INTENSIFICATION AND URBAN METABOLISM– ANALYZING CURRENT TRENDS FOR MUMBAI

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ABSTRACT: The growth process of the Metropolitan city of Mumbai, in India, has been linked with the national and global processes of colonization, industrialization, development and underdevelopment. Over the last few years, Mumbai has emerged as a regional economic powerhouse with a sophisticated workforce and a large middle class. Mumbai is currently on the verge of major redevelopment with about 16000 buildings, covering an area of about 59 sq. km and supporting around 2.5 million people. There is a nationalistic desire to establish Mumbai as a World Class city and project it as an image of social welfare and technological progress in the country.

To encourage the redevelopment of these low-rise, old and dilapidated buildings, and to increase the average floor-space index (FSI), the Government is providing additional FSI as incentive. High-rise residential buildings are being promoted as a sustainable solution by the government and researchers alike, with almost no consideration of the environmental impact of increased density. Also, it does not take into account the finite resource availability for which the city is dependent on its hinterland or the potential for any new development to harness its own water or energy from renewable resources.

This research challenges the current convention that the increased densification of cities is compatible with sustainability.

The purpose of the paper is to analyse the negative impact, of increasing density on infrastructure and environment, and devising ways to minimise them in large scale brownfield redevelopment projects. Case studies of existing urban areas will be systematically compared with proposed denser developments in terms of their physical characteristics and urban metabolism to derive the infrastructural and environmental implications of proposed further densification. The results of this research are likely to go beyond Mumbai and provide a lesson to all cities in emerging economies.

Keywords: Density, Mumbai, Sustainability, Urban Redevelopment, Urban Metabolism.

1. INTRODUCTION

Cities and their surrounding areas are often considered the engines of economic growth in most countries. They are the centres of productive services, finance, employment, and coordination and control. However, the continuous increase in the size of the cities in terms of population and area put considerable strain on the limited growth of infrastructure. With the rapidly increasing global urban population, the task of trying to accommodate millions of people in a space that is becoming increasingly limited is a challenge that cities across the globe are facing, and certainly one that Mumbai knows well.

As the title suggests, the main theme of the research is to use 'urban metabolism' model as a means to understand and measure the sustainability (or resilience) of high 'density' development and its further intensification through the process of 'urban renewal'. It is critical to evaluate the impact of population growth and intensification on the consumption of resources and the ability of the infrastructure and nature to provide these resources, before allowing any large scale redevelopment projects. Figure 1 explains the basic structure of the study.

