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Urbanization: Smart Urban Transit System using Artificial Intelligence

Dilip Jain[1], Siddhesh Kadam[2], Aditya Mahimkar[3], Prof. Vaishali Yeole[4]

[1,2,3]B.E. Student, Computer Department,
[4]Project Guide, Smt. Indira Gandhi College of Engineering Navi Mumbai, Maharashtra, India.

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Abstract - *Urban areas are home to more than half of the world's population, and around 2.5 billion people are projected to be added in the next 3 decades. The way we construct new cities is at the core of our existence, from climate crises to economic vibrancy, to our well-being and sense of community. Bringing "smartness" to the town and the township has been the vision of various research and policies addressing issues with the existing system and providing a vantage to sustainable development for a healthier, happier, and happening tomorrow. We explore these studies and use publicly available data to build an intelligent pipeline of amalgamated algorithms to produce a blueprint for smart city development.*

Key Words: *City, Urban, Urbanization, Planning, People, Population, Pollution, Transportation, Artificial Intelligence.*

1. INTRODUCTION

Smart cities emphasize the capacity to build a secure, happier, and more sustainable environment that is centred around people's well-being through improving accessibility, transit, healthcare, waste and inconvenience reduction, and social and economic quality. It is based on the notion that citizens make up the city and not the other way round. Smart Cities utilize techniques that have worked in other locations to meet genuine local needs. To support smart city growth, cities must build quadruple-helix collaborative ecosystems capable of merging open innovation, bottom-up development activities, and local entrepreneurship in a civic framework.

Transportation has an impact on the shape and liveability of cities, as well as their socioeconomic, cultural, and environmental features. The efficiency of public transportation is one of the most obvious and crucial aspects of the transportation system for inhabitants. It is vital to construct an ideal transit network and transit service in order to deliver smart services.

McKinsey & Company gathered comments from two sources to address the issue of what are the most significant components of urban transportation systems: experts and a poll of locals. According to both professionals and citizens, the most important component of transportation systems is safety, which is followed by efficiency, affordability, availability, convenience, and ecological sustainability [1]. Availability, Affordability, Convenience, Efficiency, Sustainability (AACES) transit is what we must focus on. Solutions need to be resilient, and this paper advocates the use of technology to produce smart results for residents in order to increase economic growth and improve people's quality of life while maintaining environmental balance by using both historical and future trends to propose a set of research-backed principles and practices for a better, greener, and more sustainable future by using both historical and future trends to propose a set of research-backed principles and practices for a better, greener, and more sustainable future.

2. LITERATURE SURVEY

Todd Litman in his paper, 'Determining Optimal Urban Expansion, Population and Vehicle Density, and Housing Types for Rapidly Growing Cities', examines the economic, social, and environmental consequences of numerous urban development characteristics such as population and vehicle density, housing type, highway design and management, and recreation facility accessibility [2].

a) Unrestricted cities are surrounded by an abundance of lower-valued land. They have a lot of room to grow.

b) Semi-constrained cities have a limited ability to expand. Their development policies should include a combination of infill development and modest expansion on major corridors.

c) Constrained cities cannot expand much.

d) In spatially constrained cities, optimal concentrations can be above 80 residents per hectare; however, as urban expansion is limited, optimal densities rise, optimal vehicle ownership rates fall, and a greater share of housing should be multi-family. Cities should provide a variety of housing and transportation options that respond to consumer demands, particularly affordable housing inaccessible, multimodal neighbourhoods, and affordable travel modes, with pricing or roadway management that favour resource-efficient modes, as well as convenient access to parks and recreational facilities, in order to be efficient and equitable. Unrestricted cities are surrounded by an abundance of lower-valued land. They have a lot of room to grow.

e) According to a study published in the Journal of Global Economics, the ideal population density is 300 people per square kilometre.

f) 32 homes per hectare. [3]

Factor	Unconstrained	Semi-constrained	Constrained
Growth pattern	Expand as needed	Expand less than population	Minimal expansion
Regional density (residents / ha)	20-60	40-80	80 +
Vehicle ownership (per 1,000 pop.)	300-400	200-300	< 200
Intersection density per sq. km.	40+	60+	80+
Portion of land in road	10-15%	15-20%	20-25%

Table 1: Optimal Urban Expansion, Densities and Development Policies [2].

Effective transportation systems must be constructed which fulfil the present needs and serve future purposes as well. Increased job prospects, a consolidated market, better pay, and increased individual wealth are all factors that have attracted individuals to cities. For a long time, these factors have been a driving force behind urban expansion. Based on the World Urbanization Prospects: 2018 report by the United Nations Population Division, the World Bank estimated annual global urban population growth at 1.81% in 2020 [4]. By 2045, an estimated 1.5 times increase in global urban population is expected [5]. But this global trend shows that the growth in the area of a city is comparatively slower than the population. The increasing urban demands and rapid urbanization aggravate poor air and water quality, insufficient availability of water, huge waste generation and energy demands.

