Assessment of Urban Growth and Ecological Sustainability: Insights from Mumbai, India

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Abstract

This study quantifies the overall impact of urban growth on the ecology of Mumbai by using an Ecological Footprint analysis. Its aim is to help determine the natural resource consumption of existing urban settlements. The objective is to assess the environmental impact resulting from the existing urban layouts on Mumbai's region.

The research employs a comparative analysis of footprint and land ratio for different urban layouts of Mumbai. There are different layouts in Mumbai, primarily by MHADA (Maharashtra Housing and 10 Development Authority) & private builders. Footprints and land ratio of these layouts are calculated as per the Development Control Rules of Mumbai.

The results are referred to as footprint per capita and land ratio required for the layout. The land ratio is the ratio of land required for the building's total footprint to the actual built-up area of land on which the building is erected. The land ratio is directly proportional to the quantity and type of material used for building. The land ratio required in case of MHADA (Maharashtra Housing and Development authority) layout is almost double than layout by private builders as much more material quantities is required in case of MHADA layout due to more no buildings, and extra FSI utilized i.e., FSI of 2.50 as against 1.33 for private layout. Hence, layouts like private builders shall be preferred for Mumbai city to achieve the region's environmental sustainability.

Keywords: Urban growth, Mumbai, Footprint per capita, Land ratio & Environmental sustainability.

Introduction

Urbanization, the process by which rural areas become urban due to population growth and socio-economic change has rapidly increased over the past few decades. This phenomenon has brought about significant shifts in land use, resource consumption, and waste generation. These shifts have profound implications for the planet's carrying capacity, which refers to the maximum population size that an environment can sustain indefinitely without degrading.

Urbanization, when unchecked and not managed sustainably, can place significant strain on our planet's carrying capacity. Addressing the challenges posed by urbanization is crucial not just for the health and well-being of urban residents, but for the balance and sustainability of the entire planet. It underscores the need for sustainable urban planning & efficient resource management.

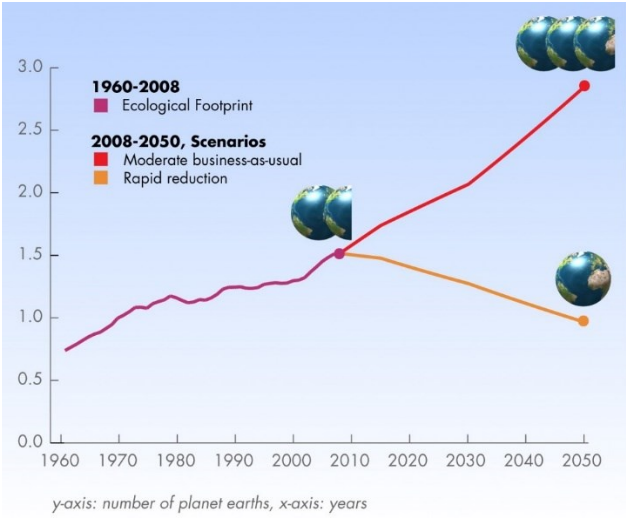

Fig. 1: The Earth's carrying capacity and sustainability in balance with the planet's resources
Source: Lenrosen,2012

The growth of urban areas inevitably leads to the expansion and development of neighborhoods, especially in bustling cities like Mumbai, a hotspot for economic, social, and cultural activity. While urbanization comes with numerous advantages, it also poses significant sustainability challenges. Cities act as major consumers of resources and generators of waste, impacting ecosystems both near and far. In the context of Mumbai, neighborhoods rely on energy and materials sourced from distant ecosystems, while simultaneously generating waste and pollutants that affect the local environment. This unsustainable pattern can strain nearby ecosystems to their limits, compelling the city to increasingly draw on these already stressed resources and ecological services.

The rapid expansion of urban areas underscores the critical need to address the multifaceted challenges arising from urban growth. Specifically, evaluating the sustainability of neighborhoods in Mumbai is vital for mapping a sustainable path forward for the city. Utilizing metrics such as the ecological footprint becomes indispensable in this context, as they offer a scientific framework for assessing the environmental consequences of developmental actions. This allows for informed decision-making aimed at achieving sustainable urban development.

Ecological footprints offer a quantitative measure of the environmental impacts of various human activities, including urban development. In the context of urban layouts in Mumbai, the ecological footprint is calculated using a combination of different studies and conversion factors to accurately represent the environmental impact of building materials and energy use. Its aim is to examine the ecological effect of the current metropolitan patterns in Mumbai. Its objectives are:

- To quantify the overall impact of the urban growth on the ecology of Mumbai by using Ecological Footprint analysis at neighborhood level.
- To study and analyze various methods of calculating ecological footprints and select appropriate method to calculate ecological footprints of neighborhoods in Mumbai.
- To assess the environmental impact resulting from the existing neighborhoods in the region of Mumbai.

Theoretical Framework

Neighborhoods, ecological footprints, and land ratios all play important roles in understanding the dynamics of urban sustainability. It is better to understand how urban systems affect the earth by delving into these concepts.

Neighborhoods: Well-known urban sociologist Robert Park famously said that the city is essentially "man's most consistent and, on the whole, successful attempt to remake the world he lives in more after his heart's desire." The neighbourhoods of these cities serve as the microcosms where the urban experience is most strongly felt. They are complex social ecosystems rather than just residential neighbourhoods. The way these neighbourhoods are designed and built has a big impact on how much resources are used. Well-designed communities may reduce waste, improve public transportation, and promote sustainable living, reducing the city's overall ecological footprint. Major typologies of neighborhoods are traditional, developer created, Ad-hoc, informal and government created.