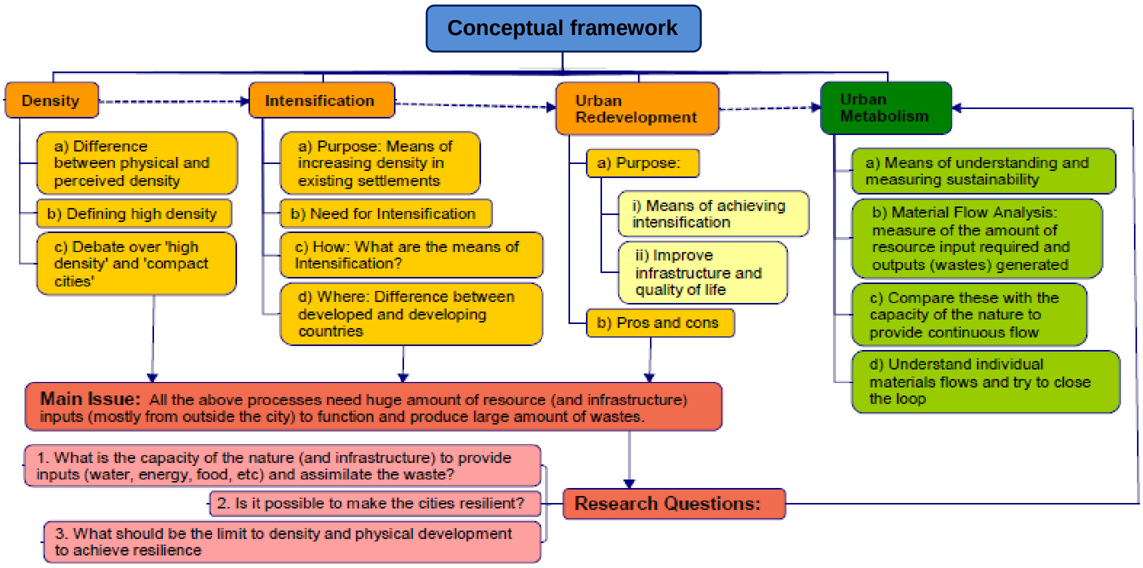

Figure 1: Structure of the research

1.1. Urban Metabolism - Understanding Sustainability

'Urbanisation affects the structure and function of natural systems both directly, through converting the land surface, and indirectly, modifying energy flows and the availability of nutrients and water' (Alberti, 2000). Urban Metabolism Model is both a means of understanding and measuring the sustainability / resilience of a development, in terms of energy efficiency, material cycling, waste management and effectiveness of infrastructure, and can be applied to various levels of urban planning.

Metabolism is defined as *'the sum of all the biological, chemical and physical processes that occur within an organism or ecosystem to enable it to exist indefinitely'* (Steemers, 2003, p. 124). Like all living organisms, urban areas have a linear metabolism system that depends on the input of resources and elimination of wastes. If the rate of metabolism is higher than nature's ability to provide resources or remove wastes, then it would eventually lead to the death of the organism. The same logic is applicable to urban areas.

1.2. Density and Compact City

With the current rate on increase in the global populations, and the subsequent demand for housing and related infrastructure, compaction and high density is being considered a solution globally. At a regional level, the Compact city is claimed to be a Sustainable Urban Form, based mainly on its fuel efficiency.

However, before discussing the merits and de-merits of high density and compaction, we need to understand what 'density' means. *'The word "density" although familiar at first glance, is a complex concept upon closer examination. The complexity mainly stems from the multitude of definitions of the term in different disciplines and under different context'* (Ng, 2010, p. 3).

