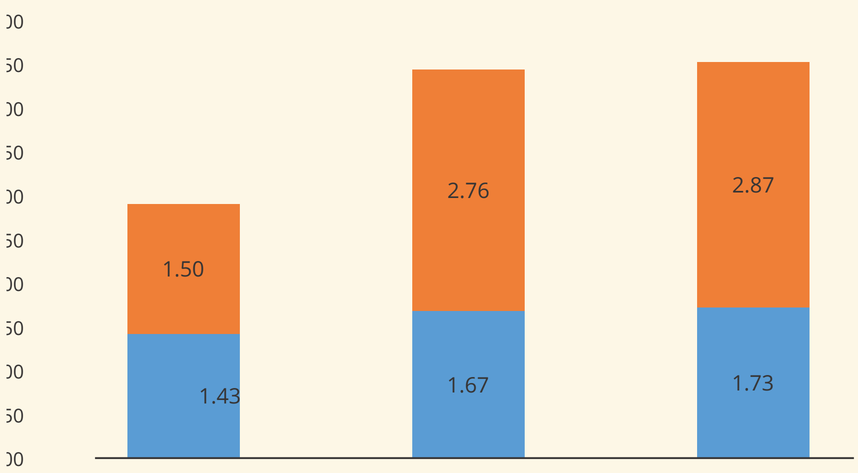
8 Annez, P., Bertaud, A., Bertaud, M.-A., Bhatt, B., Bhatt, C., Patel, B., & Phatak, V. (2012). Ahmedabad: More but Diverent Government for "Slum Free" and Livable Cities. The World Bank. Sustainable Development Network. Finance Economics and Urban Department. https://www.researchgate.net/publication/256039893_Ahmedabad_More_But_Different_Government_For_'Slum_Free'_and_Livable_Cities

9 Challis (or chawls) refers to a single large building divided into many individual tenements primarily housing daily wage earners/migrant labourers. Even though ownership arrangements and administrative treatment of slums and challis may differ, challis constitute underserviced substandard informal housing similar to slums. The population living in slums and challis together accounts for a much larger proportion than what is ascribed to notified slums alone.

Box 1: Development Regulations and Affordable Housing

A study conducted on the potential for low-carbon affordable housing in Rajkot[10] (Ashok B. Lall Architects, Greentech Knowledge Solutions Pvt. Ltd., 2017). Gujarat, 200 km from Ahmedabad strongly recommends low-rise high-density form of development for affordable housing, with permissible FSI not more than 1.5, as compared to upto 2.7 FSI allowed in GDCR. High density-high rise housing is normally justified by Planning authorities on account of land cost and scarcity within urban limits which favours more floors to maximize plot utilisation. However, in reality land can be freed for development through change in land-use regulations, land pooling, land readjustment and Transit oriented development strategies.

Figure 5: Comparison of per-person circulation space and area taken by built mass in 3 scenarios of height



Source: Position paper on Low Carbon Affordable Housing, Case study Rajkot

The study of various other parameters like energy efficiency, parking requirement, built up area efficiency, solar roof top availability per unit area and open space per capita reveals that Stilt+4 is the ideal form to be adopted for delivering quick energy efficient mass housing in the affordable segment without compromising the living environment. The study concludes that low-rise housing typology requires only 12% more land area per capita. Hence, with 12% increase in plot area efficiency, same density can be achieved with low-rise housing as in mid-rise. Increase in height reduces the Space Efficiency of the built up area to deliver the same habitable space or Carpet area (see graph). **High rise construction results in a greater quantum of building materials are used to deliver**

10 Ashok B. Lall Architects, Greentech Knowledge Solutions Pvt. Ltd. (2017). Position Paper on Low Carbon Resource Efficient Affordable Housing.

the same carpet area, thus increasing the per capita Embodied Energy and therefore greater Carbon Emissions. From low-rise to mid-rise and high-rise buildings, CO_2 emissions will increase around 15% and 35% respectively - primarily on account of higher steel and cement content per built-up area. As the amount of Building material increases, the cost/sq.ft. to deliver the same Carpet Area also increases, thus decreasing affordability.

RESIDENTIAL AFFORDABLE HOUSING

Affordable housing is a key segment of the housing sector in Ahmedabad, much like in most Tier 1 cities in India. Taking into account the population growth and income distribution of the city's population, housing for low-income settlements including the slum population of the city, poses the highest demand, over the next two decades. The Affordable Housing Policy of the Gujarat government set a target of 50 Lakh houses in the 2015-2020 period, out of which 22 Lakh were to be constructed in urban areas. The policy defines five categories of urban affordable housing - EWS (25-30sq.m), LIG1 (31-40 sq.m), LIG 2 (41-50 sq.m), MIG1(51-60 sq.m). Minimum 60 sq.m built-up area is considered as affordable housing. However, there are two versions of affordable housing – one that is being developed by Urban Local Bodies and the Gujarat Housing Board, and the other being constructed by private developers and tagged as 'affordable'. The latter category can be seen as misleading, as even a house costing INR 60 Lakh and above 60 sq.m carpet area is marketed as affordable. Growth in real estate-housing sector in Ahmedabad since the early 1990s has largely been concentrated in middle and high-income housing, with a significant chunk of houses developed costing between INR 40-60 Lakh (USD 52000- 78000) and nearly 30% houses costing above INR 60 Lakh. In the year 2010, the Gujarat government released 'The Regulation for the Rehabilitation and Redevelopment of the Slums 2010' to bring in the private sector to develop slums with the incentive of transferable FSI (also called TDR).

The target population for affordable urban housing under the national 'Housing for All' mission lives currently in informal settlements, including slums. Gujarat has 2.84 lakh households living in non-notified slums which accounts for almost 9% of the non-notified slum population in the country. Ahmedabad has the second highest population residing in informal settlements in Gujarat, after Surat.

Figure 6: Low income housing in Ahmedabad

Top Row Left, centre- Slum settlements Bhagat Na Chapra and Mahalaxmi Nagar in east and west zone;

Top row Right – typical lower middle class housing

Bottom left - Layout – Govind Ni Chali 46 households/ 172 population average dwelling size 60 m2

Bottom right – Layout – Gandhi Vas/ 538 households/2063 population/ average dwelling area 47 m2

Source: Ahmedabad Slum Atlas Part 1 – CEPT University

During 1996-2009, the AMC implemented a pro-poor housing programme called Slum Networking Programme (SNP), that aimed at in-situ upgradation of slums through provision of a package of basic services like household water connections, household toilets and drainage lines, street lights and paving of internal roads. This changed to a resettlement-driven housing approach under Basic Services for Urban Poor (BSUP) programme - by December 2013, AMC and AUDA constructed 32,842 dwelling units under BSUP – many of these catered to population displaced by the infrastructure projects in the city. The dwelling units are of 28 m^2 built-up area (each costing about INR 6 Lakh) and have been built as G+3/G+4 buildings - each provided with water supply, sewerage and electricity connection. The first Residential Affordable Housing (RAH) spread over 76 km^2 along the SP Ring road was proposed in 2013, with a plan to construct 15 Lakh houses of 36-80 m^2 area. The plan is based on **transit-oriented development** (TOD) geared towards high-rise development allowed by high FSI (4 near rapid transport infrastructure and 5.4 in Sabarmati riverfront area), with maximum height of building restricted to 70 meters (22 storeyed). To make the city slum free, 450 crores (USD 587000) has been invested under the slum area development project[11] (BW Smart Cities, 2018).

11 BW Smart Cities. (2018, March 9). *Smart Cities in Gujarat: Sincere Efforts towards Urbanization*. Retrieved from BW Smart Cities:http://bwsmartcities.businessworld.in/article/Smart-Cities-In-Gujarat-Sincere-Efforts-Towards-Urbanization-/09-03-2018-142890/

INFRASTRUCTURE

Ahmedabad is one of the 100 cities selected under the Government of India's Smart City Mission launched in June 2015. Responding to this, a smart city proposal was submitted for Ahmedabad in which the AMC had sought active citizen participation in formulation of a smart city vision, mission and plan for Ahmedabad. Ahmedabad has a successful Bus Rapid Transit (BRT) system - as of June 2018, there are eleven routes in both directions and two in circular direction connecting 149 BRT stations and cabins at extended routes. The work on Ahmedabad Metro is in progress - phase 1 of the project approved in October 2014 is expected to be completed by 2020. The city has made significant progress with respect to construction of roads. The Sardar Patel Ring Road in Ahmedabad demonstrates how public-private partnership (PPP) models can be used effectively for the development of city infrastructure. Innovative financing for this project has been undertaken in two phases, in the first phase, a consortium of nationalised banks had provided a loan of 100 crores and in the second phase, Build, Operate and Transfer (BOT) model was used to accrue funds from the private sector. Table 2 summarises the new infrastructure investments made by AUDA (1999 – 2010)

Table 2: Key infrastructure built by AUDA between 1999 and 2010

Infrastructure	Coverage	Expenditure (Rs Crores)
Roads	1472 km	825
Water Supply Network	144 sq. km	80
Water Treatment Plant	275 MLD capacity at Jaspur	106
Sewerage Network	144 sq. km	83
Sewerage Treatment Plant	At Vasna	106.9
Sewerage Treatment Plant	At Vinzol	36.8
Storm Water Disposal	144 sq. km	101

Source: Urban Planning Cell, Ahmedabad Urban Development Authority, Ahmedabad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2 MATERIAL FLOW ANALYSIS AND LIFE CYCLE ASSESSMENT

MATERIAL FLOW ANALYSIS

Material Flow Analysis (MFA) is a tool to quantify the flow and stock of materials within complex systems in order to provide a basis for material flow management and to identify de-materialisation strategies aimed at resource efficiency. MFA is widely used in industrial ecology for understanding and controlling pathways for material use and industrial processes, creating closed loop industrial practices, dematerialising industrial output, rationalising patterns of energy use - ultimately balancing input and output to natural ecosystem capacity. Conceptually, MFA is a key component Life Cycle Assessment (LCA) which has become integral today to address the challenges of Resource Efficiency and Circularity. LCA is essentially an assessment of environmental repercussions associated with various stages of a product's life. Buildings, with their life cycle from extraction of virgin resource for building materials to the ultimate demolition and disposal in land-fills, are the 'product' in the LCA of construction sector.

The analysis in the study is based on data about quantum of construction projects in the cities, typical material consumption rates of construction items and potential sources of secondary materials available for utilisation in the cities. In order to understand the environmental implications of the construction sector, a software – Umberto LCA+[12] – was used to analyse the data through MFA and LCA. While MFA delineates the quantum (tonnage) of material flow across the life cycle of a building, LCA makes known the carbon footprint (CO_2 equivalent) of building, along with other environmental indicators.

System Boundary for MFA

The MFA undertaken in the study is qualified by certain boundaries. The materials considered for analysis are those mineral based materials which are extracted from abiotic resources and which constitute the bulk of materials (more than 90%) consumed by the sector. These include Cement, sand, stone aggregates, clay bricks, reinforcement steel, structural steel, Aluminium, Glass and Steel. Fly ash has also been considered because it has become an important raw material for masonry blocks in India. The physical boundaries are defined by the development plan areas of urban agglomerations of Ahmedabad, as defined by their respective municipal authorities. The sectoral boundary

12 Umberto® is a software developed by ifu Hamburg (www.ifu.com) which is used for modelling and assessment of all types of material and energy flow systems, in order to identify improvement potentials, conduct scenario analysis or develop models for alternative processes. It is one of the popular tools available worldwide to undertake LCA with integrated cost analysis and MFA. CO2-equivalent emissions (calculated as per IPCC 2013- climate change, GWP 100a assessment method) and tonnage of material to assess quantum of material flow. Umberto LCA+ is integrated with the ecoinvent database (version 3.6) which is a comprehensive data set of over 17,000 Lifecycle inventory (LCI) datasets in various areas, such as energy, transport, construction, waste treatment, etc.

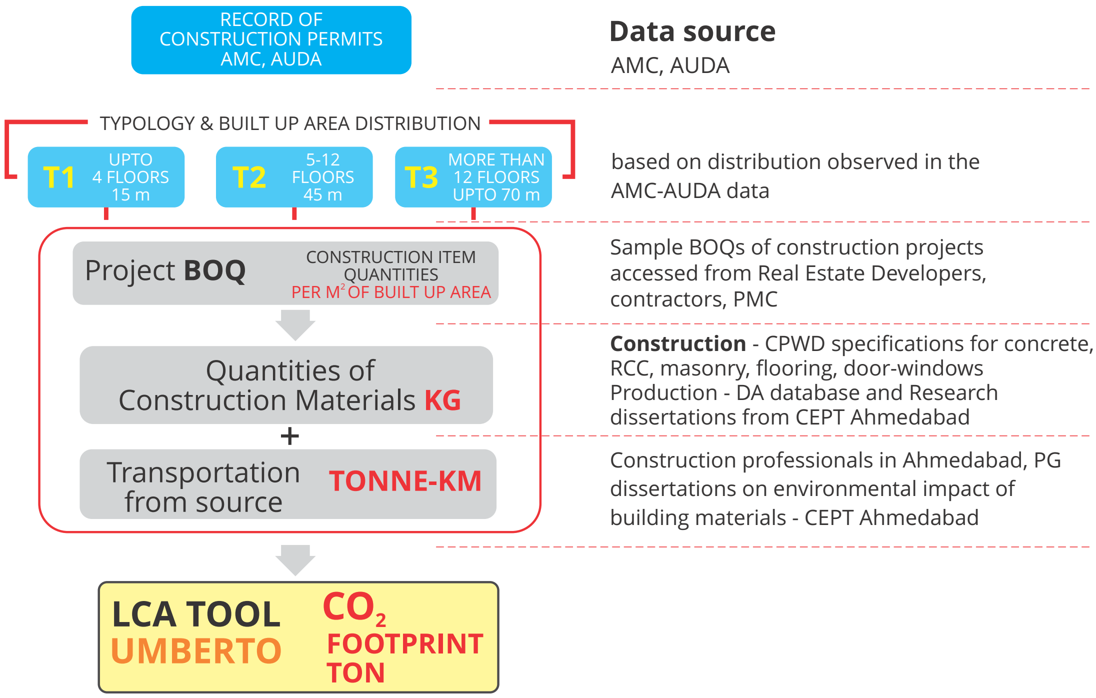
consists of residential buildings in the two cities. The timeframe selected for (residential) building projects is 2014-19 for Ahmedabad – this corresponds to the data of construction permits issued by the respective municipal authorities. The LCA considers environmental footprint (CO_2 emissions equivalent) from resource extraction till demolition and C&D waste processing.