Mumbai has a rich history of human settlement that dates to when it was a cluster of seven islands. These early settlements, often referred to as "vernacular settlements," were built using traditional construction techniques handed down through generations. These methods were refined through trial and error and made use of locally available materials, forming an architecture that met the community's specific needs and aspirations.

Residential typologies play a significant role in shaping the urban fabric of Mumbai, making up a substantial and crucial portion of the city's land use. These residential forms can be categorized as follows:

Traditional Types:

- Fisherman's Houses (Koli Houses): Built to suit the needs of the local fishing community.
- Wadas: These are communal living spaces that emphasize community interaction.
- Chawls: Originated as group housing for mill workers, these structures emphasize communal living.
- East Indian Bungalows: Influenced by Portuguese architecture, these bungalows have distinct design elements.
- Art Deco Bungalows: These showcase the global Art Deco architectural style while remaining locally relevant.

Post-Independence Types:

- State-sponsored Mass Housing: Developed by the government after independence to accommodate the growing population.
- Plotted Developments: These are individually owned houses within larger, planned residential areas.
- Private Apartments from the 70s and 80s: These structures saw the beginning of modern apartment living in Mumbai.
- Public Sector Employee Housing: Built to accommodate employees of the public sector.
- Slums: Informal settlements that house a significant portion of the city's population.

Mumbai's residential typologies are, ranging from vernacular to contemporary. it has been observed that traditional vernacular typologies are more ecologically harmonious. These forms are tailored to the local environment, responding well to regional factors such as climate and resource availability. In contrast, contemporary housing designs have a higher consumption of energy and material resources, which has led to detrimental effects on the local ecosystem. These negative impacts include altered climatic conditions, disrupted water cycles, increased pollution, and waste generation.

Given this, it is crucial to measure the ecological disruptions caused by these different housing types. Utilizing the ecological footprint as a metric is a significant step toward evaluating and improving the ecological sustainability of the region. Calculating Mumbai's ecological footprint will offer valuable insights into the area's environmental condition, aiding in the planning for more sustainable urban development.

The types considered for this study are state-sponsored mass housing (developed by MHADA) and plotted developments (developed by private developers).

The Ecological Footprint Concept and its Significance

The concept was first developed in the 1990s at the University of British Columbia and was popularized by Wackernagel and Rees (1996). Its foundation can be traced back to studies by Vitousek (1986) and even further to 18th-century Physiocrats who believed all value stemmed from land. Notably, Malthus and Ricardo, classical economists, highlighted the constraints of land availability on population growth. Modern parallels to the concept include Borgstrom's 'ghost acreage' and the works of sociologist Catton and researchers like Folke et al. and Brown and Ulgiati.

The Ecological Footprint, as articulated by Loh (2000), serves as a sustainability indicator by quantifying the total ecological cost of providing goods and services to a population. This includes not just the direct land usage but also the indirect land incorporated in producing consumed goods. Moreover, this concept also delves into the notion of 'carrying capacity', which denotes the maximum sustainable population a land can support. Exceeding this limit leads to resource scarcity and possible population decline.

Ecological footprints are known as in hectares per capita, though carrying capacity is by and large communicated in units of people per hectare, making one idea the opposite of the other. The ecological footprint is a more suitable notion to apply to human populaces. Not at all like carrying capacity, the ecological footprints catch all the biophysical effects of a given local area paying little mind to where those effects happen. Little or diminishing per capita Ecological Footprints show that the locale is moving towards sustainability while those extremely huge or quickly developing demonstrate the exact inverse.

Land Ratio

The idea of land ratio sits at the nexus of urban development and ecological footprints. It talks about how much land is needed for the preparation of building materials required for neighborhood, which is a spatial component of resource consumption. The land ratio provides us with information on the amount of space required to support the building/ neighborhoods, as metropolitan areas look to far-off ecosystems for resources, high land ratios indicate more environmental pressure. When evaluating sustainability, it's important to consider how well urban constructed environments coexist with the agricultural or natural areas that support them.

The land ratio is the ratio of land required for the building's total footprint to the actual built-up area of land on which a building is erected. For this study building materials are taken as a resource to calculate ecological footprints and land ratio.

The theoretical framework provided by the notions of neighborhoods, ecological footprints, and land ratios aids in illuminating the complex interrelationship between urban centers and the environment. For initiatives that balance urban expansion with ecological sustainability, an understanding of this dynamic is essential.

Literature Review

There are several studies for utilizing Ecological Footprint Analysis (EFA) and related approaches on the significance of sustainable practices in construction and urban development. The literature in this field examines a variety of geographies and methodologies, concentrating on many facets of buildings and human settlements, from material use to consumption patterns in households. The key findings and conclusions of significant studies are summarized below.

Utilising life cycle energy assessment (LCEA) and life cycle ecological footprint (LCEF), the study focuses on India's composite climatic zone. An innovative addition is a mobile app and MATLAB model for the choice of low-emission materials. The findings show that using environmentally friendly building materials greatly lowers both the LCEF and LCE, providing the pathway for sustainable development. (Singh, 2021).

A user-friendly calculator to measure the ecological footprint of embodied carbon in construction materials, designed to be accessible to SMEs. The calculator was tested on new and renovated condominiums in Hungary, showing that materials like concrete, steel, and masonry largely determine the ecological footprint. The research suggests that renovation is far less impactful than new construction, offering guidance for investors, clients, and policymakers. (Szigeti, 2023).