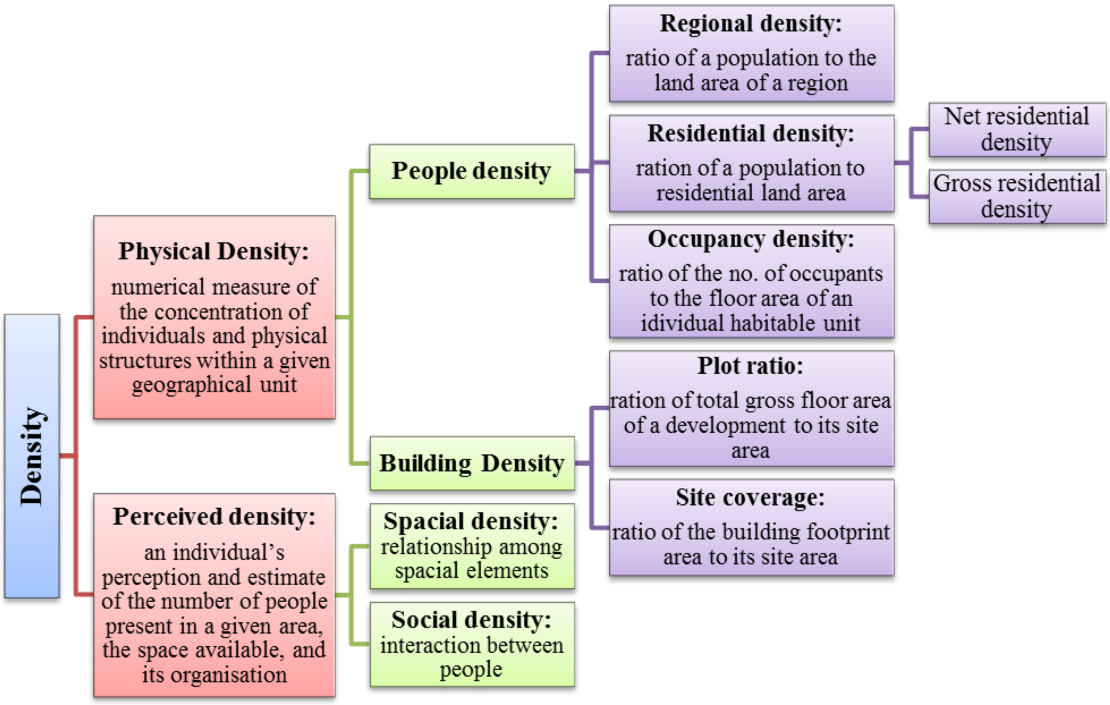

Figure 2: Categorization of different types of density
Source: Definitions have been quoted from (Ng, 2010, pp. 4-12)

The two dimensions of density and their further classification has been represented in Figure 2. In addition of the various ways of expressing physical density, the definition of different types of densities also vary across various cities and countries. While physical density is an important urban planning tool, the definition of high density is a matter of perception. *'…It is subjective and depends upon the society or individuals judgement against specific norms. Hence, societies or individuals of different backgrounds and under different contexts come up with different definitions of high density'* (Ng, 2010, p. 14).

'High Densities in Developing Countries: A Sustainable Solution?' (Dave, 2010) concludes that high density (in terms of number of Households and total population) and compact urban form are socially acceptable and have the potential to be a sustainable solution for Mumbai, though it does not provide an optimum density or city size. While, the research provides empirical evidence to assess the relation between density and sustainability, it is mainly based on social acceptance of people to live in such developments.

Newton and AHURI (1997) modelled 6 future scenarios of urban development for Melbourne, and compared them with the base development of the year 1991, and with each other. Based on their calculations, compact city consumed 43% less fuel compared to business as usual form of development. Newman and Kenworthy (1999) developed a graph (by plotting energy consumption verses urbanised land area) that infers that low density scattered land-use is unsustainable compared to high density compact urban areas due to increased transport energy consumption, air pollution from automobile exhaust and infrastructural investments.

Cities like Denver, Houston, Montreal, etc. with their model of central commercial areas and far flung houses/cottages have poor sustainability whereas dense, mixed use planning like Hong Kong and Singapore are far more sustainable models because of their low energy expenditure in transportation (Barret, 1996; Network, 2010). The theory, however, does not account for domestic energy consumption and the potential generation of energy from renewable sources. It is also based on a cost effective public transport system already being in place and does not account for rapidly growing Asian cities, where it is yet to be developed.

While some researchers are questioning the relevance of the 'Compact city model' in developing countries, due to the high growth rates of both their population and urban areas (Hillman, 1996; Jenks, Burton, & Williams, 1996; Wackernagel et al., 2005; Williams, Burton, & Jenks, 1996; Wolman, 1965), other are refuting the sustainability of the Compact city concept, even in developed countries. Research conducted by Ghosh (2004) reveals that '*compact urban form limits the potential sustainability of residential blocks'*, based on an ecological footprint analysis, five residential blocks in Auckland. The research concludes that the low density (1800 households/sq. km) block at a reasonable distance from the Central business district was the most sustainable urban form.

However, none of the above mentioned researches answer the question of where and how to accommodate the rapidly increasing urban population, as is the case with most part of the developing world.

1.3. Intensification and Urban redevelopment

Rapid urbanisation of developing countries, such as India and China, is caused, not only by natural increase in population, but large scale rural-to-urban migrations. Intensification through the redevelopment of inner city neighbourhoods is promoted as a means of improving the availability and condition of housing stock, promoting economic growth and re-imaging the city to be more 'world-class'. In the case of Mumbai, the government agencies advocate the change in urban form (the existing high density, medium rise developments to be replaced by higher density, high rise buildings) based on its potential to provide more open green spaces that would compensate environmentally the impact of the increased density. However, the hypothesis/notion has not been tested.

Figure 3 examines some of the problems related to housing in Mumbai city and identifies factors that led to the proposed developments.