METHODOLOGY

Keeping in mind the objective of analysing the material flow in construction sector in Ahmedabad and its environmental footprint, the starting point in the process was to get a perspective on the scale of construction activities in Ahmedabad. The Municipal authorities in the city – AMC and AUDA were contacted for this to access record of construction permits issued by them. These records for 2014-18 timeframe are the basis on which the scale of construction and distribution of the typologies of buildings was understood. The next step was to calculate coefficients of selected items of construction in terms of **quantity per m^2** of the built-up area. These were calculated from sample Bill of Quantities[13] (BOQ) of different projects in Ahmedabad sourced from a Project Management Consultancy and real estate developers. For EWS/LIG housing specifically, BOQs of some projects from Rajkot were also referred to because not enough data on BOQ could be accessed from AMC. EWS/LIG are mostly standardised designs following the recommended built-up area of units in which there is uniformity across the state. The construction items considered for establishing construction co-efficients were Concrete (foundation and superstructure), Masonry (foundation and superstructure), Doors and Windows and Flooring. The material intensity was further converted to its constituent materials for production and construction stage. For construction stage, CPWD 2016 specifications were referred. For production stage, research publications were the basis – including data available with Development Alternatives and Ahmedabad-specific material production data from research dissertations from CEPT (Centre for Environmental Planning and Technology) archives. The transportation data for material production and construction were fixed in consultation with building professionals in Ahmedabad. Finally, the combined data on total built-up area, construction coefficients (based on BOQ), constituent material consumption in production and construction and transport factors were fed in MFA software ***Umberto*** – for calculating the environmental footprint in terms of CO_2 emissions for material production, transportation and building construction.

13 Bill of quantities (commonly referred to as BOQ') is a standard quantitative document that provides project specific measured quantities of the items of civil work identified by the drawings and specifications in the project tender document

Figure 7: Methodology for material flow analysis and environmental footprint



Data framework for MFA

SOURCES OF DATA COLLECTION

The primary data for the study has been sourced essentially from records of municipal authorities and project information available with building professionals (see Table 3). Secondary data is sourced from reliable/peer reviewed resources - chiefly research based papers/reports from leading organisation (such as GIZ, DA, Adelphi) and government bodies (NITI Aayog, MoEFCC).

Table 3: Primary data collection sources in Ahmedabad

Source	Data
AMC- Town Development Officer, Additional City Engineers in housing & infrastructure, Deputy Commissioner (Housing) AUDA Officials in housing & infrastructure	• Data on development of housing, commercial and infrastructural projects • Construction Permits in affordable housing • Bill of Quantities • Development details of housing projects
Town Planning Department – Chief Town Planner	Feedback on calculation of materials calculation
CEPT University	Master level dissertations on construction sector in Ahmedabad
Private Builders and Developers (Gihed –CREDAI) Project Management Consultancy firms-Development 2020	• Perspective on housing sector in the city, emerging trends • Area wise building typologies and Coefficients for material consumption for different building typologies
Structural Consultants	Coefficients for material consumption for different building typologies

Figure 8: Snapshot of AUDA Data on building permits

Date:- 10/07/2019

Approved PRM Case Report

Total Case = 1580

	Sr.No	Name	Village	Building Type	TP Scheme	Rev-Survey No	FP No	Subplot No	Plot No	Date	Outward No	Outward Date	Prm Type	Total Area	Total Unit	Total Use
6	1	SURESH BHAI VAGJIBHAI	MEMNAGAR	Residential	T.P.1(Memnag	----	108	13	0.00	22/11/2013	PRM/400/11/	02/01/2014	G+2	107.20	01	RESIDENTIA
7	2	Smt VEENA ASHOK	KATHWADA	Industrial	T.P.131(KATH	NEW BL.NO-	55/2	40	800.00	18/11/2013	PRM/390/11/	02/01/2014	G+2	318.35	01	INDUSTRIAL
8	3	SHRI K.K.SONI DY.CEO	BHAT	Educational	T.P.79(BHAT-	77,78,79,80,	38	-	82610.	25/07/2012	PRM/349/7/2	04/01/2014	G+4	22471.12	44	TRAI.CENT.,
9	4	ABHRAM RASULBHAI &	TELAV	Agriculture	Telav	493/P	-	-	2800.0	21/03/2012	PRM/99/3/20	04/01/2014	G+2	396.75	01	PETROL
10	5	SAMIRBHAI M. SHAH	BOPAL	Residential	T.P.3(Bopal)	335	57	08	346.00	27/05/2013	PRM/206/5/2	06/01/2014	G+2	273.46	01	RESIDENTIA
11	6	FOR-JAYAMBE	MUTHIYA	Low rise	T.P.109(muthi	BL NO-91	14		3217.0	13/11/2013	PRM/386/11/	23/01/2014	G+4	3880.13	56	PARKING+R
12	7	VINOD SAGARLAL	BOPAL	Residential	T.P.3(Bopal)	586	219	17	343.75	21/11/2013	PRM/399/11/	23/01/2014	G+2	227.75	01	RESIDENTIA
13	8	PARTNER,SHALIGRAM	BOPAL	Residential	T.P.3(Bopal)	BL	199/1+2	-----	17024.	05/10/2013	PRM/367/10/	27/01/2014	G+2	17262.72	88	RESIDENTIA
14	9	SURESH BHAI .S.PATEL &	BOPAL	Residential	T.P.2(Bopal)	269	STERLI	B1-	318.43	27/08/2013	PRM/278/8/2	28/01/2014	G+2	337.10	01	RESIDENTIA
15	10	FOOD	VAMAJ	Industrial	Vamaj	2009/A,2008/	-----	-----	6777.0	13/06/2011	PRM/133/6/2	28/01/2014	G+2	1016.26	01	AGRO
16	11	OWNER:ESTATE OFFICER	KATHWADA	Residential	T.P.110(NIKO	----	86	01	34150.	15/01/2014	PRM/12/1/20	31/01/2014	G+7	83421.32	1824	RESIDENTIA
17	12	Mrs. ILABEN MANSETTA	BODAKDEV	Residential	T.P.1/B(Bodak	------	696	6+7	570.09	03/12/2013	PRM/408/12/	31/01/2014	G+2	500.82	01	RESIDENTIA
18	13	ASHWINBHAI C. SHAH &	RAKANPUR	Residential	Rakanpur	1/P	-----	-----	5318.4	19/12/2013	PRM/418/12/	03/02/2014	G+4	8947.12	191	PARKING+R
19	14	ARCHABEN.J.SHAH &	BOPAL	Residential	T.P.3(Bopal)	347	87	53	262.53	28/10/2013	PRM/376/10/	06/02/2014	G+2	323.91	01	RESIDENTIA
20	15	ESTATE OFFICER--	KHODIYAR	Residential	T.P.60(Khodiy	-----	57	----	2670.0	15/01/2014	PRM/14/1/20	07/02/2014	G+14	11852.11	112	PARKING+M
21	16	ARVIND KESHAVLAL	LILAPUR	Residential	LILAPUR	BL.NO:115+1	---	HISSA NO	4001.0	23/03/2011	PRM/66/3/20	07/02/2014	G+2	329.97	01	RESIDENTIA
22	17	MAULIBEN HETALBHAI	BOPAL	Residential	T.P.3(Bopal)	564,565	223+23	46	943.50	10/09/2013	PRM/297/9/2	11/02/2014	G+2	788.95	01	RESIDENTIA
23	18	M/S MOTHERSON	BOL	Industrial	Bol	56,144/1,145	---	SM-42	39907.	10/10/2013	PRM/372/10/	12/02/2014	G+2	18254.19	11	FACTORY
24	19	Mr JIGNESH VITHALBHAI	AMIYAPUR	Low rise	T.P.46(MOTER	28/P	174/2		1497.0	29/07/2013	PRM/263/7/2	12/02/2014	G+4	4340.34	80	RESIDENTIA

Snapshot of data on construction permits issued by AMC and AUDA –
the red rectangle highlights data entry on No. of Floors, Total built-up area, Use of project (residential, industrial, commercial, mixed) no. of units (in case of residential project)

3 FINDINGS AND ANALYSIS

This section presents key learnings from the study. Construction and redevelopment trends in Ahmedabad are based on visits to the city and discussions with public and private sector building professionals in the city. The core of this chapter are key findings from the Material Flow Analysis carried out using Umberto LCA+, based on Ahmedabad specific primary data and construction permits data from AMC and AUDA.

CHANGING TRENDS IN CONSTRUCTION

- There has been almost 90% reduction in use of burnt clay bricks over the last 5-6 years
- The use of Burnt clay bricks will further reduce in the coming years – already they are mainly confirmed to construction of independent bungalows
- AAC blocks are emerging as the most popular choice for masonry – however, the trend is to use them to build 6" thick masonry in RCC frame structures
- Construction practices are also undergoing a change in Ahmedabad –
    - Ready Mix Concrete (RMC)[14] is most commonly followed now, and in which, 15-20% cement is replaced with Fly ash. Today, concrete is inherently greener than what it used to be. Complementary to RMC, more equipment such as pumps, cranes are being used now – all this improves efficiency of producing and placing concrete.
    - Similarly, ready mixed mortar is being used for plastering – this is usually sprayed on the wall – this consumes less water and also minimises wastage.
    - Also, high quality shuttering (such as German brand Parry) is being used which enables upto 5000 sq.m of RCC slab to be cast in 2-3 days.
    - AAC (Autoclaved Aerated Concrete)[15] blocks are rapidly becoming common – the main advantages being reduction of dead load of building, higher productivity in construction and savings in plaster because of even surface of the blocks. Until now, their use has largely been limited to middle-high income housing and commercial buildings. However, the continuing increase in their market acceptance has the potential to make them affordable for low-income housing.

14 Ready Mix Concrete is concrete that is manufactured in a batching plant according to a set engineered mix design. The concrete is delivered to construction sites either through transit mixers which deliver ready-to-use plastic state concrete or through a concrete mixer which delivers the mix in a dry state.

15 AAC is a lightweight material produced by mixing silica rich material, fly ash, cement, lime, gypsum and aluminium powder/paste (for generating aeration). The material is used to produce light-weight masonry units of relatively large size in the form of AAC blocks. The blocks have environmental advantage of using 50-60% fly ash and possibly, reduction in operational energy for indoor comfort cooling.

- Ceramic tiles are the most common option now for flooring due to competitive costs, local availability and lowest maintenance
- Steel frames with Aluminum Composite Panels (ACP) are common for commercial buildings
- Glazing in commercial buildings is mainly 12mm toughened glass
- Pre - cast concrete panel technology has been used for low-income housing as a demonstration project by AUDA. Apart from that, there is no indication of its replication. There are some instances of its use in private housing in the outskirts of the city.
- Monolithic construction (RCC walls) has also been used in some government housing by the AMC housing department.

- **Precast construction**
  - New 'precast' construction techniques have been used in low-income housing – for example, monolithic construction for EWS/LIG housing in Thaltej (a suburban town in Ahmedabad district) by the Housing Department of AMC. This initiative is to showcase techniques for rapid construction. It has been demonstrated in some 35000 houses in 2006-12 timeframe, but there is no trend of larger scale adoption of these new precast technologies for mass housing.
  - There is a risk perception yet associated with precast construction - this is primarily AMC's perception because they have a larger answerability for at least 30 years for the housing they construct (as opposed to private developer housing).
  - The potential of precast technology is in the G+1 to G+4 segment.

- Demolition waste is utilised in C&D plant to mainly produce paver blocks, kerb-stones and concrete benches for parks/public spaces.
- Ready Mixed Concrete (RMC) is mandatory for all housing work done by AMC.
- AAC blocks, LED lights, photo reflective glazing is among other eco-friendly materials in the housing sector.
- UPVC is becoming a more common option now for door window frames, and to some extent for plumbing also.
- Double-glazed glass units are also becoming common in high-income housing.
- New products, which market themselves as environment-friendly by eliminating the need for sand, have started appearing in the market, though their credentials are yet to be established. For instance, Perlcon Premix Pvt Ltd, has launched a range of 12 self-curing sand-free products in India, which are pre-mixed cement-based formulations for plaster and masonry mortar. It has set up 1 Lakh tonne/annum manufacturing facility at Kadi, 45 km from Ahmedabad.

CONSTRUCTION AND DEMOLITION WASTE SCENARIO IN AHMEDABAD

Ahmedabad is one of the first cities to successfully implement model for management and utilisation of C&D waste for making new building products. According to AMC estimates, approximately 700 tonnes of C&D waste is manufactured per day in the city with an annual generation of 0.21 million tonnes of waste per day. Ahmedabad is the second city in India to implement a PPP model between AMC and Amdavad Enviro Projects Private Limited (AEP). A 300 TPD processing facility was launched in 2014, the capacity of which was increased to 600 TPD in 2016 after successful operation and now to 1,000 TPD in 2018. Design Build Operate Finance and Transfer (DBOFT) model is followed in which Amdavad Enviro Projects Pvt Ltd. (AEP), a private enterprise picks up waste from designated collection points by charging a tipping fee of Rs 160/tonne from AMC and transports the debris by private transport contractors to its C&D facility. GPS tracking system is used to track the waste transportation. Even though there are 32 C&D waste collection points in the city, currently the C&D facility is mainly fed by wastes from 2-3 collection points which receive a large amount of C&D waste. Picking waste from a few other designated sites has not been financially viable due to transport costs over long distance and insufficient quantum of waste at these sites.