Ecological footprint (EF) method is used to assess the sustainability of a residential area in Adama City, Ethiopia. Results demonstrate that EF is directly related to factors like floor area, family size, and plot area and show that there is a resource imbalance, indicating that current practises are unsustainable. Considering the rising urbanisation, the study recommends the creation of urgent policies to reconcile ecological and socioeconomic needs. (Tesema, 2014).

The ecological footprints (EF) of three subdivision designs are compared: an ecovillage, a new-urbanist design, and an up-scale estate. It finds that while higher-density designs result in lower EFs, consumption patterns have a more significant impact on the overall footprint. The study argues that EF is a useful metric for urban planners in assessing the environmental impact of built forms. (Markus, 2006).

The environmental and economic implications of housing projects in Spain and Chile is evaluated using the Ecological Footprint indicator and detailed bill of quantities. The study reveals that both nations have comparable ecological footprints per unit of floor area, however the type of materials used, and their costs differ significantly. The study also demonstrates that using recycled materials can substantially reduce the ecological footprint in both settings. (Vallejo, 2018).

Ecological Footprint Analysis is utilized to assess the environmental impact of different types of buildings in Italy, specifically looking at embodied energy and land use. Despite the inherent complexity of applying EFA to buildings, the study is designed to identify factors that consume high levels of energy. The paper concludes that employing eco-friendly materials and renewable energy sources, along with building multi-storey structures, can effectively reduce the ecological footprint. The study only focuses on the construction phase and does not consider other stages like transportation, operation, or demolition. (Bastianoni,2006).

The relationship between urban planning and household consumption, focusing on its environmental impact is assessed through surveys in Norwegian towns, it uses Ecological Footprint to analyze housing-related consumption. The findings suggest that sustainable urban development is best achieved through decentralized concentration, meaning smaller, high-density cities where houses are closely located to essential services. (Erling, 2004).

Transportation and food consumption play significant roles in Canada's ecological footprint. Research has demonstrated that residing in apartments, especially in urban areas, is associated with a decreased ecological footprint because of energy-efficient heating systems and a reduced reliance on personal vehicle ownership. The study proposes that public transport systems and green building practices are crucial steps for reducing ecological footprints in Canadian cities. (Carl,2016).

The housing size preferences among 878 Swiss tenants are investigated & it reveals that affluent tenants prefer larger homes, making downsizing challenging. The study suggests that financial and non-monetary costs inhibit smaller housing choices, recommending incentives for downsizing and ensuring a supply of quality, smaller dwellings to promote sustainable housing. (Claudine, 2022).

The application of Ecological Footprint analysis is used to evaluate the sustainability of Aurora, residential community in Melbourne. This study delineates three primary functions of sustainability evaluation tools within the context of residential estate developments: facilitating the processes of planning and design, assessing the progress made, and furnishing feedback to foster ongoing enhancements. Although the Ecological Footprint analysis provides a comprehensive evaluative framework, its reach is limited as it does not completely consider local environmental challenges or traditional measures of urban development. The study suggests that the efficacy of the tool is depending upon the developers' intentions to pursue either conventional or sustainability objectives (Joe,2007).

Ecological Footprints of two neighborhoods in Minna, Nigeria, were derived considering factors like building design and lifestyle. It finds that Tunga Low-Cost estate has a lower Ecological Footprint than M.I Wushishi, attributing the difference to building type, household size, and lifestyle. The study suggests that urban planners should consider these factors for more sustainable city design. (Aremu, 2017).

Ecological Footprint (EF) method is used for the analysis of neighbourhood to provide valuable insights to local decision-makers, such as planners and architects. Nevertheless, the study identified deficiencies in data collection at this smaller scale, resulting in inaccuracies in EF results and thus shifted its focus toward improving methods for future neighbourhood-scale EF evaluations. (Smith, 2008). The concept of embodied energy in building materials and construction practices in India is investigated to explore the energy costs associated with transportation and manufacturing. A comparative analysis of the energy consumption associated with various masonry and roofing systems concluded that utilization of energy-efficient or alternative construction materials can result in a significant reduction, up to 50%, in the overall embodied energy of load-bearing masonry structures. (Reddy, 2003).

A life cycle assessment of a multi-use, six-story building at the University of Michigan is conducted and total primary energy consumption is calculated to be 316 GJ/m2 over a 75-year lifespan. Most of the energy (94.4%) is consumed by HVAC and electricity, while building material production and transportation account for just 2.2%. The study also examined the challenges and implications of developing life cycle models for complex, long-lived structures. (Scheuer, 2003).

The Living Planet Report of 2006 published by WWF International talks about the equivalent factor for conversion of embodied energy into equivalent land. It also talks about the impact of urban growth on the ecology. The conversion factor of embodied energy into land is taken as 0.155M^2 MJ.

New Zealand is one of the few developed countries living within its overall land carrying capacity, although there are regional disparities. Urbanized regions like Auckland, Wellington, and Nelson exceed their local carrying capacities and rely on resources from other areas, which is sustainable if the entire country remains within its limits. It also states that the energy required for construction of the building assumes as 5% of its life span energy consumption (Gary, 2003).

The relationship between urban planning and household consumption was established aiming to inform sustainable development practices. Based on surveys in Norwegian towns, the study finds that the design and location of houses significantly impact various aspects of consumption, including energy and transport. The study also suggests that sustainable urban development could be achieved through decentralized concentration—small, high-density cities with short distances to services. (Erling, 2004).