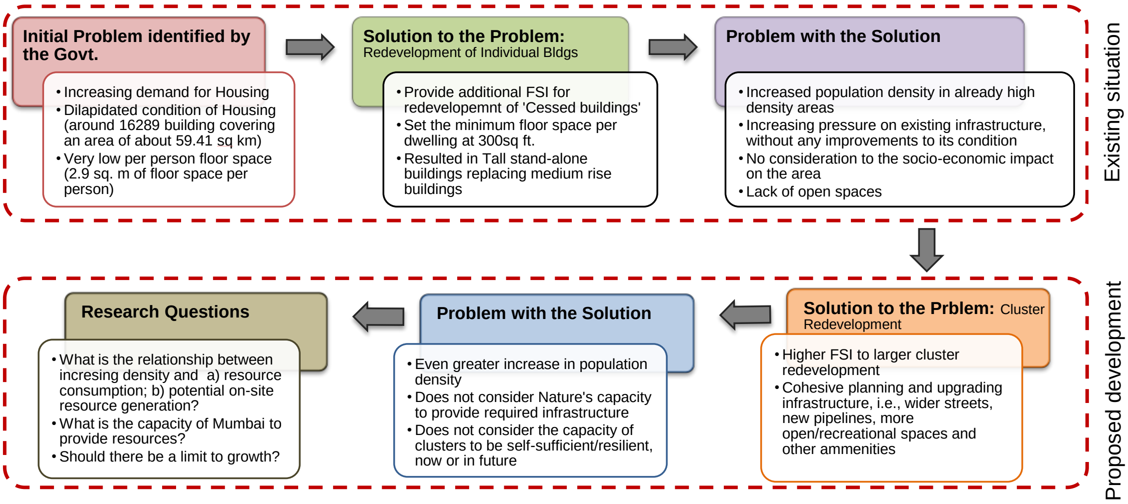

Figure 3: Current situation of Mumbai

Similar to Mumbai, *'Hong Kong's urban form has mainly been driven by the explosive population growth and land scarcity, and the strategy for urban compaction is the response to the physical constraints on its urban growth' (Zhang, 2000, p. 252)*. It has already undergone the process of urban renewal favouring urban intensification and high-rise developments since the late 1970s. Based on their studies of Hong Kong, Zhang (2000) and Zaman.et.al (2008), agree with conclusions drawn by Dave (2010) that high-density high-rise urban form (of Hong Kong) is a success based on people's satisfaction, its ability to provide housing for a larger population and provide increased floor space per person, in addition to the increased economic opportunities of mixed-use development.

Zhang (2000) and Zaman.et.al (2008), highlight that the environmental negative implications, such as air pollution, have been serious. Also, it can lead to a worse pedestrian environment (Williams et al., 1996). However, Burgess (2000) attributes urban environmental problems to the deficiencies in urban structure, and supports the idea that sustainability benefits from compaction in developing countries can be achieved through urban restructuring.

2. ABOUT MUMBAI

Mumbai, located on the west coast of India, is India's centre of finance and culture. The Mumbai Metropolitan Region (consists of seven municipal corporations and fifteen smaller municipal councils, including Greater Mumbai) extends over an area of 4355 sq. km, being the second largest (in terms of area) of Asia's mega-cities.

In 2001, Greater Mumbai (603 sq. km approx.) had a population of about 12 million with an average household size of 4.62 (MMRDA Planning Team, 1996 - 2011). Based on gross land area under residential use, the density was estimated to be 58,000 persons per sq. km (MCGM, 2005 to 2025). However, the case study areas, located in mixed use areas of the Island city (wards B to G), have even higher densities reaching 111,000 people per sq. km.

Households in Mumbai consume an average of 2.9 sq. m of floor space per person which is one of the lowest residential floor areas per person in the world (Bertaud, June 2004). The average size of tenements in existing dilapidated buildings in the study areas is 14 sq. m (150 sq. ft.).