Only concrete from C&D waste is being used to make non-structural products – mainly paver blocks, kerbstones, manhole covers, park benches, etc. As per discussion with AEP, around 750- 1000 MT C&D waste is generated per day, out of which 50-60 MT of C&D waste is used in the production of paver block. Out of the bulk of C&D waste (about 700 MT), 50% is Fines and Clay which gets used up in back-fill in civil projects. This can be washed to recover sand which can be used to replace coarse sand. The remaining waste is primarily brickbats which is used in the Granular Sub Base (GSB) in road construction. This is a more significant application of C&D waste because conventionally, GSB is sourced from the riverbed which is environmentally damaging. 20% of this can easily be replaced with C&D waste. 20% of C&D waste still goes to landfill. The C&D waste is mainly from residential sector – G+4 to mid-rise buildings. Cost of transporting this waste is about Rs.200 per MT, whereas cost of transporting Municipal Solid Waste (MSW) is Rs.1200 per MT. The average transportation distance for C&D waste is 12-14 km and an average 20MT waste is transported in one truck trip.

Box 2 : Trends in Redevelopment

Redevelopment is poised to emerge as a significant trend in the coming years in Ahmedabad - this will take place in old housing societies of Ahmedabad and will ultimately be a higher volume than new buildings. No more building societies, which have been a traditional feature of urban housing in Ahmedabad, are being constructed any more. Redevelopment of 40-50-year-old buildings, and in many cases, even 30-year-old buildings are opting for redevelopment. Private builders are beginning to respond to the redevelopment business opportunity. The government of Gujarat has recently notified the final rules of the Redevelopment Act, making it possible for the community to go ahead with redevelopment with a 75% consent, instead of the previous 100%. It is estimated that almost 5 lakh households in 10,000 housing societies constitute the near-immediate demand for redevelopment in Ahmedabad. Most redevelopment will take place at old housing societies in Ahmedabad - typically G+1 or G+2 structures, which are at least 50 years old will be redeveloped.

A study conducted by DA and GIZ on C&D waste utilisation in Ahmedabad[16] (DA, GIZ, 2016) points out that economic viability of C&D waste utilisation depends on viable business cases for decentralised C&D waste management infrastructure like mobile crushing units or standalone C&D waste processing facilities of small capacities. Recycled Aggregates (RA) are the main resource which can be generated at the material level from C&D waste and their cost is mainly determined by their transport from point of generation to processing facility. The study indicates possible cost savings up to 20% as compared to cost of virgin aggregates and 15% for RA-based finished products such as paving blocks.

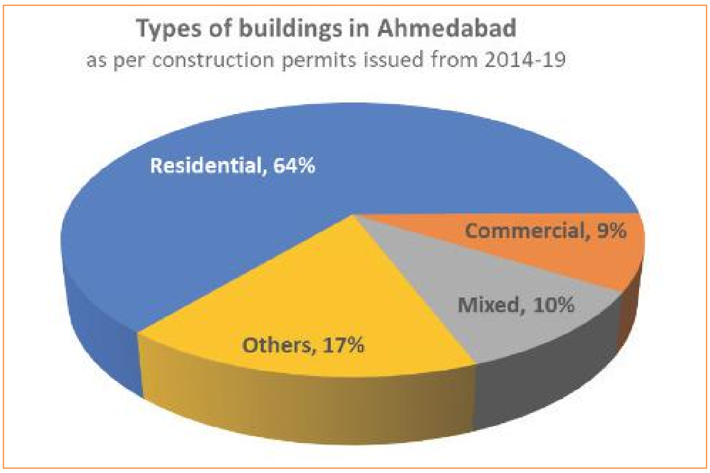
Apart from recycled C&D waste, there is an informal network of re-used materials sourced from demolitions – door window frames, bathroom fittings, furniture, etc. The Gujri Bazaar is one such area in Ahmedabad where such products can be sourced.

ANALYSIS - BUILDING TYPES

This part of analysis is based on data of construction permits of buildings sanctioned in Ahmedabad, collected from AMC and AUDA. Data from AMC included records of buildings from 2013-2018 and data from AUDA included records of buildings from 2014-19.

16 DA, GIZ. (2016). Market Study on Construction and Demolition waste utilization in Ahmedabad. Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH.

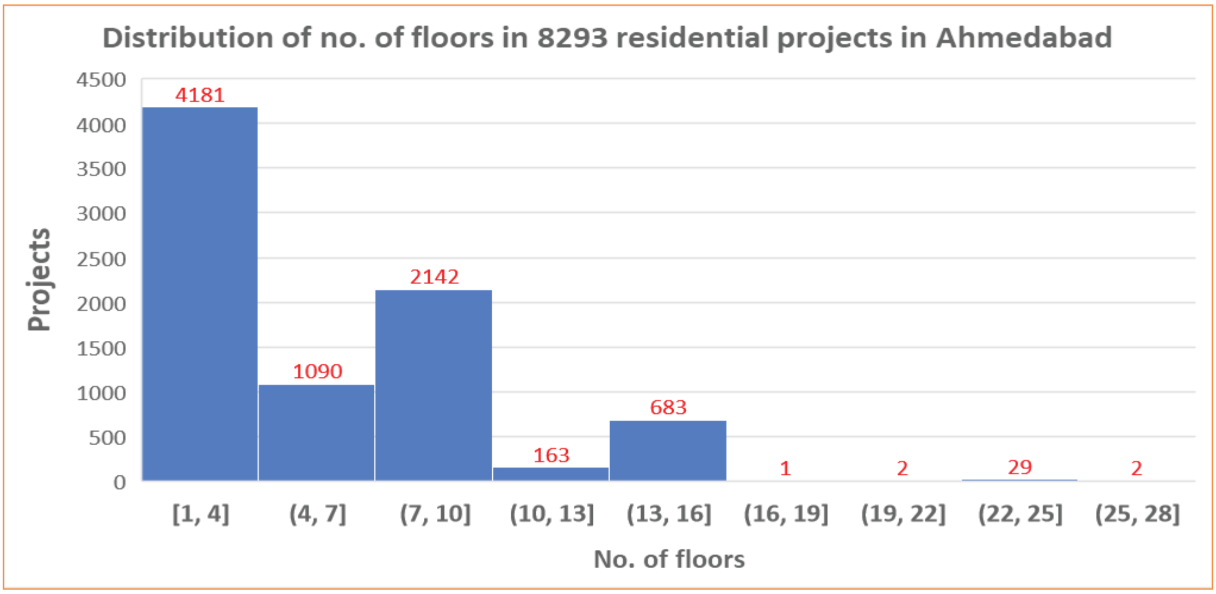
Figure 9: Types of buildings in Ahmedabad as per construction permits from 2014 to 2019



The records of construction permits – AUDA and AMC combined from 2015 were analysed to identify some key trends. From a total of 12325 permits issued, 64% buildings constructed are for residential usage, 9% for commercial usage and 10% for mixed residential and commercial usage – denoting multi-storeyed buildings with the ground and first floor used as retail space. The remaining 17% mostly includes industrial and institutional buildings. Overall, residential buildings account for nearly 3/4th of the built-space in Ahmedabad.

In view of the height of the built landscape, Ahmedabad is dominated by low to mid-rise buildings represented by upto 4-storeyed and from 5-8 storeyed buildings respectively. As per construction permits issued from 2014-18, 50% of the total buildings are not more than 4 storeyed high (12-13 metres). Nearly 65% of the buildings are not more than 25 metres high (8 floors).

Figure 10: Distribution of no. of floors in 8293 residential projects in Ahmedabad



Going ahead, there is a trend of taller buildings in both residential and commercial category. This is borne out by about 10% of the approved buildings which are more than 40m high (13+ floors). This is expected, as there is an active push by the Gujarat government to boost the real estate sector through a slew of FSI relaxations in some designated areas – specially along the mass rapid transit zones. An FSI of 4 is being provided for developments along 45m wide roads. Looking at the FSI values calculated by the ratio of built up area to the plot area (from the municipal records of construction permits), it is observed that 50% of the projects have an FSI under 2 – corresponding to low-rise buildings of upto 4 floors. About 35% buildings have FSI between 2.5 and 3.5 - corresponding to mid-rise buildings of G+4 to G+8. About 15% buildings have an FSI more than 3.5. 1% buildings have FSI more than 7 – these are high rise buildings of height between 50-70m.

Figure 11: FSI Distribution in residential buildings in Ahmedabad based on 6646 projects

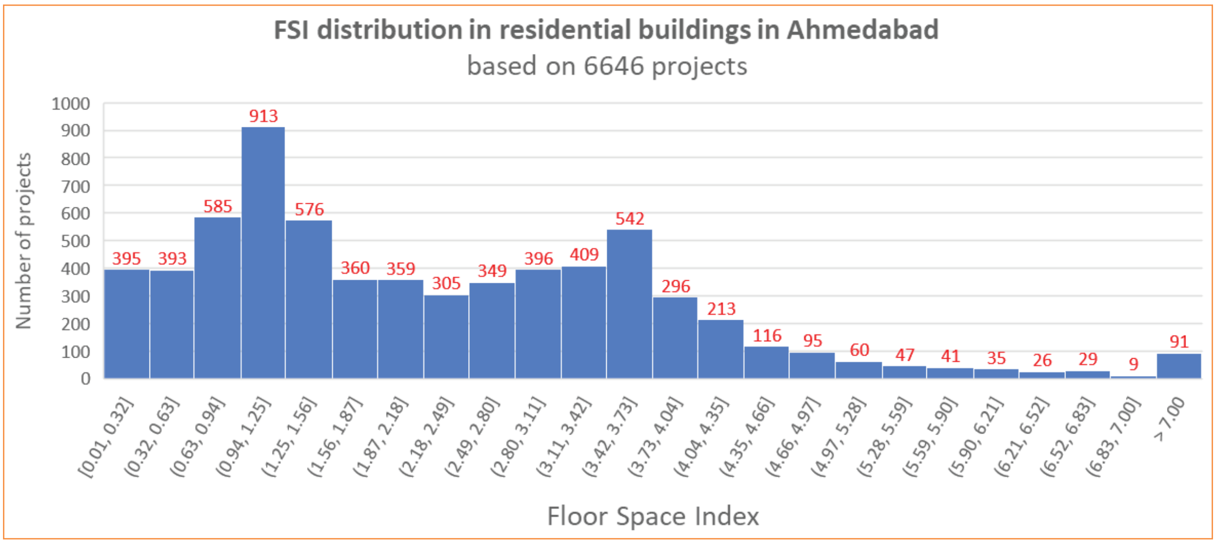


Figure 12: Residential buildings in Ahmedabad

Residential buildings in Ahmedabad – high rise apartments (left, 4 years old) are coming up in designated high FSI areas, mid-rise apartments (right, 9 years old) are the most common typology

Figure 13: Transportation infrastructure

Transportation infrastructure – Flyover bridges are being constructed at a hectic pace in the city. Between 2015 and 2022, AMC would have constructed 6 FOB in Ahmedabad covering about 5000 metres in length

Figure 14: Housing societies available for redevelopment

Housing Societies in Ahmedabad available for redevelopment – This G+4 building is more than 40 years old and have been approached by a leading developer with a proposal for a G+7 building

ANALYSIS – MATERIAL FLOW IN RESIDENTIAL BUILDINGS

This part of analysis is concerned with the Material Flow Analysis of residential buildings in Ahmedabad. It combines two parameters of 'building typology' and 'construction typology'. While the former emerges from data on construction permits, the latter is based on consultations with AMC/AUDA personnel, private developers and structural consultants and sample Bill of Quantities gathered for each typical building typology.

Material flow has been estimated in Mass of building material (tonnage) which is consumed by four main items of construction – Concrete and RCC in foundation and super-structure, Masonry in foundation and superstructure, Flooring, Plastering and Door-window. These five construction items are responsible for the bulk of the mineral based building materials which are needed in construction.

The conversion of built-up area to quantities of materials is based on technical specifications of the above items of construction and further, coefficients of material consumption per unit quantity of item of construction. Coefficients for quantities of concrete, RCC, masonry, flooring and door-windows were derived from Bill of Quantities of housing projects (sourced from AMC and private consultants). Coefficients for consumption of primary materials (cement, sand, aggregates, bricks) were sourced from CPWD (Central Public Works Department) 2016 Rate Analysis.