The concept of 'Ecological Footprint' is applied to assess the environmental impact of household units throughout their entire life cycle, focusing on an urban context in the Tirurangadi Municipality area. It emphasizes that architects and planners should consider the life cycle ecological footprint to make informed decisions in design, construction, and maintenance, advocating for the use of life cycle ecological footprint as an effective tool for sustainable urban development. (Laditta & Nithin, 2021). Despite its complexity and limitations, ecological footprint analysis offers useful insights into the sustainability of construction and urban growth. Minimizing ecological footprints requires comprehensive strategies that consider material selection, urban design, and consumption habits. To enhance the depth of understanding regarding sustainability in human settlements, future research endeavours would greatly benefit from integrating many strands of investigation.

The approach of Ecological Footprint (EF) has been expanded to include productive systems to evaluate the appropriation of natural capital, the efficiency of natural resource usage, and the resulting environmental effect. The consumer-oriented approach of this assessment tool is highly beneficial for evaluating the construction sector, since it offers a comprehensive awareness of how buildings depend on global resource production and waste absorption capacities.

In the realm of architecture and construction, the implementation of Ecological Footprint (EF) is based on several fundamental assumptions:

- It is possible to consider most materials utilized in the building construction.
- The calculation of embodied energy for each material can be performed using specific coefficients.
- The quantification of embodied energy in construction materials allows for its conversion into the biologically productive land area required material manufacture.

The EF technique provides a comprehensive framework for assessing the environmental dependencies and repercussions of buildings, encompassing several aspects such as material utilization and land required to manufacture these materials. This facilitates the adoption of a well-informed and environmentally conscious approach to urban planning and construction methodologies.

Research Methodology

The study is based on case study approach and quantitative method to calculate Ecological footprint as planning tool, which determines natural resource consumption facilitating the impact of existing urban settlements on natural resource consumption. Ecological footprints of two predominant urban patterns are calculated.

The research employed a mixed methods which incorporated the use of primary and secondary data to evaluate the ecological footprint of two specific neighbourhoods in Mumbai. The research framework was informed by an extensive literature survey that covered subjects such as urbanization, concept of ecological footprint, calculation methods of ecological footprints, land ratio, residential typologies of Mumbai etc. A spreadsheet tool was developed to calculate the ecological footprint of these neighborhoods with infrastructure and with buildings as per development control rules of Mumbai. Factors such as land allocated for infrastructure (including roads, buildings, parking spaces, and walkways) and material consumption for construction were considered as physical parameters. Furthermore, an analysis was conducted on the lifestyle and consumption patterns of the residents inside the neighborhood. The resultant data provided both household-level and per capita estimates of the ecological footprint, offering valuable insights into the environmental impact of urban residential areas.

Tools and Methods

Data was collected for the calculation of Embodied Energy, Conversion factor of Embodied Energy to land, Footprints & land ratio. The data was collected from the following sources respectively:

- Embodied Energy values: Embodied Energy values as per (Reddy, 2003)
- Conversion factor of Embodied Energy to land (Living Planet Report 2006)
- Plot size & specifications for neighborhoods as per development control rules of Mumbai

To calculate the footprint, all the materials required are listed, and their quantities are worked out initially in the unit in which they are popularly measured. The unit of doors and windows are sqm, whereas the unit of concrete, brick masonry, is Cum. Then the quantities are converted into the equivalent weight of the material by multiplying with each material's density.

To calculate the embodied energy of the material, it is divided into two parts:

- Energy required during construction, i.e., for the electricity, erection, etc.
- Energy required during the life of the building.

Initially, the Embodied Energy of each material is calculated by using the formula.

$$\text{Embodied Energy} = \frac{\text{Quantity X embodied energy coefficient}}{\text{The life span of the material}}.$$

After calculating each material's EE as per the above formula, the building footprint is calculated in terms of the area of land required for each material by multiplying the conversion factor to convert the embodied energy into the land area.

The Case Study

The City of Mumbai

Mumbai, previously known as 'Bombay,' until 1996, is India's largest city located in the western state of Maharashtra. Originally formed from seven islands, they were unified into a single peninsula during the 18th and 19th centuries. Today, under the governance of the Brihan Mumbai Municipal Corporation, this coastal city boasts a significant bay in the Arabian Sea, which solidified its role as a vital seaport during colonial times. As the administrative heart of Maharashtra and the nation's commercial hub, Mumbai contributes immensely to India's economy. Rapid population growth, driven by its economic potential and job opportunities, has led to expansive suburban development, straining the city's public resources and infrastructure. Mumbai has been taken as a case to assess the environmental impact resulting from the existing built form on the region of Mumbai with special emphasis on material as a resource and land ratio.