3. RESEARCH QUESTIONS AND AIM

Mumbai is dependent on areas far beyond its municipal limits for deriving its resources, such as food, electricity and water and discharging its wastes. In addition to global concerns over peak oil and climate change, the current infrastructure of the city is also under considerable strain with power cuts and water shortages in many parts of the city, accompanied by increasing food prices, flooding during monsoons, etc. Under these circumstances, increasing residential density to provide more housing raises several questions, such as: *'Is it sufficient to provide housing without the supporting infrastructure?'* or *'Should the residential density be increased if it is beyond the capacity of the infrastructure and nature to provide the necessary resources?'* or *'What is the limit to the availability of resources?'* or *'How resilient would the proposed developments be when faced with resource shortages or climate change?'*

In order to answer these questions, the research aims to evaluate the impact of population growth and intensification on the consumption of resources and their potential localised regeneration. This is achieved by comparing and contrasting the existing medium rise high density development and the proposed high rise, higher density developments.

4. METHODOLOGY

Material Flow Analysis model of Urban Metabolism is used as the main method for comparing and contrasting the existing and proposed urban form. The comparison of even the partial metabolism of the existing high density medium rise developments versus the higher density high rise buildings will provide the much needed quantitative data needed to decision making and would be very helpful for land-use planners and policy makers, and thus the city. Therefore, considering that redevelopment is inevitable due to poor condition of housing and infrastructure, the research focuses only on the operation energy and material requirement. Due to lack of primary data for many of the metabolic processes, the research draws upon several secondary sources to derive the data required for the comparison.

4.1. Preliminary study

In the initial stage of this research a pilot study was conducted on a typical cluster within the study area, to compare the difference in consumption of resources and potential for on-site regeneration, between the existing developments and potential re-development, based on available data. The bulk of a hypothetical building was designed based on the requirements and Municipal regulations (MCGM, 2007). The intention was to derive the density and physical form/height and not to design it architecturally. While there were many permutations possible, the highest density solution was selected on the basis that this would be the approach taken by a developer. Figures 4 and 5 show the built forms of the first pilot study cluster, while table 1 represents the results of the comparison.

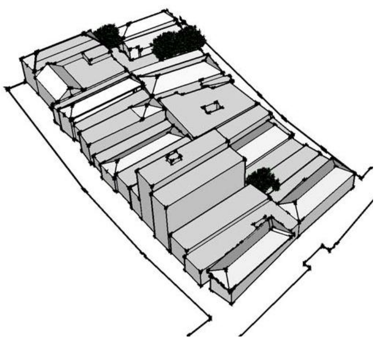

Figure 4: Existing Cluster

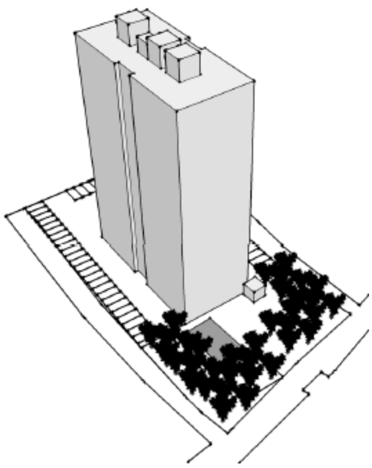

Figure 5: Proposed Cluster

Table 1: Comparison of Existing Development and Potential Redevelopment

	Existing	Potential
Land Area	3725 sq. m	
FSI	1.705	4.34
Built-up Area	6349.365 sq. m	16181.88 sq. m[1]
	-	155% increase
Avg. Tenement Size	13 sq. m (140 sq. ft.)	27.8 sq. m (300 sq. ft.)
		47 sq. m (500 sq. ft.)
		70 sq. m (750 sq. ft.)
Population (approx.)	1030 people[2]	1305 people[3]
	-	27% increase
Density (population)	276,510 persons/sq. km	350,335 persons/sq. km
No. Of Floors	2-6	30
Car Parking	< 10	35 - 80 (approx.)
Estimated CO_2 produced by Cars[4]	>2340 Kg/year	8190 – 18720 Kg/year
	-	71% - 88% increase
Amenity Open Space	None	930 sq. m
Roof Area	3375 sq. m	385 sq. m
	-	88.5% reduction
Energy Consumption	-	50% increase[5]
Water Use	-	80% increase[6]
RWH potential	-	90% decrease[7]
No. of Trees	3-5	47[8]
CO_2 Sequestering Potential[9]	69–115 Kg/year	1081 Kg/year
	5-3 %	13-6%