The material consumption is first understood at the level of a single residential building in each of the three categories identified for the study – upto 4-storeyed, 5-12 storeyed and more than 12-storeyed. It is then extrapolated at the city level by assigning a proportion to each building typology (see table below)

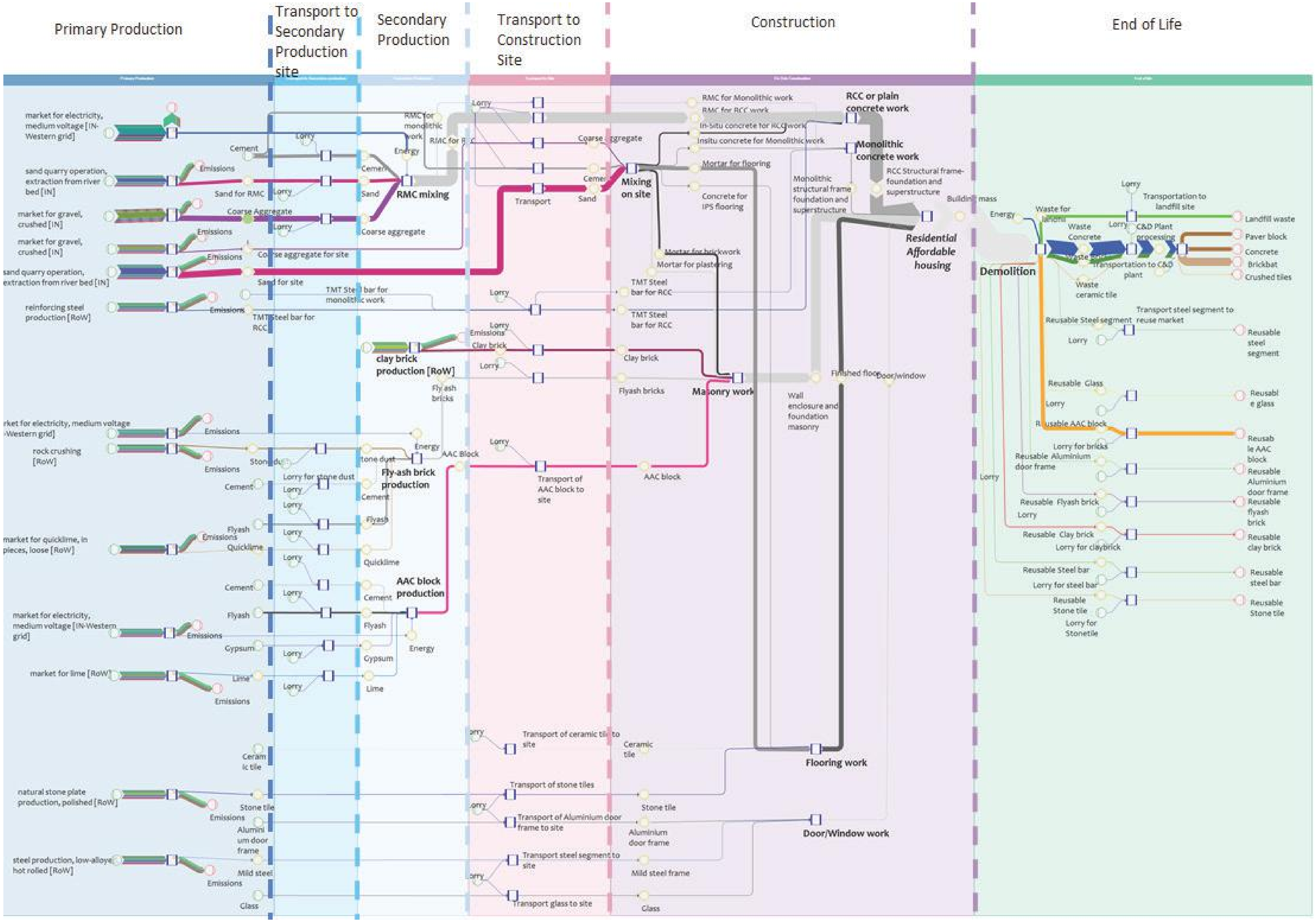
Table 4: Break-up of building typologies for MFA

Building typology and typical project built-up area	Distribution among 8293 residential buildings	Total built-up area (city level)
Type 1 Low-rise construction, G+4 11227 m^2	3% - EWS/LIG housing	982798 m^2
	48% - Middle income housing	13103976 m^2
Type 2 Mid-rise construction, G+5-12 4392 m^2	2% - EWS/LIG	655199 m^2
	38% - Middle income housing	12448777 m^2
Type 3 High rise construction G+13 and above, 23895 m^2	8% - High income housing	2620795 m^2
Type 4 Monolithic RCC construction- Low-rise G+3, 53519 m^2	1% EWS/LIG housing	2948395 m^2
Total built-up area		32759939 m^2

Table 5: Material and technology specifications – residential buildings

Part of building	Category of building		
	EWS/LIG	Middle income	High income
Foundation and structure	RCC frame, RMC M30 predominantly in foundation, M20/25 for columns, beams and slabs		
Masonry	Clay bricks (30%)/ Fly ash bricks(15%)/ AAC blocks (55%) in cement mortar	Clay bricks (20%), Fly ash bricks(15%) and AAC blocks (65%) in cement mortar	AAC blocks (90%)/ Clay bricks (10%) in cement mortar
	For Monolithic construction, masonry is replaced with M20 concrete walls – 150mm external, 90mm internal		
Plaster (wall and ceiling)	Cement sand plaster 1:3 – 20mm thick external, 12mm thick internal Gypsum		
Flooring	Vitrified tiles/glazed tiles in rooms Kota stone in common areas	Ceramic/vitrified tiles in rooms and common areas, Kota stone in kitchen	Vitrified tiles/stone tiles in rooms, stone floor in kitchen
	Laid in 1:6 cement mortar on a concrete M15 base and bedding mortar		
Door-window frames	MS frame for doors, Aluminium frame for windows 4mm float glass	Wooden door frames, Aluminium frame for windows 4mm float glass	wooden door frames. Wooden/ UPVC (10%) window frames

Figure 15: Material flow in construction sector in Ahmedabad for BUA 32.75 million sq.meter from 2014 to 2019 (Umberto model)



MFA FINDINGS

Every m² of built-up residential space consumes about 2.16 tonnes of materials. This corresponds to RCC frame + infill wall type of construction and a distribution of 50%, 40%, 8% and 2% built up area to upto G+4, G+7, G+12 and G+21 type buildings, as reflected by the construction permits data. In comparison, studies reveal that load bearing G+2 construction consumes 3.5-4 tonne sq./m^2. The material use is by concrete (RMC) which accounts for 40% consumption. AAC blocks, which are rapidly replacing clay bricks, account for 10% of the material mass, which would have been closer to 25% if clay bricks were used. **Cement, sand and coarse aggregates, which are used in concrete, mortar and plaster, constitute 17%, 32% and 21% of material mass, accounting for almost 70% of the total quantum of material use.**

There is no comparable data from a similar research in the context of India. However, research in the sustainable buildings sector in India[17] (Jagadish K. , 2019) indicates a material intensity of 4.38 T/m^2, 3.23 T/m^2, 1.43T/m^2 and 1.5 T/m^2 for 4 categories of Single storey load bearing, G+2 load bearing, G+4 RCC frame and G+10 RCC frame respectively. An MFA study of the construction sector in Brazil[18] finds the material intensity of residential construction in the range of 0.8-2.5 T/m^2 of constructed area.

17 Jagadish, K. S. (Ed.). (2019). Sustainable Building Technology. I K INTERNATIONAL PUBLISHING HOUSE PVT LTD.

18 Condeixa, K. de M. S. P. (2016). Material Flow Analysis And Environmental Impact Assessment of the Construction Sector in Brazil (dissertation). Retrieved from https://www.tesisenred.net/bitstream/handle/10803/454715/TESI.pdf?sequence=1&isAllowed=y

Table 6: Raw materials used for 8293 residential buildings in Ahmedabad

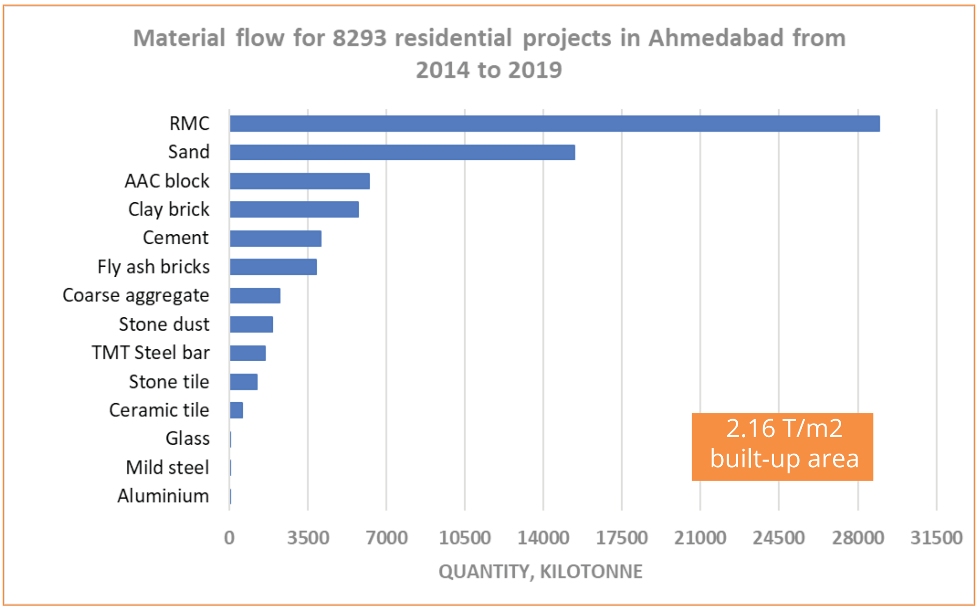
Material	Material quantities in KiloTonnes (KT) consumed for 8293 residential buildings in Ahmedabad, BUA 32.75 Million sq.m				
	0-4 floors	5-12 floors	Greater than 12 floors	Total Flow, Kiloton	Average (weighted for the 3 categories) material intensity – Kg/m²
Aluminium	14.3	8.19	3.18	25.71	**0.78**
Mild steel	26.3	7.02	5.86	39.26	**1.20**
Glass	23.6	26.4	5	55.05	**1.68**
Ceramic tile	333.6	192.7	47.54	573.88	**17.52**
Stone tile	988.6	142.8	103.5	1234.92	**37.7**
TMT Steel bar	660.87	688	242.4	1591	**49**
Coarse aggregate	2083.3	162.5	0	2245.80	**68.55**
Fly ash bricks	3336.5	520.6	0	3857.10	**117.74**
Cement	2083.26	258.4	195	4087.87	**124.78**
Clay bricks	4925.36	484.12	73	5482.49	**167.35**
AAC blocks	4575.8	1418.9	250.3	6245.03	**190.63**
SAND	13047.2	1100.27	849	16361.79	**499.45**
RMC	15499	10072	3381	28952	**884**
TOTAL	**1.9 T/m²**	**2.1 T/m²**	**2.5 T/m²**	**70752**	**2.16 T/m²**

The quantum of material flow and consumption is dominated by Sand, being a material, which is consumed in concrete, masonry, flooring and plastering.

The usage of river sand is an issue of environmental costs and long-term availability of the resource. Almost all sand consumed in construction is river sand which is sourced from Sabarmati and its tributaries in close vicinity of Ahmedabad. There is a strong perception of easy and continued availability of river sand across public and private sector developers. Although, the issue of ecological impact of river sand extraction in Gujarat has been highlighted at the government level and across environmental fora, instances of illegal river sand mining continues at an alarming rate[19] (SANDRP, 2020). The Sustainable Sand Mining Management Guidelines (MoEFCC, 2016), while framed essentially to regulate sand mining and to promote environmental safeguards, also emphasise the importance of artificial alternatives to natural sand. (See Box 3: Sand – criticality of a prime resource).

Coarse aggregates account for the second biggest quantum of material use. Sand and coarse aggregate together account for 50% of the total material flow in the form of concrete for RCC frames predominantly and bed concrete for flooring. This pattern of material consumption is observed in all three categories of buildings because of the basic technology of RCC frame and in-fill construction being common to all three. The intensity of concrete use in residential construction is 0.45 m^3 and 0.57 m^3 per m^2 of built-up area, corresponding to a 4 storeyed building for EWS category and 13 storeyed building for upper middle-income category – this difference is attributable to the increase in the cross section of RCC elements for taller buildings. **This increase in mass of material is more pronounced for reinforcing steel which is about 40 kg/m^2 and 65 kg/m^2 for low-rise and high-rise building, respectively.**

Figure 16: Material flow for 8293 residential projects in Ahmedabad from 2014-2019



19 SANDRP. (2020, January 3). Gujarat Riverbed Mining Overview 2019: Six People Died Due To Illegal Sand Mining. Retrieved from South Asia Network on Dams, Rivers and People: https://sandrp.in/2020/01/03/gujarat-riverbed-mining-overview-2019-six-people-died-due-to-illegal-sand-mining/

Box 3: Reducing the environmental burden of natural sand

It is primarily river sand that is used for construction purposes in most parts of India, including Ahmedabad. The mining of this sand, which happens in the active channel or the flood plain of the river has tremendous deleterious impacts. If sand and gravel are extracted in quantities exceeding the capacity of the rivers to replenish them, they can cause severe damage to the river's eco-system, its channel form, water flow and physical habitats. In spite of the huge quantum of sand being removed from Indian rivers, very few studies on sand mining have been conducted in the country, which is the reason why the issue remains under-appreciated in many states – Gujarat (ranks 5th in illegal sand mining in India), Tamil Nadu, Karnataka, Madhya Pradesh- even after evident ecological damage. According to the Commissioner of Geology and Mining (Government of Gujarat), the total revenue collection from royalty and fines imposed for illegal mining in Gujarat was INR 700 Crore (USD 9.16 Crore).