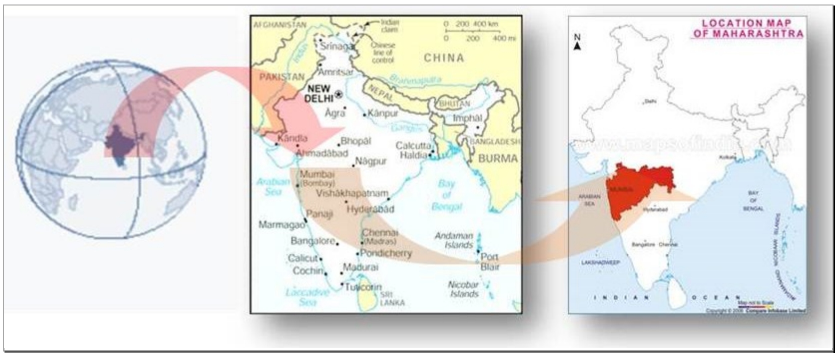

Fig 2: Location of Mumbai city in India and the world map.
Source: Author

The process of urbanization has altered the character of the natural environment of the region. Land reclamation, vegetation clearances, plantations, changes in land use, etc. have created manmade environments. In the process of urbanization, Mumbai's natural ecosystems are replaced by the man-made. This has impacted the natural resource resulting in environmental degradation and an increase in the settlement vulnerability to natural disasters. The ecology of the region has also adapted to these changes. The ecosystem has become very dynamic and complex. Mumbai's rapid population growth has put a strain on the city's resources and infrastructure. The population growth has made Mumbai more vulnerable to natural disasters such as floods and climate change. The city is located on a coastal plain and is prone to flooding during monsoon season. Climate change is also expected to increase the frequency and intensity of flooding in Mumbai.

The city needs to be developed only in terms of its carrying capacity as there is a limit to the resources that can be artificially imported to the city. The greatest challenge is to check Mumbai's conversion into a consumer city as its sustainability depends on addressing the massive inequalities and disparities in resource distribution. It is imperative to study the ecosystem dynamics of Mumbai and its urban form to organize its resources optimally and adapt sustainable urban forms.

Therefore, it is imperative to quantify the ecological disturbance of the region. Ecological footprints are a parameter considered a significant step towards ecological sustainability of the region. Ecological footprint of urban layouts of Mumbai are calculated to show the ecological condition of the region.

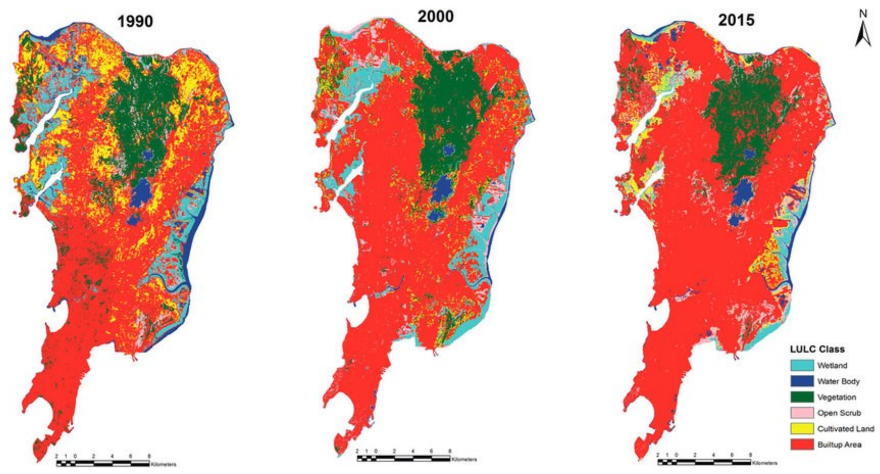

Fig 3: Map of Mumbai showing increasing built up and decreasing natural resources.
Source: Mehebub, 2018

Mumbai: The Urban Layouts

In a neighborhood, buildings require basic infrastructures such as roads, water supply, drainage, and electricity, leading to fewer open spaces around the building and increasing the built-up area, which is having impervious surfaces. Such impervious surfaces harm the natural water cycle. By replacing soil cover with impervious surfaces and reducing the land's ability to absorb precipitation, impervious surfaces contribute to floods and deplete groundwater table.

There are different urban layouts in Mumbai with basic infrastructure, the road, the drainage system, the sewerage system, drinkable water, and street lighting. Footprints of these urban layouts are calculated for two types as per the development control rules of Mumbai. One shows for the only layout with infrastructure, and another shows the layout with the building. The results are referred to as footprint per capita and land ratio required for the layout.

Mass Housing by the State

After independence-refugee migration raised housing demands in the city. Rents increased so the rented accommodation was not viable. The Rent Control Act was enacted in 1947.Introduction to F.S.I: In 1967 the Development Plan was sanctioned with the concept of FSI (Floor Space Index) which laid restriction on how much one could build according to the infrastructure available. The State through the Housing Board and later MHADA (Maharashtra Housing and Area Development Board). With concepts of FSI and Urban Land Ceiling act; land became a scarce commodity and very expensive.

- The concept of housing supply started as per the economic class such as HIG (Higher Income Group), MIG (Middle Income Group), LIG (Lower Income Group) and EWS (Economically Weaker Section). State started building rented apartments for these classes.
- The house size and specification of construction depend upon the income group. However, adequate open spaces, light, ventilation, and sanitation arrangements were ensured in these colonies. The lower income group houses were like the chawls but had larger tenement sizes and individual toilet facilities.
- All colonies were typically low rise and the densities depended on the class of the inhabitants. These colonies are places with maximum number of open spaces around them.

These types reflected socio economic aspects of the people rather than climatic aspects.

Houses in Plotted developments

Housing agencies and the government planned suburban areas for housing purpose. Small plots of 450 square meters to 1000 square meters were plotted. These plotted developments are characterized by broad streets with adequate health and education facilities.

- The buildings were low rise with 12-36 self-sufficient apartments. While the cooperative societies built the apartment.
- Several bungalows were built in these areas by richer families.
- It is typically a large single-family house within a bounded plot with open spaces on all sides.
- It may be one or two storied. In Mumbai, it is characterized by having verandas at lower level and balconies at a higher level. Today these areas are one of the most expensive residential pockets of the city.