The analysis indicates that a typical re-development with increased density would mean more than double the energy consumption, double the use of water, reduce the amount of rainwater that could be collected or returned to the ground and reduce the scope for collecting solar energy, causing further strain on the already overloaded infrastructure. Also, it would encourage an increase in the

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[1] Considering incentive of 55% on built-up area required to rehabilitate existing users

[2] Considering an average tenement size to be 140 sq. ft. (13 sq. m) and average household density to be 4.5 persons

[3] Considering an average tenement size for rehabilitation to be 27.8 sq. m, and additional built –up area used for tenement sizes of 47 sq. m and 70 sq. m; average household density to be 4.5 person

[4] Considering CO_2 for cars to be an average of 101gm/Km and usage to be about 3 trips of 15 Km equivalent per week

[5] Due to increase in the energy required for lighting and ventilating the additional built-up area and other building services such as pumping of water, lifts, common area and security lighting.

[6] Due to a combination of an assumed 'take-back' (increased use of water due to improved bathing facilities), watering of trees and other landscaped areas and for washing the increased number of cars

[7] Due to significantly reduced roof area

[8] At the rate of 5 tree per 100 sq. m or part thereof of the said recreational space to be grown within the entire plot (as per DCR for Greater Mumbai, 2007)

[9] Considering CO_2 Sequestering Potential to be 23 Kg (50 pounds) per year per tree, and high leaf density tropical trees between 20-50 years of age. Also the deficit percentage is calculated in comparison to the CO_2 likely to be produced by cars.

number of private vehicles, without providing an opportunity to increase road width.

Based on analysis of various plot sizes, it is observed that, smaller plot sizes encourage tall buildings, due to the current height-to-open space regulations. However, amalgamation of plots into a singular development can help achieve the same density through medium rise development. A comparative analysis of a singular verses fragmented development, resulting in medium and high rise developments respectively, was carried out by amalgamation of plots covering 10,000 sq. m of ground area and surrounded by roads on all sides. Figures 6 and 7 show the built forms of the second pilot study cluster, while table 2 represents the results of the comparison.

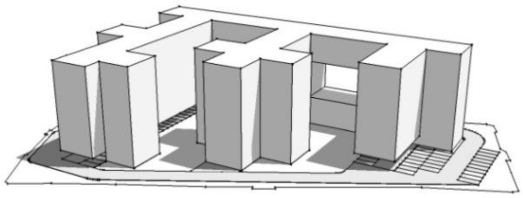


Figure 6: Medium Rise Development

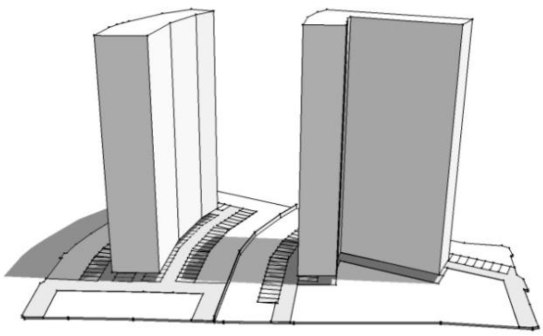


Figure 7: High Rise Development

Table 2: Comparison of Medium and High Rise Developments

Land Area		10,000 sq. m	
Proposed Built-up Area		29750 sq. m	
Open Space Required		1733 sq. m (20%)	
Population (approx.)		3814 persons	
Density (population)		381,400 persons/sq. km	
Estimated Water Requirement		125,289 – 320,185 cu. m	
Car Parking		76 - 267	
Estimated CO_2 produced by Cars		17,962 – 63,103Kg/year	
No. of Trees (min. required)		87	
CO_2 Sequestering Potential		1993 Kg/year	
		11 – 0.5 %	
Type of development		**Medium Rise**	**High Rise**
No. Of Floors		10	25
Roof Area		3264 sq. m (32.64%)	1311 sq. m (13.11%)
Total Rain Water Harvested[10]		5,587.6 cu. m	1,845.6 cu. m
RWH potential		4.45 – 1.75%	1.47 – 0.58%
Open Space	paved	2884 sq. m (28.84%)	3208 sq. m (32.08%)
	unpaved	3852 sq. m (38.52%)	5460 sq. m (54.60%)