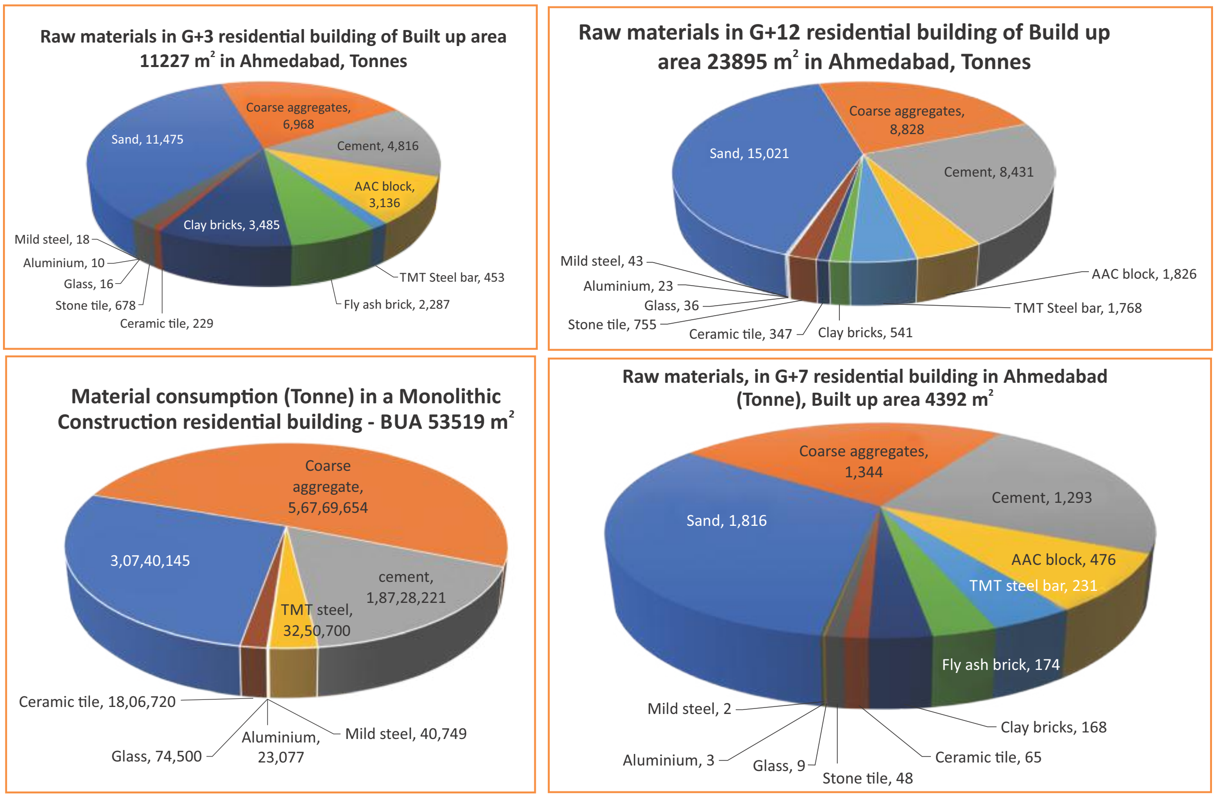
The Sustainable Sand Mining Management Guidelines (2016), in addition to specifying environmental safeguards in river sand mining, also identify important complementary action areas to reduce the quantum of river sand used in construction. Renewable and recycled materials need to be targeted for building houses and roads - in this, the use of Manufactured Sand (M-Sand) also needs to be promoted. Dams, which regularly release large amounts of water to flush out aggregates can also be targeted as alternative sources of sand and gravel.

Bureau of Indian Standards (BIS), considering the scarcity of sand and coarse aggregates from natural sources, has evolved number of alternatives aimed at conservation of natural resources apart from promoting use of various waste materials without compromising quality. These include permitting the use of slag (waste from steel industry) and fly ash (waste from thermal power plants), crushed over-burnt bricks and tiles (waste from brick and tile industry) in plain cement concrete as alternatives to natural aggregates. BIS has also formulated an Indian Standard Specification for artificial lightweight aggregates covering manufactured aggregates, such as foamed blast furnace slag, bloated clay aggregate, sintered fly ash aggregate and cinder aggregate (IS 9142). Training of architects and engineers about new laws and regulations, and technical developments in artificial aggregates is needed to initiate a shift for lowering our dependency on sand.

Masonry accounts for the third biggest quantum of material use. This is dominated by AAC blocks which have emerged as a preferred option in multi-storeyed construction. They are typically used in 150mm thickness, as compared to 230mm for clay bricks. This results in both volumetric and weight reduction of masonry – **while a G+12 building using clay bricks needs about 0.24 m^3 masonry per m^2 BUA, the same building will need about 0.15 m^3 masonry per m^2 BUA using AAC blocks.**

Under the Housing for All mission, there has been a push for large-scale precast technologies such as EPS panels, hollow core prestressed slabs and monolithic construction using aluminium formwork. These technologies have only been tried at a demonstration level yet – monolithic construction has been used in construction of low-rise (G+2) EWS houses in Rajkot, Gujarat. It is probable that precast technologies will be further promoted for EWS/LIG category affordable housing. These technologies are feasible only for low-rise construction, typically not more than 10 metres high.

Figure 17: Material consumption break-up in building typologies



The material consumption pattern in monolithic construction differs from RCC frame construction in its high consumption of coarse aggregates as compared to sand because masonry walls are replaced by RCC walls. The concrete intensity in monolithic construction is 60-70% higher than conventional RCC frames.

Reinforcement steel (TMT steel) is another high priority material to influence the environmental impact of construction sector. The intensity of reinforcement steel varies from 40-45 kg for low-rise RCC frame construction upto 20 metres to 65 -70 kg per m^2 of built-up area for high rise construction upto 50 metres. As per structural consultants, this will increase further by at least 30% in case of 70 metres high buildings which is the current limit for multi-storeyed construction in Ahmedabad. Steel consumption in Monolithic RCC construction for 15 m high buildings is 60-70 kg per which is comparable to 50 metre high buildings with conventional RCC frames.

Flooring accounts for about 3% of the total material flow. Ceramic tiles/vitrified tiles are the most common material in residential buildings at 1.2-1.3 m^2 per m^2 built-up area. Stone flooring, most commonly kota stone, is used in select areas like kitchen and in common areas like staircase and accounts for about 65% of the quantum flow of flooring material. IPS floor is mainly limited to EWS/LIG housing and is accounted for in cement and sand material flow.

CARBON FOOTPRINT

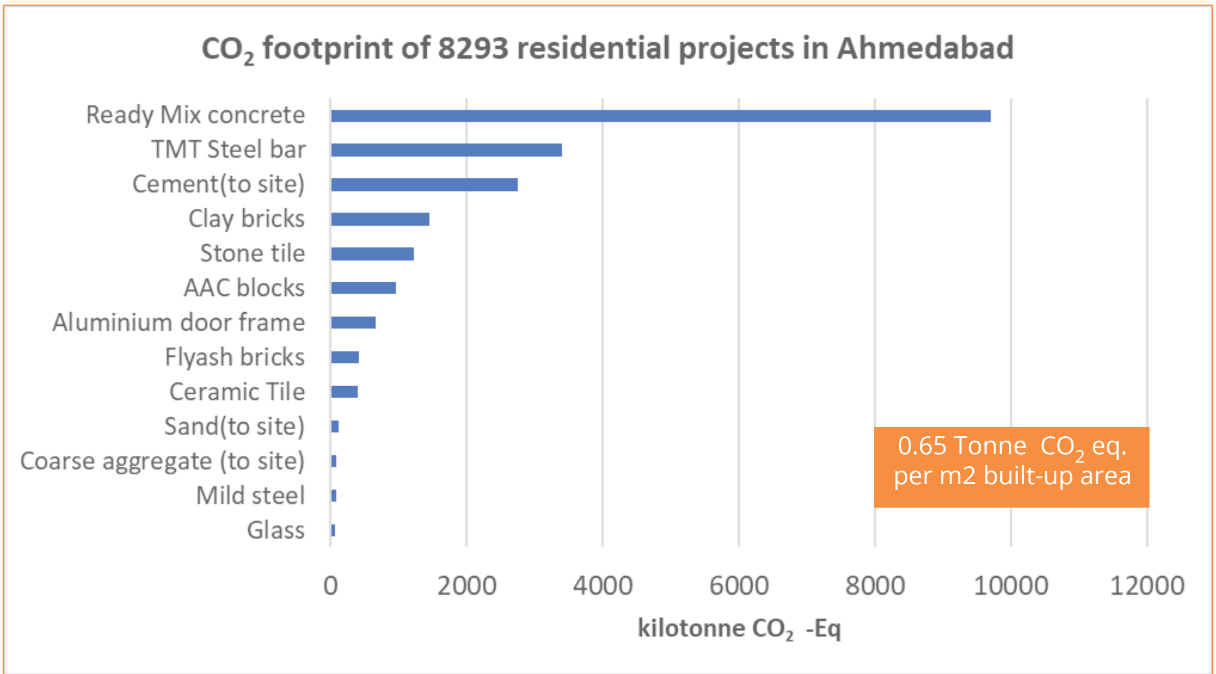
Based on material consumption and flow through the city, a carbon footprint of the residential construction sector was estimated using Umberto software. The carbon footprint accounts for the emissions from production of materials and transportation of materials from production source to construction site. Emissions at the construction stage have not been considered in carbon footprint. These include emissions from electricity consumed by on-site operations like welding, concrete vibration and material trolley. Studies indicate that, given the technology level, in India, construction phase energy varies from 2-4% of the total energy. Considering the type of building technologies (as indicated in the previous section), **the carbon footprint is estimated to be 0.62 tonne of CO_2 equivalent.**

Table 7: Total carbon footprint for 32.75 Million m^2 built up space, tonne CO_2 eq.

CO_2 Footprint for 32.75 Million m^2 built up space, Tonne CO_2 eq.			kg CO_2 per m^2
Material	**Production**	**Transportation**	
Glass	66	0.15	**2.02**
Mild steel	77	0.36	**2.35**
Coarse aggregate (to site)	78	6.3	**2.58**
Sand (to site)	80	46	**3.84**
Ceramic Tile	390	11	**12.24**
Fly ash bricks	375	41	**12.69**
Aluminium door frame	668	0.12	**20.41**
AAC blocks	902	67	**29.58**
Stone tile	1197	34.5	**37.57**
Clay bricks	1417	34	**44.28**
Cement (to site)	2657	95	**84.01**
TMT Steel bar	3400	42.5	**103.78**
Ready Mix concrete	9401	297.20	**296.04**
TOTAL, Kiloton CO_2 eq.	20707	675	**651.4**

The CO_2 emissions are dominated by use of concrete in construction, followed by steel – accounting for 48% and 16% respectively of the total emissions. On a raw material level, **cement alone accounts for 42% of the total emissions** – this is primarily due to its use in concrete and mortar. The trend of higher RCC frame buildings which consume 15-20% more cement on a per m^2 basis, also contributes to the overall increase in cement use. This is likely to further increase with adoption of concrete-based techniques such as Monolithic construction which has currently been taken as 4% of the total residential built-up area. **Sand, which constitutes 33% of the flow of primary materials, accounts for less than 2% of the total emissions.** This is because of the almost exclusive use of river sand in construction which consumes only transportation energy.

Figure 18: CO_2 footprint of 8293 residential projects in Ahmedabad



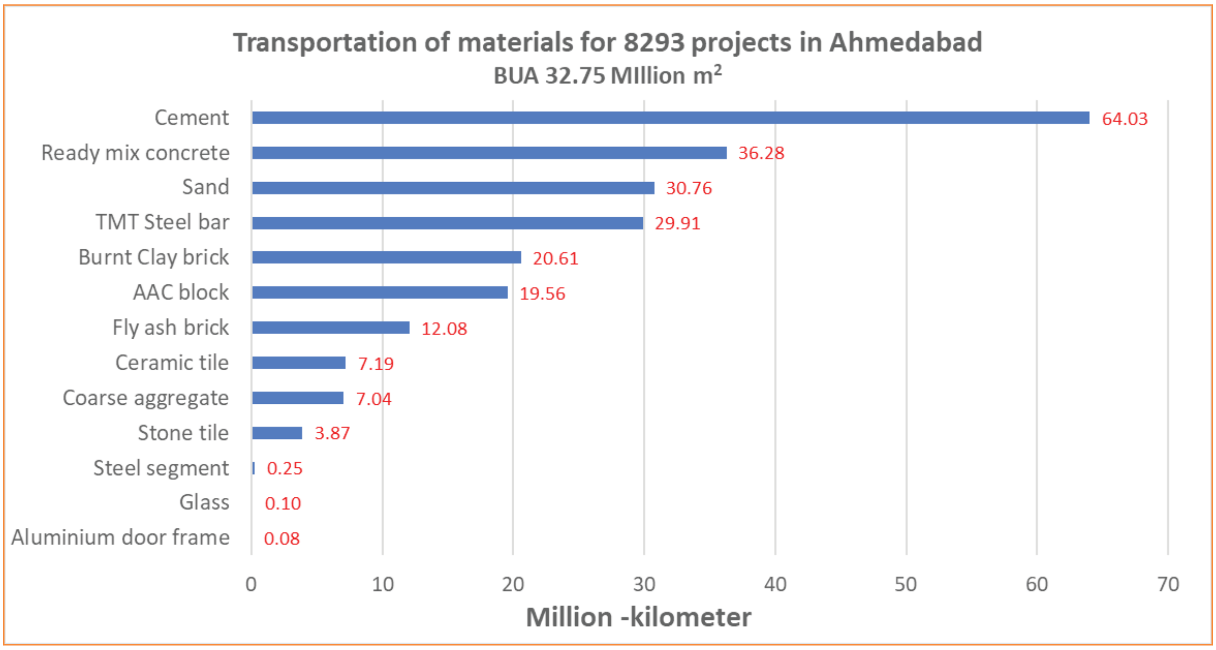
The three masonry materials – clay brick, AAC block and Fly ash brick- together account for about 9% of the total emissions in which AAC blocks account for 50%. Masonry being a volumetric item of construction, it is more instructive to assess CO_2 emissions for masonry on per-volume basis. Even though the tonnage of AAC blocks is 65% of combined tonnage of clay and fly ash bricks, the CO_2 emissions. The transportation emissions for the flow of materials across the city are about 4% of the total emissions.

TRANSPORTATION

Being an essential component of Life Cycle Analysis, transportation contributes to emissions of construction sector. Transportation generates 0.025-0.035 Tonne CO_2 per m^2 built-up area - this accounts for 3-4% of the total CO_2 emissions. Transport is considered for distance from source/manufacturing facility (outside the city) to the construction site in the city. The following key distances were considered after consultation with building professionals in Ahmedabad -

- River sand is sourced from Vathrak river, Sabarmati river and gets transported over an average distance of 25 kms.
- Cement travels an average of 250 kms till Ahmedabad. Gujarat has 24 cement plants – the 5th highest in India. It is self-sufficient in terms of demand for cement- roughly 90% of the cement consumed in Ahmedabad comes from within the state.
- A place situated about 200km from Ahmedabad, is a major hub for ceramic tiles and sanitary hardware – about 605 of buildings in Gujarat source sanitary hardware from Morbi. Other sources for sanitary hardware are Kadri and Mahesana.
- Steel is sourced largely from outside Gujarat and travels about 300 km.
- There are a number of AAC plants within a periphery of 30km within Ahmedabad.