Findings

A comprehensive analysis was conducted on several urban layouts, wherein the ecological footprints of each layout were computed in compliance with the Development Control Regulations of Mumbai. For this study, the analyses were performed on a standardised plot size measuring 100m x 100m. The research also integrated insights obtained from pertinent case studies.

Urban Layouts with Infrastructure by Private Builders

- Internal Roads: 12 m wide, two nos. × 100
- Plot size: Size 100m x 100m
- FSI: 1.33
- 9 m wide five nos. × 9m
- Water mains MS pipes: 300m dia. 7×100
- Drainage line RCC pipes: 300mm dia. 7×100m
- SWD line: 600mm dia RCC

As per Fig. 4.0, footprint per capita for private builders is 1.59 and Land Ratio is 13.25.

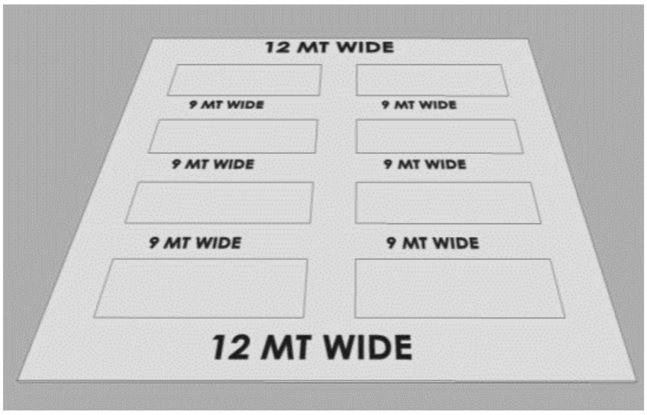

Fig. 4: Schematic sketch for the layout of infrastructure by the private builder
Source: author

Urban layout with infrastructure by MHADA

- Plot size: 100mx100m
- FSI: 2.50
- Internal roads 12m wide: 1× 100m, 9m wide 5×100m, 6m wide 10x100
- Water mains MS pipes: 600mm dia. 1×100m, 300mm dia. 15×100m
- Drainage line RCC pipes: 600mm dia. 1×100m, 300mm dia. 15×100m
- SWD Line: 600mm dia. RCC

As per Fig. 5.0, footprint per capita for MHADA is 0.37 and Land Ratio is 26.99.

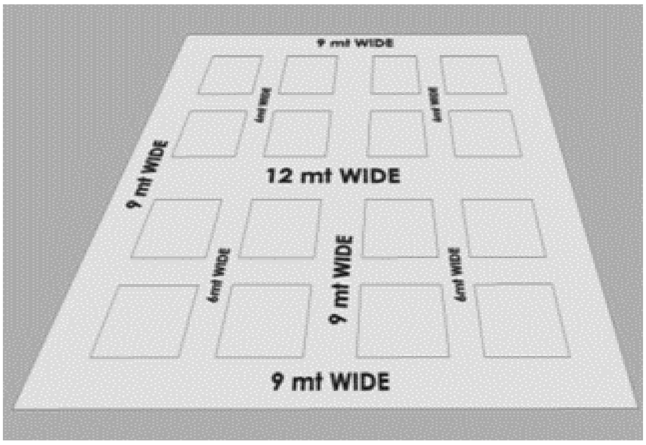

Fig. 5: Schematic sketch for the layout of infrastructure by MHADA
Source: author

Urban layouts with building Urban layout with Building by Private Builders

- Area of plot: 10000Sqm
- No of buildings: 4
- BUA of each building: 2500 × 1.33 × 1.30 = 4323 Sq m
- Plinth area: 20mx20m = 400 Sq m
- No of floors: 4323/400 = 11 Nos.

As indicated in Fig. 6.0, footprint per capita for building by private builders is 42.81 and Land Ratio is 357.09.

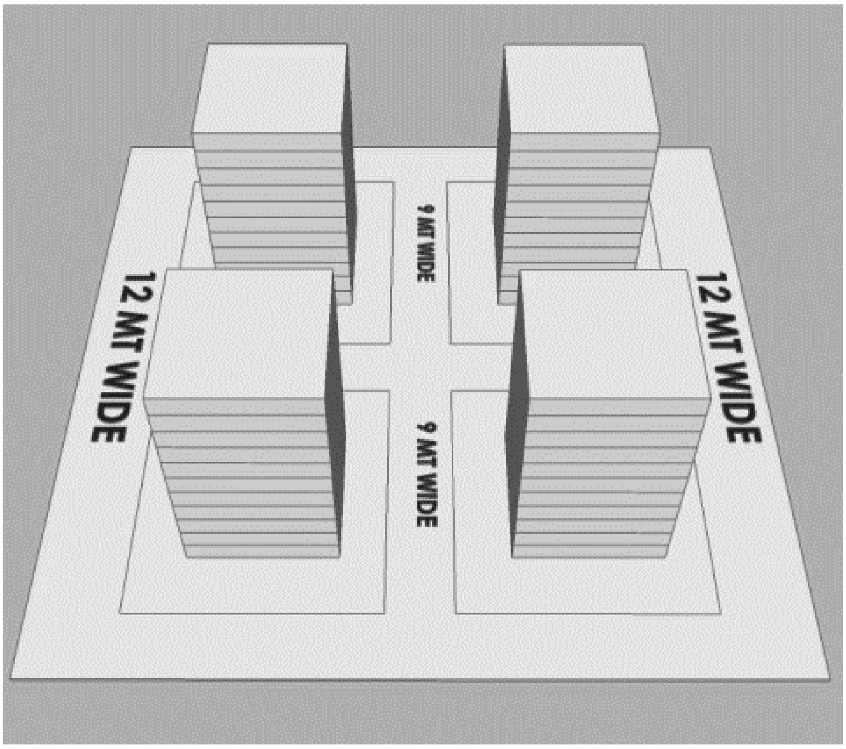

Fig. 6: Schematic sketch for urban layouts with building for Private Builders
Source: author

Urban layout with building by MHADA

- Area of plot :10000Sqm
- No of buildings: 16
- Built up area of each building: 600 × 2.5 × 1.20=1800 Sq m
- Plinth area: 22M × 14M = 308 Sq m
- No of floors: 1800/308 = 6 Nos.