[10] Rainwater from roof top only has been collected for domestic use, whereas rainwater falling on paved areas can be used to recharge underground water. Total rainwater collected is the total of rainwater collected over the 12 months that is calculated using the formulae

$$VR = R \times HRA \times RC / 1000$$

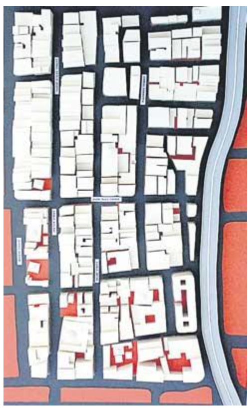
Where *VR :* annual volume of rainwater per development (in cubic meters)
R : annual rainfall depth (in millimetres) *HRA :* roof area (in square meters) and
RC: runoff coefficient (0.85 - no unit).

The comparison reflects that the medium rise development has greater potential for rainwater harvesting, electricity generation from photovoltaic cells due to increased roof area, whereas, high rise development has greater potential for CO_2 sequestering and ground water recharge due to increased open space on ground. Also, the open areas in low rise development are better shaded, which is an advantage in the hot climate of Mumbai, especially during summers.

5. FURTHER RESEARCH

While the preliminary study has looked at the replacement of single building or group of buildings by individual towers, the proposed cluster developments aim at transforming entire neighborhoods. Therefore, the next step in the research is to conduct the complete urban metabolism of existing neighborhoods, which will then be compared with that of the proposed cluster redevelopment, and attempts will be made to close the supply-consumption-waste generation loop by introducing on-site renewable technologies, such as rainwater harvesting, etc. Of the few proposals for large scale cluster redevelopment, the Bhendi Bazaar project[11] has been selected as it is a typical example that has got the government's approval to begin work. Table 3 illustrates its key characteristics.

Table 3: Key characteristics of the Bhendi Bazaar Project

	Existing layout	Proposed development
Built Form		
Land Area	66,773 sq. m (16.5 acres)	
Built up area	46,605 sq. m	320,683 sq. m
No. of buildings	250	22
No. of floors	4-6	Up to 40
Avg. Tenement Size	14 – 18.5 sq. m (150 – 200 sq. ft.)	32.5 - 70 sq. m (350 – 750 sq. ft.)
No. of residential tenements	3200	4450
Car Parking	Almost nil (few on street parking)	60,000 sq. m (underground car park for 1400 vehicles)

[11] http://www.mumbaimirror.com/index.aspx?page=article&sectid=15&contentid=200908282009082804230495389a185fa

6. CONCLUSION

Buildings require longer periods of realization (typically 3-4 years, depending on scale of project) and are also expected to last longer (at least 60 - 100 years) as compared to other consumer products (such as cars, electrical appliances, etc). An opportunity to redevelop large parts of a city doesn't occur often and therefore '*it is vital that modifications of the urban tissue are implemented in present day developments to reduce environmental impacts and unfavourable consequences that may last over centuries'* (Zetter & Watson, 2006).

The research hypothesis is that redevelopment of existing settlements at a higher density not only causes a disproportionate increase in resource consumption, but also reduces the potential for utilising renewable technologies, thereby reducing the sustainability and resilience of the city. This has been validated by the preliminary study.

The initial findings for a small 'cluster' and concludes that, although it is physically possible to increase density with tall buildings, there is a high price to pay due to an increased metabolism and reduced scope for incorporating renewable energy technology or rainwater collection. These factors, combined with a net increase in Carbon dioxide production resulting from such a development, question the sustainability of this built form.

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