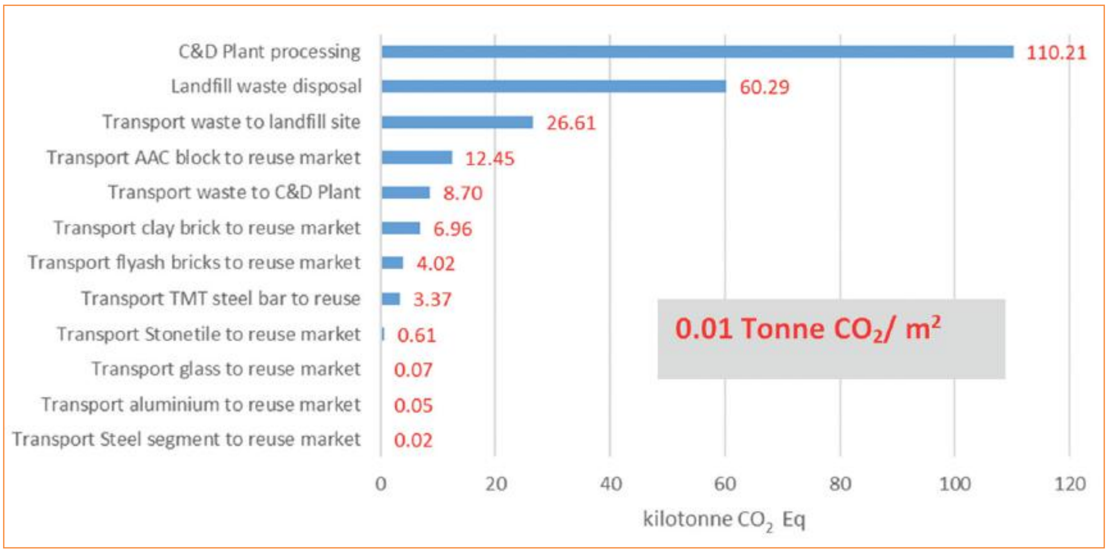
Figure 19: Transportation of materials for 8293 projects in Ahmedabad



END OF LIFE PHASE

The end of life (post demolition) phase of buildings has been assessed with respect to three outcomes – depositing demolition debris in landfill sites, salvage material for re-use and processing C&D waste for conversion into aggregates for recycling. The resultant CO_2 emissions are from fuel (diesel) used in transport, demolition and fuel+ electricity used at the C&D plant in pre-crushing and processing stages. Data for transport above fuel consumption has been collected from the C&D plant operating agency in Ahmedabad. **The end of life phase accounts for about 0.01 Tonne CO_2 emissions per m^2 of demolished area. Transport and C&D processing each accounting for half of this footprint.**

Figure 20: Carbon footprint of end-of-life phase for 8293 buildings in Ahmedabad from 2014 to 2019



KEY ASPECTS FOR RESOURCE EFFICIENCY

The figure below shows the flow of construction material across the life cycle of residential buildings in Ahmedabad. With respect to the main findings stated above, there are 5 key aspects of the material flow which are critical for resource efficiency improvements. These are given below, in order of priority.

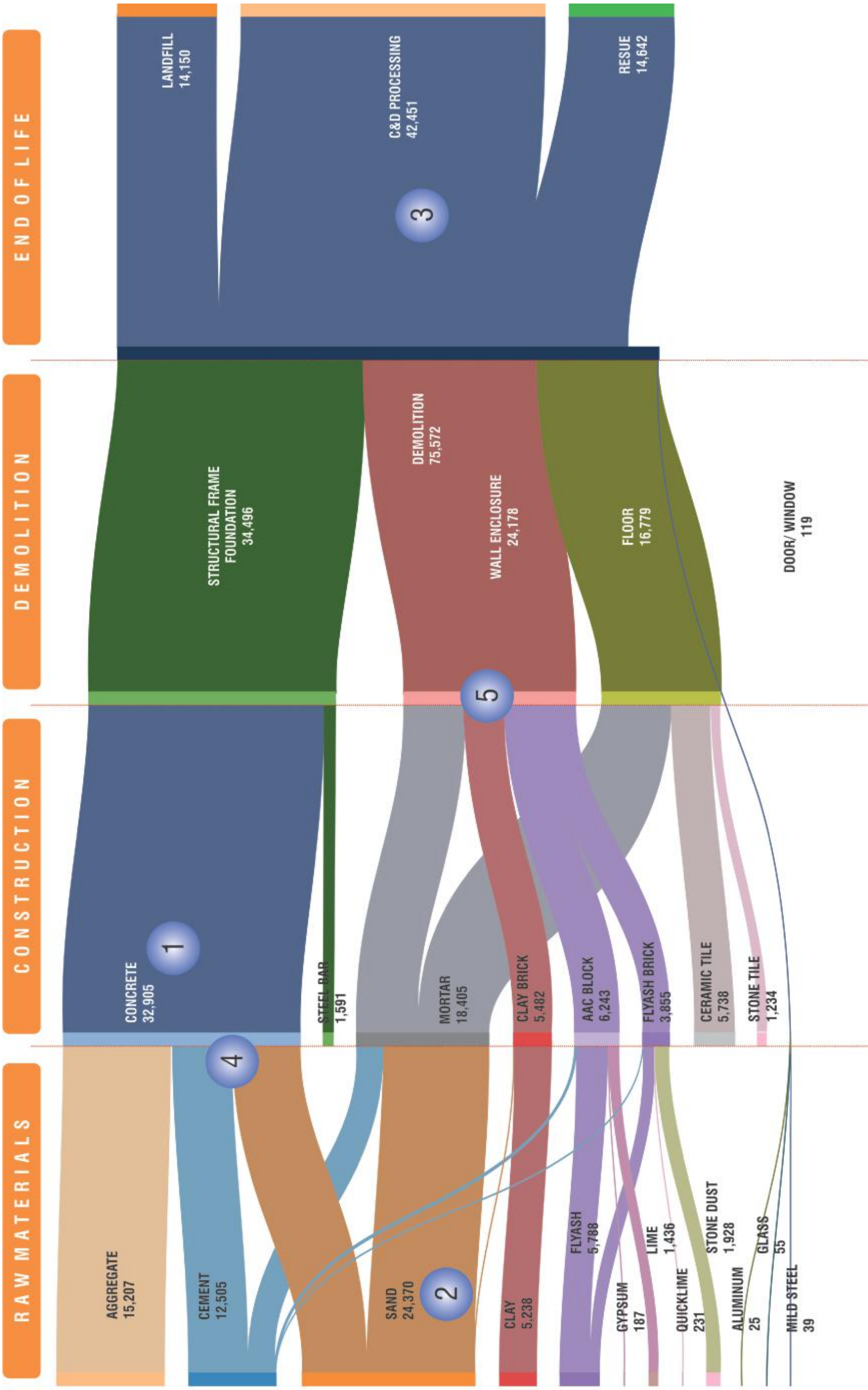


Figure 21: Sankey diagram - Material flow for housing in Ahmedabad for projects from 2014-2019 BUA 32.75 Million sq.m

1. **Ready Mixed Concrete (structural frame)**

   Considering processed materials, concrete has the highest material flow (tonnage) and carbon emissions among building materials. This will continue to be adopted on a large scale to meet housing and infrastructure requirements. Ahmedabad has a strong culture of good quality, and often, architectural concrete along with a good contractor-base. The strong emergence of RMC in the construction sector in Ahmedabad can play an important role in reducing its resource footprint by integrating secondary materials such as high volume fly ash, recycled aggregates, GGBS into concrete production. Improvements on this front are also possible with greater efficiency in the structural design of buildings complemented with the regulatory measures to allow a greater share of low-rise buildings in residential construction to reduce the 'concrete' faction of construction.

2. **Sand**

   Accounting for the biggest quantum of virgin material use, sand is potentially a major environmental stress point for construction in the long term, if river sand continues to be predominantly mined. Among possible alternatives to river sand, demolished concrete and masonry has high potential of generating post-demolition resource in the form of recycled fine aggregate.

3. **C&D waste processing**

   Currently, the C&D processing has negligible impact on the overall material flow for construction. This is an area which needs to grow substantially in scale, and in scope from the current conversion to paving blocks and miscellaneous non-structural items to greater absorption in low-grade concrete and conversion to masonry units. Even though the impact of C&D waste utilisation will not substantially reduce CO_2 emissions, but its potential in replacing virgin resources needs to be realistically established and utilised.

4. **Cement**

   Cement alone contributes more than 40% to CO_2 emissions, largely through its use in concrete, followed by cement mortar. This makes cement a critical material for improving resource efficiency and carbon emissions of construction.

5. **Masonry (wall enclosure)**

   Masonry, which accounts for the third biggest quantum of material use , is witnessing a steady decline of conventional clay bricks in favour of fly ash and concrete-based alternatives. This can be for increased use of secondary material-based masonry alternatives.

UTILIZATION OF SECONDARY MATERIALS

Construction & Demolition waste

Redevelopment of old buildings into multi-storeyed apartments is poised to become a major trend in the city. If channelised in a planned and organised manner, demolition of old buildings can be a major source of secondary construction materials in the form of processed demolition waste. A comprehensive assessment of demolition waste arising from existing building stock is needed. Bulk of building stock, which is likely to qualify for demolition comprises of old housing societies in Ahmedabad- typically G+2/ G+3 structures. Out of the 5.6 million population in 2011, 25% has been considered to be residing in slum settlements. The variable nature of material usage and type of construction in slum settlements is likely to limit its C&D waste potential. Out of the remaining population, 75% (approx.4158000 persons) is assumed to be residing in housing societies. Taking an average household size of 4 persons, 10,39,500 houses are available. Because redevelopment will only take place in areas where requisite FSI is available (predominantly residential Zone R3 as per AUDA zoning), it is reasonable to assume that 50% i.e., 5,19,750 houses are available for demolition over the next decade. Table 8 presents the potential demolition waste available from these houses.

The major bulk items in demolition waste come from concrete and masonry which together account for about 80% of the demolition waste. As per discussion with AEP which operates the C&D processing plant in Ahmedabad, about 10% of the C&D waste will continue to be assigned to landfill. Majority of the residential building stock in Ahmedabad available for demolition in the coming years is distinguished by a hybrid type construction where both RCC frame and masonry have load bearing functions. Keeping this in mind, the distribution of demolition waste is estimated as follows:

Table 8: *Potential demolition waste available from re-development*
(as per author's calculations based on old housing societies in Ahmedabad)

Material	Quantity
Concrete	26 million m^3
Steel	1963 million kg
Brick	65.6 million m^3
Plaster	8.4 million m^3
Flooring tiles	42.2 million m^2
Soil	29 million m^3
Glass	108 million kg

In India, numerous research studies have been carried out on properties of concrete made using recycled aggregates. The results of these studies[20] (Jagadish K. S., 2019) indicate that 'higher the percentage of RCA replacing virgin aggregate, the lower is the workability and compressive strength – the reduction in strength is more prominent in mixes with more than 30% replacement. It is possible to develop 30-60 Mpa (28 days) strength concrete with 80mm slump with 100% replacement by RCA to suit structural applications. In a similar study

20 Jagadish, K. S. (2019). Construction and Demolition Waste. In K. S. Jagadish, Sustainable Building Technologies. I K International Publishing House.

on recycled fine aggregate (RFA), it was observed that for a M30 design mix, satisfactory results were obtained with RFA replacement less than 50%. Studies conducted on utilisation of demolished brick masonry (DBM) waste as coarse and fine aggregates show that part replacement of natural sand with DBM upto 50% produced satisfactory concrete (28 day strength more than 20 Mpa) and mortar (28 day strength more than 6Mpa) for structural use.

Steel has one of the highest potentials of re-use in various industries. Secondary steel production – essentially steel produced from scrap steel or sponge iron – accounts for 50% of India's steel production. The Steel Scrap Recycling Policy (2019) has been formulated by the Ministry of Steel to guide the path to self-sufficiency in meeting the 70 Million Tonnes demand for scrap steel by 2030 which is 35-40% of the total anticipated steel demand. The Policy envisages a hub and spoke model in which 4 collection and dismantling centres will cater to 1 scrap processing centre. Currently, there is no specific data on proportion of C&D waste-derived steel consumed by the construction sector.

CERAMIC INDUSTRY WASTE

The Indian Ceramic Industry ranks at 8th position in the world and produces around 2.5% of global output. Gujarat accounts for around 70%[21] of total ceramic production in India. Morbi, a small industrial town 200 km from Ahmedabad, in Rajkot district of Gujarat, is the 2nd largest tiles manufacturing cluster in the world. About 600 manufacturing units in Morbi produce ceramic tiles, sanitaryware, technical and industrial ceramics. As per industry estimates, Morbi accounts for about 70% (CARE Ratings, 2019) of India's output and 90% of ceramic and sanitaryware output of Gujarat. Considering India's annual ceramic output of 750 Million sq.m[22] (Indian Council of Ceramic Tile and Sanitaryware, n.d.),, Morbi's annual production (at 60% of India's output) is about 450 Million sq.m.

Though the production technology has improved in terms of fuel efficiency, the massive amount of ceramic waste generation persists as a major environmental issue facing the industry in India. About 15%-30% waste material is generated from ceramic production – considering Morbi's output, this translates into 2.14 Million Tonnes per year. This waste is primarily of two types - ceramic waste powder generated during dressing and polishing stage and in the form of defective and broken ceramic pieces. Ceramic waste is a high quality waste, being durable, hard and highly resistant to biological, chemical, and physical degradation forces. This waste is not recycled in any form at present, being mostly dumped in nearby pit or vacant spaces, or in some cases at notified areas marked for dumping.