As indicated in Fig. 7.0, footprint per capita for MHADA layout with building is 8.30 and Land Ratio is 604.47.

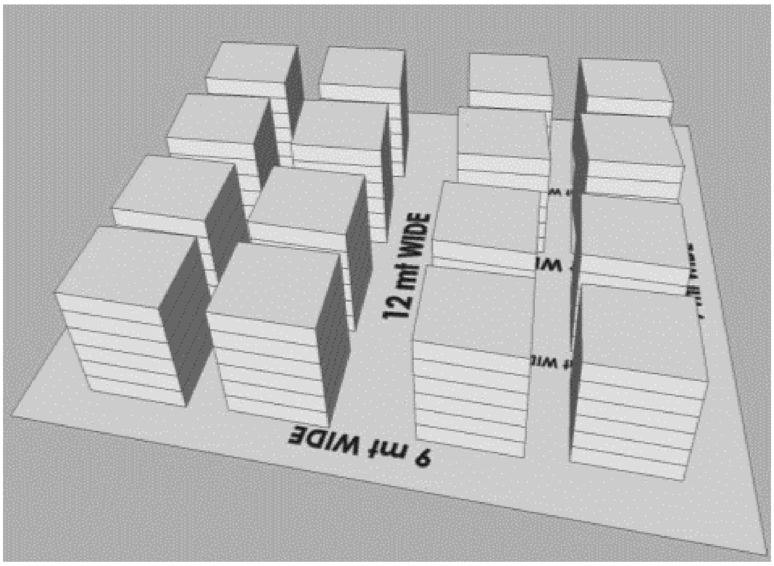

Fig. 7: Schematic sketch for urban layouts with building for MHADA
Source: author

Table 1: Summary of footprint & land ratio for different urban layouts.

TYPE	FP PER CAPITA	LAND RATIO
Private Layout	1.59	**13.25**
MHADA Layout	0.37	**26.99**
Pvt Layout with Building	42.81	**357.09**
MHADA Layout with Buildings	8.30	**604.47**

Discussion

- The land ratio required in case of the urban layout of MHADA is almost double that of the private layout by builders as much more material quantities are required in case of MHADA layout due to a greater number of buildings, and extra FSI utilized, i.e., FSI of 2.50 as against 1.33 for private layout. Hence private layouts shall be preferred to conserve natural resource consumption and ecology of the region.
- Footprints per capita depend upon the density of tenements. Hence in the case of MHADA buildings, the FP is much lesser, and in the case of Private buildings, it is maximum due to larger sizes of tenements and fewer persons occupying in the tenement.
- Land ratio increase for increased FSI due to more requirements of material and vice versa. Hence land ratio required is much less in the case of single-storied building and much more in MHADA building.
- Building footprints are directly proportional to the type and quantity of material used for constructing buildings and inversely proportional to the population's density.

Fig. 8.0 summarizes footprints & land ratio for different urban layouts of Mumbai.

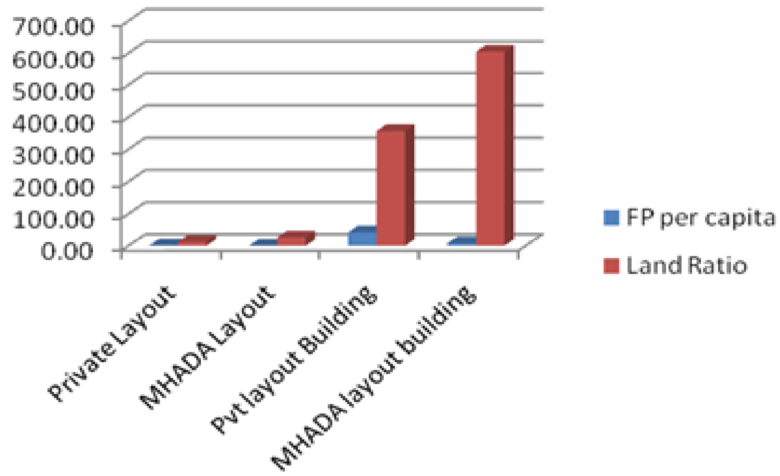

Fig. 8: Footprints & land ratio for different urban layouts of Mumbai.
Source: author

Conclusions

The number of occupants a building can accommodate and the number of natural resources it uses are both closely related to the size of a building's footprint, or the area of ground it occupies. According to the study, the building footprint grows as the number of floors increases, resulting in fewer residents in high-rise buildings. This may first seem illogical, but it may be explained by the fact that high-rise buildings have more infrastructure needs and supporting systems, which increases the footprint. Single-story constructions demand more land than multistorey buildings when it comes to the ratio of the land needed for construction to the actual plot area. This rising land ratio indicates the need for more land, which will increase the use of natural resources. Essentially, because of this greater resource consumption, a higher land ratio results in weaker sustainability.