21 CARE Ratings. (2019, April 1). Indian Ceramic Tile Industry: Structural shift with focus on higher value-added products. Retrieved from CARE Ratings: http://www.careratings.com/upload/NewsFiles/Studies/Indian%20Ceramic%20Tile%20Industry.pdf

22 Indian Council of Ceramic Tile and Sanitaryware. (n.d.). Indian Ceramic Tile Industry. Retrieved from ICCTAS:http://www.icctas.com/ceramic-tiles-industry-statistics.htm

Various studies have been conducted on utilising waste from the ceramic industry. A study on utilising ceramic waste powder (CWP)[23] (Patel, Arora, & Vaniya, 2015) concludes that on replacing cement by 40% CWP is capable of producing M25 grade concrete and can potentially reduce cost of concrete by 18%. Another study on utilising broken ceramic waste[24] (Verma, Verma, & Meena, 2017). indicates that 20% replacement of aggregates with waste ceramic produces good quality concrete with similar water absorption as conventional concrete. Design research conducted at National Institute of Design in Ahmedabad highlights the potential of ceramic products with upto 70% replacement of clay with powdered ceramic waste.[25] (The Better India, 2019).

23 Patel, H., Arora, D. N., & Vaniya, S. R. (2015). Use of Ceramic Waste Powder in Cement Concrete. IJIRST –International Journal for Innovative Research in Science & Technology, 2(1), 91-97. http://www.ijirst.org/articles/IJIRSTV2I1024.pdf

24 Verma, Abhishek & Verma, Abhishek & Meena,. (2017). Experimental Study of Ceramic Waste Electric Insulator Powder Used as a Partial Replacement of Cement in Concrete KEYWORDS OPC 43 Grade of Cement Ceramic Waste Insulator Concrete Hardened Properties Durability Properties.DOI:10.jmsse/2348-8956/5-4.7

25 The Better India. (2019, March 26). NID Grad Recycles Ceramic Waste to Make New, Eco-Friendly Tableware. Retrieved from The Better India: https://www.thebetterindia.com/176345/nid-eco-friendly-innovation-recycle-ceramic-waste-india/

4 PRIORITY AREAS FOR POLICY ACTION

The study highlights some issues for the construction sector which needs policy to enable positive action. Although the analysis focuses on CO_2 emissions (Global Warming Potential) to represent environmental impact, there are also critical implications about rate of exploitation of mineral resources for production of primary building materials. The following are key areas for policy action for resource efficiency of construction sector.

SUSTAINABLE CONCRETE

Concrete dominates both the material flow (quantum) and CO_2 emissions of the construction sector. Addressing the sustainability of concrete is one of the key strategies for enhancing environmental performance and resource efficiency of the construction sector. Although the most effective way to achieve this is by addressing the raw materials of concrete, the project specifics in terms of building typology and its structural design also influence the volume of concrete used in the construction. The three ingredients of concrete – cement, sand and coarse aggregate – each offer possibilities for enhancing sustainability of concrete. While alternative cements are more significant for CO_2 emission reduction, alternative aggregates will reduce the ecological burden of concrete resulting from indiscriminate sand mining. Provisions for compliance for requisite quality of concrete, including RMC, made using fly ash and slag have been duly covered in the BIS and National Building Code of India.[26] A series of Indian Standards has also been formulated on various precast concrete products such as solid and hollow concrete blocks, light weight concrete blocks, autoclaved aerated concrete blocks, preformed foam concrete blocks, partial prefabricated concrete flooring and roofing units, concrete pipes, etc., all permitting use of fly ash and slag.

CEMENT

Cement is the top contributing primary material to overall CO_2 emissions from construction. **Although normally, it is 8-10% by weight of concrete, it is responsible for almost 90% of CO_2 emissions attributable to concrete.** The most effective way to reduce cement related emissions is to replace with a cleaner alternative which needs a reduced quantity

26 Aggregates from other than natural sources, including iron slag aggregate, steel slag aggregate, copper slag aggregate, bottom ash from thermal power plant, and aggregate derived from construction and demolition waste, have been included in the IS 456 : 2000 Code of practice for plain and reinforced concrete (4th revision), through cross reference to IS 383:2016 Specification for coarse and fine aggregate for concrete (third revision). The Indian Standard on concrete mix design (IS 10262) has also been upgraded to include guidance and examples of designing concrete mixes using fly ash and slag.

of clinker in manufacturing. The bulk of cement consumed in Ahmedabad is Ordinary Portland Cement (OPC) which has the highest emission factor of 0.72 kg CO_2 per kg cement as well as a high environmental impact of global air pollutants and reduced forest cover. The general perception of high strength from use of OPC and unreliable supply of alternatives like Portland Pozzalana Cement (PPC) are reasons for predominant use of OPC. Out of all the cement-based applications, it is most feasible to replace OPC in the production of Ready Mixed Concrete.

50% replacement of OPC with PPC in Ready Mix Concrete leads to 16-21% saving in CO_2 emissions. The corresponding replacement with Portland Slag Cement for RMC saves 12-15% CO_2 emissions. This can be further increased to about 26-30% reduction in CO_2 emissions with the use of LC3 cement.

AGGREGATES

Coarse and Fine aggregates account for more than 50% of the material flow, out of which 32% is attributable to sand. However, the CO_2 emissions from aggregates account for 2% of the total emissions. The reason for this is the low-energy input for extraction of aggregates. Sand is currently almost exclusively mined from the rivers - primarily Sabarmati and its tributary Vartak. CO_2 emissions from sand are due to the transportation which is not more than 30km. Aggregates are sourced from stone crushing units within a 50 km radius. While the CO_2 emissions from aggregates are negligible, the critical issue, particularly for sand, is of ecological damage and long-term availability. **With the impending supply of affordable housing and continuing concrete-based infrastructure in the city, river sand will need substantial replacement with alternatives in the form of manufactured sand and recycled aggregates from demolition activities which will expand in the city in the coming years.** The draft guidelines (Sand Mining Management Guidelines) of MoEFCC emphasise the use of Manufactured Sand[27] (m-Sand), slag from steel industry, fly ash and overburnt bricks and tiles from the brick and tile industry as alternatives to natural sand.

CONSTRUCTION AND DEMOLITION WASTE

The current level of value addition through C&D waste utilisation in construction is largely limited to manufacture of non-structural products like paver blocks, kerbstones, manhole covers, etc. The area of structural use of C&D waste also offers immense possibilities of resource efficiency. This is an active area of research globally and in India. Satisfactory compressive strength results for M20 and M25 concrete using recycled aggregates have been reported in various studies in India. Ahmedabad, with a lead in C&D waste processing, can take the lead in expanding the scope of C&D waste utilisation. Specifically, demolition waste from redevelopment can be utilised to manufacture recycled aggregates. **Based**

27 M-Sand is produced by crushing hard granite stone to a stipulated size of 150 microns. As per IS-383, the chemical characteristics, bulk density and strength of M-sand are similar to the river sand, and same type of applications can be served using M-sand.

on estimated availability of concrete waste from redevelopment potential today in Ahmedabad, recycled aggregates can be used in production of 38 million m^3 of M20 concrete which at a 50% replacement of natural aggregate with recycled aggregates(RA). This volume of concrete can be used in construction to the tune of 102 Million m^2 of built-up space which is the equivalent of 7.5 Lakh housing units (2 BHK, @120m^2 built-up area).

Recycled aggregates do not lead to savings in CO_2 emissions because of the additional carbon footprint resulting from transportation of demolition waste and energy, primarily electricity consumed in processing waste into aggregates. As a result, each tonne of recycled aggregate is responsible for about 17 kg CO_2. This is comparable to about 15kg CO_2 which is emitted by stone crushing units to produce a tonne of coarse aggregate and stone dust.

PREFABRICATED CONSTRUCTION

Prefabricated construction is at an early stage in India, where it has been demonstrated in a few mass housing projects, with the single objective of speedy construction. This has mostly been through large prefab concrete elements. For instance, Monolithic concrete has been used in EWS housing in Rajkot (Gujarat). However, the demonstration projects have not yet resulted in a favourable response from the market. Also, their acceptance by the prospective house owners has been weak because of unfamiliarity and poor thermal performance of the wall enclosure. **There is need for a more balanced and innovative approach towards pre-fab building elements which increase resource efficiency of construction.** There are proven technologies in small scale pre-casting of concrete, primarily for roof construction which reduce steel consumption by 15-20%.

For instance, the use of precast plank and joists or precast ferrocement roofing elements results in reducing the steel consumption by 10 -12% per m^2 of roof constructed. Using precast concrete roofing elements in 1 Lakh affordable houses (considering average area of 40 m^2) will save 6.5 Million Tonnes of steel resulting in CO_2 emission reduction of 18.2 Million Tonnes.

BASELINE AND SYSTEMATIC DATA AVAILABILITY

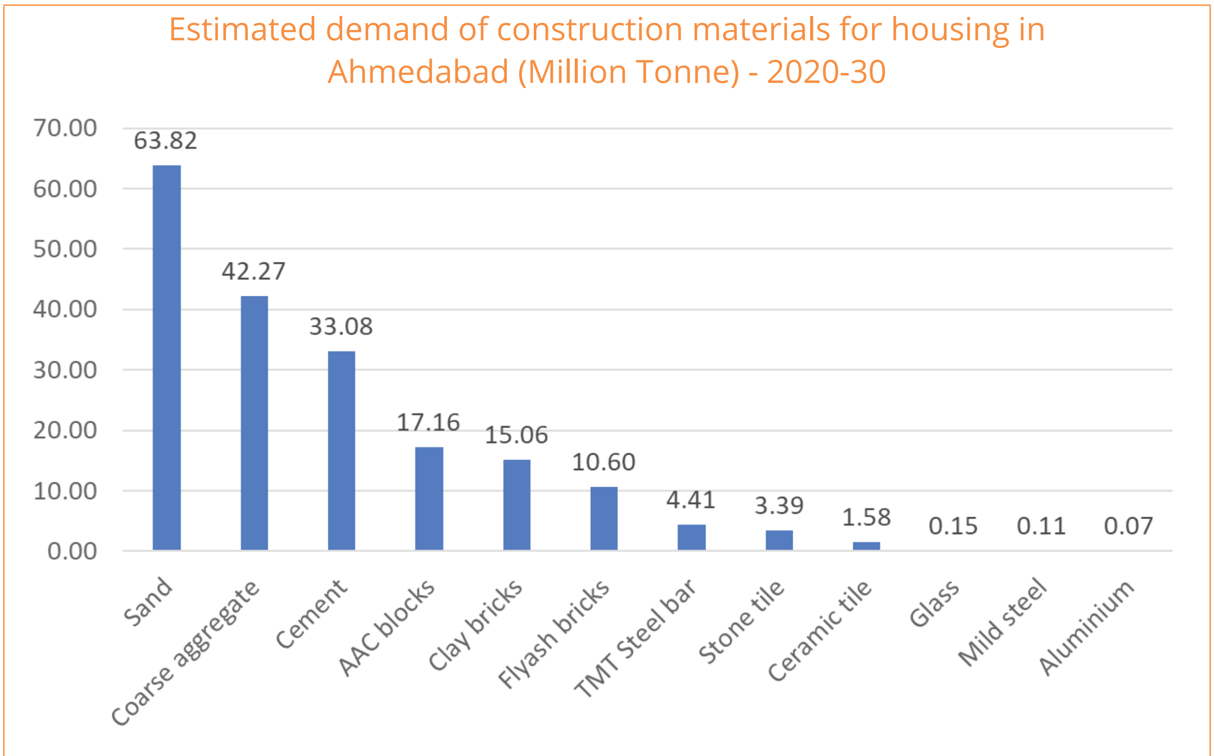
Availability of reliable data is the first requirement for developing a macro picture of implications of urban development. For the purpose of resource efficiency in construction sector, data pertaining to consumption of material resources is key. This creates a baseline against which systematic improvements can be planned. The structure for this assessment can benefit from the digitised records of AMC/AUDA and supplemented by the records maintained on the RERA website. A critical area which will benefit from more reliable data is that of C&D waste management and utilisation. **The redevelopment of existing built spaces will generate massive amounts of demolition waste along with transportation of waste across the city. This generation of waste and its parallel**

utilisation in on-going construction needs to be synched through co-ordination of data available with AMC/AUDA (in the form of redevelopment permits) and the supply end infrastructure of C&D waste plants.

FUTURE OUTLOOK

Considering a population growth of 3 million (from 8 million in 2019 to 11 million in 2030) between 2020 and 2030 and the current proportion of low-income settlements without formal housing, the residential sector will need at least 90 million sq.m of new built up space. Based on current levels of material flow and material consumption patterns, the figure below presents an approximate idea of the quantum of materials needed to meet this additional demand of built space.

Figure 22: Future Demand of construction materials for housing in Ahmedabad



This projected demand has been interpreted below for three resources of river sand, limestone and granite (mined for coarse aggregate) consumption over the next 10 years till 2030. The interpretation considers a scenario where only resources available within Gujarat are mined for consumption in Ahmedabad. Admittedly, this is not a realistic scenario but still worth considering in the interest of utilising local resources.

The demand of sand is perhaps the most critical in terms of sustained availability. As estimated by the Commissioner of Geology and Mines[28] (Ministry of Mines, 2018), the

28 Ministry of Mines. (2018). *Sand Mining Framework.* Government of India. https://www.mines.gov.in/writereaddata/Content/sandminingframework260318.pdf

production of sand (classified as a Minor mineral when used in building construction activities) in Gujarat for FY2017 was 49.64 Million Tonne . Compared to this, the above estimated demand of 64 Million Tonne (likely to be conservative as it is does not adequately reflect the low-income housing, due to lack of accurate data) over 10 years for housing in Ahmedabad alone, suggests a supply-demand imbalance. Given the high prevalence of illegal sand mining in India, the river sand would still be made available, albeit with severe environmental compromise, unless steps are taken to start mainstreaming secondary resources as alternatives to river sand.

Cement is critical both from the emissions and the critical-resource (limestone availability) perspective. Gujarat produced 25.6 Million Metric Tonne (MMT) limestone in 2016-17, out of which 22 MMT was consumed for cement production[29] (Indian Bureau of Mines, 2017). Using this limestone output as reference and considering that typically 1.5 Tonne Limestone is consumed for producing 1 Tonne clinker (the main constituent of cement along with small amount of gypsum) that means about 60% is consumed by housing sector, it can be estimated that about 10 MMT cement is available for housing in Gujarat every year. Against a demand of 33 MMT cement for housing in Ahmedabad alone, the long-term availability of cement can be sustainable only with greater resource efficiency through larger utilisation of alternative cement which use secondary materials such as PPC (Portland Pozzalana cement) and PSC (Portland Slag Cement).

Coarse aggregates which make the 2nd largest material flow in the construction sector can be produced from a variety of stone deposits, in Gujarat, Granite is the most commonly used stone for producing coarse aggregate for construction due to its large reserves of 2000 MMT[30] (Industries and Mines Department, Government of Gujarat). Being one of the most superior stones for structural use, there is a great dependence on granite for coarse aggregates. Assuming that 20% of the granite mined in Gujarat flows to Ahmedabad, we are looking at a mined output of 400 MMT. In this context, the demand of 42 MMT coarse aggregate till 2030 for housing alone threatens to make a significant dent in the granite reserves, not accounting for the granite which has already been mined and consumed out of the total reserves in Gujarat. The fact that a part of granite might go towards manufacture of Granite increases the conflict of competing use of the resource.

29 Indian Bureau of Mines. (2017). *Indian Minerals Yearbook 2017. Part III: Mineral Reviews.* Government of India.https://mitra.ibm.gov.in/Documents/IMYB/Vol.%20III%C2%A0MINERAL%20REVIEWS/03202018145745Limestone_AR_2017.pdf

30 Industries and Mines Department, Government of Gujarat. (2003). *Gujarat State Mineral Policy 2003.* Gandhinagar: Government of Gujarat https://mines.gov.in/writereaddata/UploadFile/Gujarat.pdf

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ANNEXURES

ANNEX 1 – DESCRIPTION OF UMBERTO MFA MODEL-LIFECYCLE STAGES

Table 9: Description of lifecycle stages – Umberto model

Stage	Process description in each stage
1. Production of primary materials	Production technologies for Cement, Sand, Aggregates, Steel, Aluminium, Stone dust, Stone tile, Glass, Mild steel and Ceramic tiles.
2. Transportation of primary materials to material production site	• Transportation from production source to material production facility. • Mode of transport considered in the model: Freight lorry of EURO 4 emission standard having load greater than 32 metric ton.
3. Production of secondary building materials	Production technologies for Ready mix concrete, Clay brick, AAC block, Fly ash brick.
4. Transportation of all construction materials to construction site	Transportation from secondary production and primary production site to construction site.
5. Onsite construction	Construction of RCC structure foundation and superstructure, monolithic structure, masonry, flooring, door/window work.
6. End of life stage	Stage involves post demolition process where materials are divided into three chains of C&D processing, transportation to Reuse market and disposal to Landfill.

ANNEX 2 – MATERIALS DESCRIPTION AND CO_2 EMISSION FACTORS

Table 10: Description of materials and processes used in MFA model - from Ecoinvent data/external secondary sources

S No.	Material	CO_2 emission factors used in the Umberto model, $kgCO_2$ Eq/ kg	Source and description
1.	Coarse aggregate / Gravel	**0.2**	**ecoinvent v3.6 database value:** 0.2 kg CO_2 per kg coarse aggregate manufactured **ecoinvent v3.6 database process description:** **Market for[31] gravel, crushed [IN][32]** Includes emissions from stone crushing operation and the transportation of aggregates from crushing plants to construction site within a radius of 100 km. **Rock crushing [RoW] [33]** Data corresponding to a specific type of crusher (Nordberg HP 400 SX) with a capacity of 454 Tonnes/hour has been considered for stone crushing.
2.	Sand (fine aggregate)	**0.01**	Includes emissions from mining of natural sand from riverbed deposits and its transportation to construction site within a radius of 50 km from the quarry. **ecoinvent v3.6 database value:** 0.01 kg CO_2 per kg sand processed **ecoinvent v3.6 database process description: Sand quarry operation, extraction from river bed [IN]**

31 "Market for" represents collection of all activities of the product till a reference point in a specified geography https://www.ecoinvent.org/support/faqs/methodology-of-ecoinvent-3/what-is-a-market-and-how-is-it-created.html

32 [IN] represents ecoinvent data is specific to Indian geography

33 [ROW] or Rest of the World represents activities of the product as an average of all valid countries in the world https://www.ecoinvent.org/support/faqs/methodology-of-ecoinvent-3/what-do-the-shortcuts-such-as-ch-rer-row-and-glo-mean.html

			Sand extraction and processing, as well as equipment maintenance. Machinery is taken into account within the dataset "diesel, burned in building machine", as all machinery runs on diesel. Administration buildings and the quarry's end of life are not taken into account.
3.	Lime (quicklime)	**0.29**	**ecoinvent v3.6 database value**: 0.29 kg CO_2 per kg quicklime processed **ecoinvent v3.6 database process description: Market for quicklime, in pieces, loose [RoW]** This product is generally considered to be used at the production site. Therefore, the market does not contain any transport.
4.	Stone (flooring)	**0.98**	**ecoinvent v3.6 database value:** 0.98 kg CO_2 per kg stone tile manufactured **ecoinvent v3.6 database process description: Natural stone plate production, polished [RoW].** The stone tile polishing is assumed to be done using a polishing machine and very fine grinding medium. No losses are taken into account as no data are available. The dust emissions are estimated based on the losses (0.05 mm abrasion around the granite plate with geometry of 0.5 * 0.5 * 0.03 m and a weight of 2750 kg/m3).
5.	Steel – TMT reinforcement bar	**2.17**	**ecoinvent v3.6 database value:** 2.17 kg CO_2 per kg reinforced steel bar manufactured **ecoinvent v3.6 database process description: Reinforcing steel production [RoW]** This dataset used in ecoinvent database represents Average of World and European production mix. This is assumed to correspond to the consumption mix in Europe.

6.	Steel – MS Structural Steel (door frames)	**1.95**	**ecoinvent v3.6 database value:** 1.95 kg CO_2 per kg mild steel manufactured **ecoinvent v3.6 database process description: Steel production, low-alloyed, hot rolled [RoW]** This dataset represents Average of World and European production mix. This is assumed to correspond to the consumption mix in Europe
7.	Ready Mix Concrete	**0.11**	Cement, Sand and aggregate are mixed in a proportion based on the grade of Ready-mix concrete required for construction **ecoinvent v3.6 database value:** 0.11 kg CO_2 per kg concrete manufactured **ecoinvent v3.6 database process description:** **market for concrete, normal [IN]** This dataset represents a generic market activity, for the unknown concrete type for production of 1 kg of concrete in Indian geography
8.	Clay brick	**0.32**	Manufactured using 94% Clay, and around 3% sand and husk as a source of fuel, it includes emissions from extraction of clay, burning of husk and transportation of these sources to the clay brick production site. **ecoinvent v3.6 database value:** 0.32 kg CO_2 per kg clay brick produced **ecoinvent v3.6 database process description: Clay brick production [RoW]** This dataset represents the production of 1 kg of brick. Data was obtained from literature values (average data from 12 Swiss brick plants) that were corrected and updated for some flows.

9.	Fly ash brick	**0.66**	Flyash brick is manufactured during the Flyash brick production process. It constitutes of 6% Quicklime, 40% Flyash, 4% Cement and 50% Stone dust. **ecoinvent v3.6 database value:** 0.66 CO_2 per kg flyash brick produced **ecoinvent v3.6 database process description** **market for flyash brick [IN]** Pulverized fuel ash-lime bricks are obtained from materials consisting of pulverized fuel ash in major quantity, lime and an accelerator acting as a catalyst. Pulverized fuel ash-lime bricks are generally manufactured by intergrading blending various raw materials are then moulded into bricks and subjected to curing cycles at different temperatures and pressures. These bricks are suitable for use in masonry construction just like common burnt clay bricks. This dataset is specific to India.
10.	AAC (Aerated Autoclaved Concrete) block	**0.45**	AAC block is produced in this self-defined process. Contains 68% Flyash, 23% Lime, 3% Gypsum, and 6% Cement. **ecoinvent v3.6 database value:** 0.45 CO_2 per kg AAC block produced **ecoinvent v3.6 database process description** **market for autoclaved aerated concrete block [IN]** AAC is fire and pest resistant, and is economically and environmentally superior to the more traditional structural building materials such as concrete, wood, brick and stone. The production emissions of AAC block are based on production in India.

11.	Glass	**1.2**	**ecoinvent v3.6 database value:** 1.2 CO_2 per kg coated flat glass manufactured **ecoinvent v3.6 database process description** **market for flat glass, coated [RoW]** This dataset represents the production of 1 kg of coated flat glass used commonly in windows and doors. This data is considered to be a global average.
12.	Aluminium (extruded section)	**26**	India Construction Materials Database of Embodied Energy and Global Warming Potential – Methodology report 2017 International Finance Corporation (IFC) World Bank Group Aluminium window frame is manufactured from aluminium extruded profiles which are formed, stamped and cut to the required lengths. Each meter of aluminium window frame is considered to have a mass of 2 kg. *According to a report by BALCO, 21.6 kg CO_2 emissions per kg aluminium[34] manufactured are emitted.*
13	Cement	**0.65**	**ecoinvent v3.6 database value:** 0.78 kg CO_2 per kg cement manufactured. **ecoinvent v3.6 database process description: market for cement, unspecified [IN]** This market represents the market for cement, unspecified. Unspecified cement type has been considered in the model due to variation in the cement manufactured across the Indian geography. Average emission factor in India is 0.85 kg CO_2/ kg cement[35]. 0.65 kg CO_2/ kg is considered in the model since many cement plants are using energy efficient methods and technologies for less emission intensive cement manufacturing. It is estimated that many cement industries will follow the low carbon pathway based on the current trend.

34 BALCO. (2010). Energy and Environmental Challenges in Aluminium Industry: A review. EPD Congress, 893-906. http://www.balcoindia.com/about-us/doc/publications/Energy-%20Environmental.pdf

35 cBalance.(2013, December).Carbon emissions in the cement sector in India. Retrieved April 1 2020 from http://cbalance.in/2013/12/carbon-emissions-in-the-cement-sector-in-india/#.XqeoEmgzblX

Fuel (Production, Transportation by Road)			
1.	Electricity	**0.71**	**ecoinvent v3.6 database value:** 0.71 kg CO_2 per kg cement manufactured. **ecoinvent v3.6 database process description: Market for electricity, medium voltage [IN-Western grid]** This dataset in ecoinvent database describes the electricity available on the medium voltage level in India - Western grid. This is done by showing the transmission of 1kWh electricity at medium voltage.
2.	Diesel	**0.49**	Diesel heavy weight freight lorries for transportation of raw materials to construction site and of recovered materials post demolition to C&D processing site have been considered here. **ecoinvent v3.6 database value:** 0.49 kg CO_2 per kg diesel **ecoinvent v3.6 database process description market for diesel [IN]** Inventory for regional market of refined petroleum product, encompassing the distribution to the final consumer (household, road vehicle, power plant, etc.) including all necessary transports have been considered in the dataset specific to Indian geography. For *transportation of raw materials to secondary production and construction site*, ecoinvent dataset of service of 1 Tonne-km freight transport in a lorry of the size class >32 metric tonnes gross vehicle weight (GVW) and Euro IV emissions class is taken. The transport datasets refer to the entire transport life cycle i.e. to the construction, operation, maintenance and end of life of vehicle and road infrastructures. Average load factor of this lorry class is 15.96 Tonnes and a GVW of 29.96 Tonnes *Transportation of demolished materials to the C&D processing plant* is carried out using a smaller freight lorry. The dataset used in

			ecoinvent for this activity represents the service of 1tkm freight transport in a lorry of the size class 3.5-7.5 metric tonnes gross vehicle weight (GVW) and Euro IV emissions class. Average load factor of this lorry class is 0.98 Tonnes and a GVW of 4.98 Tonnes.
3.	Coal	0.017 kgCO_2/ KWh for 1MW electricity	Electricity from thermal power plants have been considered in this model. Emissions from coal (0.017 kgCO_2/KWh for 1MW electricity generated)[36] have been included in the emissions from electricity generation.

36 Ministry of Power, Government of India, Central Electricity Authority. (2014). CO_2 Baseline database for the Indian Power Sector. http://cea.nic.in/reports/others/thermal/tpece/cdm_co2/user_guide_ver10.pdf

ANNEX 3 – TRANSPORTATION DISTANCE OF MATERIALS

Table 11: Transportation distance of materials

Transportation distance of raw materials considered in the Umberto model		
Raw Material	**Transport Distance (km) From manufacturing facility to construction site**	**Data Source**
Cement	250	Consultation with local stakeholders in Ahmedabad
TMT steel bar	300	
Mild steel	100	
Sand	30	
Aggregate	50	
Clay	5	
Stone dust	50	
Glass	30	
Ceramic tile	200	
C&D waste	20	
Flyash	60	Research Thesis – Centre for Environmental Planning and Technology, Ahmedabad[37]
Quicklime	100	
Gypsum	30	
Lime	40	
Clay brick	60	
Flyash brick	50	
AAC block	50	

37 Arpan Parikh(n.d).Study of Embodied Energy of Building Materials in Ahmedabad

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