Ecological footprint theory is crucial in this situation. The ecological footprint is a measure of how much the Earth's ecosystems are used by people. It is a gauge that measures how much Earth's resources are used by a person, a group of people, or the entire human race. This measure is highly versatile and useful because it can be used to evaluate anything from a single product to an entire city or nation. The ecological footprint can play a significant role in the planning and development process when it is applied to urban planning. It can help in assessing the possible effects of new developments at the regional, city, and neighborhood levels as well as the consumption of natural resources by existing urban communities. It gives planners a visual picture of how much 'Nature' a particular community needs so they can decide how to allocate and use resources wisely.

Urban planners can utilize techniques like the ecological footprint to design developments that are sustainable by taking the effects of greater building footprints and increasing land ratios into consideration. These advancements, which prioritize resource efficiency and have less of an environmental impact, are essential in the global struggle against resource depletion and climate change. Understanding these links and utilizing them to guide our urban planning processes will be essential to ensuring a sustainable future for everybody as cities continue to expand and develop.

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References

Bastianoni, S., Galli, A., Niccolucci, V. & Pulselli, R. M. (2006) The ecological footprint of building construction, *The Sustainable City IV: Urban Regeneration and Sustainability*, 345, 356.

Bulti, D. T. & Assefa, T. (2019) Analyzing ecological footprint of residential building construction in Adama City, Ethiopia, *Environmental Systems Research*, 8, 1-15.

Chazhoor, L.B. & Nithin, M. (2021) Life cycle ecological footprint assessment in a residential project, *International Journal of Creative Research Thoughts*, f502-f517

González-Vallejo, P., Muñoz-Sanguinetti, C., & Marrero, M. (2019) Environmental and economic assessment of dwelling construction in Spain and Chile. A comparative analysis of two representative case studies, *Journal of Cleaner Production*, 208, 621-635.

Hails, C. (2006) Living Planet Report, *Switzerland: WWF International*.

Holden, E. (2004) Ecological Footprints and sustainable urban form, Journal of Housing and the Built Environment, Netherlands: Kluwer Academic Publishers, 91-109.

Holden, E. (2004) Ecological footprints and sustainable urban form, *Journal of Housing and the Built Environment*, 19, 91-109.

Hurley, J., Horne, R. & Grant, T. (2007) Ecological footprint as an assessment tool for urban development, *3rd State of Australian Cities National Conference*, 28-30 November 2007, Adelaide, Australia.

Jouaneau, C., Beltran-Galindo, J., & Ouellet-Plamondon, C. (2016). Does Your Home Have an Impact on the Ecological Footprint?,*Substance ÉTS*.

Karlen, C., Pagani, A. & Binder, C. R. (2021) Obstacles and opportunities for reducing dwelling size to shrink the environmental footprint of housing: Tenants' residential preferences and housing choice, *Journal of Housing and the Built Environment*, 1-42.

Kumar, A.; Singh, P.; Kapoor, N.R.; Meena, C.S.; Jain, K.; Kulkarni, K.S.; Cozzolino, R. (2021), Ecological Footprint of Residential Buildings in Composite Climate of India—A Case Study, *Sustainability*, 13, 11949.

McDonald, G. & Patterson, M. (2003) Ecological Footprints of New Zealand and its regions, *Wellington, New Zealand Ministry for the Environment*.

Moos, M., Whitfield, J., Johnson, L. C. & Andrey, J. (2006) Does design matter? The ecological footprint as a planning tool at the local level, *Journal of urban Design*, 11(2), 195-224.

Razack, A. T.A. N. & Ludin, A.N.B.M. (2013) Comparative Analysis of Ecological Footprint of two Different Neighborhoods in Minna, Nigeria, *International Journal of Scientific and Engineering Research*, 178-183.

Reddy, B.V.V. & Jagdish, K.S. (2003) Embodied energy of common and alternative building materials and technologies, *Energy & Buildings*, 129-137.

Sahana, M., Dutta, S. & Sajjad, H. (2019) Assessing land transformation and its relation with land surface temperature in Mumbai city, India using geospatial techniques, *International Journal of Urban Sciences*, 23(2), 205-225.

Scheuer, C. & Keoleian, G. & Repor, P. (2003). Life cycle energy and environmental performance of a New University building: Modelling challenges and design implications, 1049-1064.

Shetty, P. & Gupte, R. & Patil, R. & Parikh, A. & Sabnis, N. & Menezes, B. (2007) Housing typologies in Mumbai, *Mumbai: CRIT*

Smith, R.E. & Senbel, M. (2008) Assessing Housing: developing a method for neighbourhood ecological footprint analysis, *WIT transactions on Ecology and the Environment*, WIT Press, 95-104

Szigeti, C., Major, Z., Szabó, D. R. & Szennay, Á. (2023) The Ecological Footprint of Construction Materials—A Standardized Approach from Hungary, Resources, 12(1), 15.

Wackernagel, M., Monfreda, C. & Deumling, D., 2003. Ecological Footprint of nations, s.l.:s.n.

Wackernagel, M. & Rees, W. (1996) Our Ecological Footprint: Reducing Human Impact on the Earth. Gabriola Island, Canada: New Society Publishers.

Wixted, B., Yamano, N. & Webb, C. (2006) Output Analysis in an Increasingly Globalised World: Applications of OECD's Harmonised International Tables.