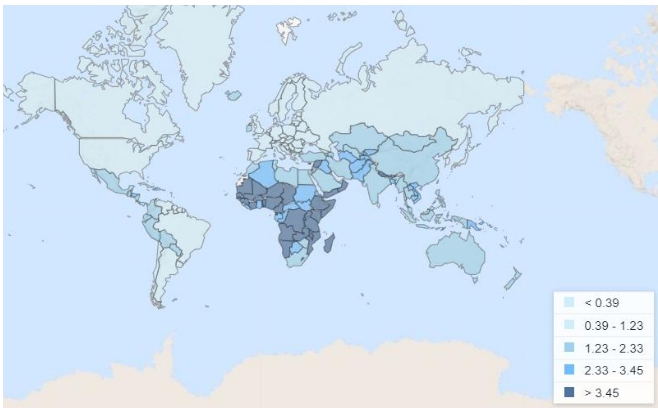

Figure 1: Population Growth Worldwide [5]

Climate change has a wide range of consequences for people's lives and health. It puts the pillars of human health in jeopardy - clean air, safe drinking water, nutritious food, and safe shelter - and has the potential to undo decades of global health gains. Malnourishment, malaria, diarrhoea, and heat stress are anticipated to cause an additional 250 000 fatalities per year between 2030 and 2050 as a consequence of climate change. By 2030, the direct health damage costs are expected to reach between USD 2-4 billion per year. Even 1.5°C of global warming is not regarded as safe; every tenth of a degree of warming will have a significant impact on people's lives and health [6].

3. PUBLIC HEALTH AND ENVIRONMENT

Improved health can be achieved by reducing greenhouse gas emissions through better transportation, dietary, and resource alternatives, particularly through reduced air pollution. Transportation accounted for 29 percent of the United States' total emissions of 6.4 billion metric tons of carbon dioxide equivalent in 2017 [7]. Transportation and its carbon release make for a large and complicated matter.

Commutation is a daily travel habit and thus a crucial research factor in urban geography, sociology and planning since it may represent both the standard of living and the effective and efficient use of urban space. Cities and metropolitan areas serve as hubs for a multitude of activities, many of which necessitate rapid and efficient people and commodities movement.

A San Francisco based urban planner, urban designer and architect Peter Calthorpe advocates pedestrian-friendly streets and human-scale neighborhoods. Walking is a low-impact, not expensive, non-polluting and by-far the healthiest mode of commutation. Adults should engage in mild-intensity strenuous cardiovascular aerobic activity, such as a brisk walk, for at least 30 minutes five days a week (or a total of 2 hours and 30 minutes), according to the US Department of Health and Human Services' 2008 Physical Activity Guidelines for Americans [8]. Walking improves cardiovascular and pulmonary fitness, manages hypertension, high cholesterol, joint and muscle discomfort and also diabetes, and controls body fat. It also enhances balance, muscle endurance and strength with stronger bones.

According to the World Health Organization, each individual should have access to at least 9 square meters of urban green space [9, 10], as long as it is accessible [11], safe [12], and functional [13]. In 2016, Mercer's Quality of Living Survey named Vienna the most livable city in the world, with 120 square meters of urban green space for its 1.7 million residents. Singapore, the world's third densest metropolis, offers each of its citizens about 66 square meters of urban green space. It's vital since the most livable city is one with enough green space for its citizens [14–16].

4. VISION ZERO

Vision Zero is a global movement aimed at eliminating traffic-related fatalities and casualties through a systematic approach to road safety. This strategy is founded on the notion that traffic injuries and deaths are both intolerable and preventable.

Oslo, Norway's capital, has been designated a "Car-Free City". Many new pedestrian paths have been added, and one street has been converted to a mixed-use area. Two-thirds of the space in the city is dedicated to pedestrians and other municipal activities. Throughout the city, playgrounds for children and families have been created. [17]

Oslo proves that car-free cities are not beyond reality. A city with no cars, a strong public transport network, and a supportive community can exist, making its citizens healthy and happy. More green space, less pollution, a more aesthetically pleasing environment, fewer accidents and casualties, better health, a raised sense of community and togetherness are all achievable with vision zero.

5. PUBLIC TRANSPORTATION

Transportation accounted for 29 percent of the United States' total emissions of 6.4 billion metric tonnes of carbon dioxide equivalent in 2017, according to the U.S. Department of Transportation (US DOT) [7] and its carbon release make for a large and complicated matter.

The Transit system is often referred to as a city's "lifeline". High-density movements necessitate the use of high-capacity means of transportation like the bus, light rail, and metro, which are less expensive, more energy-efficient, and take up significantly less space than private automobiles. Automobiles, unlike public transportation, are only available to those who own and are capable of operating them.

As Peter Calthorpe speaks [18] about the importance of pedestrian-friendly walkable cities, focusing on Available, Affordable, Efficient, Convenient, Sustainable (AACES) Transit systems must be our prime focus. A rich metro network is highly essential in a city going car-free. Optimal metro connectivity is where the network is strong and as quickly as possible, but also ensuring no extreme linkage.

To promote walking, we consider an average of 10,000 steps per day and the U.S. Department of Health and Human Services recommended 30 minutes brisk walk, five days per week, as a benchmark for the minimum number of steps a normal individual should cover daily, and divide the city into circles of the radius of 0.8 km which is 10-minute walking distance (3 to 4 miles per hour is typical for most people. [19]) or 1049 steps using a conversion factor value 1312.33595801. The centre (approximately. based on 3E explained in section 7. Algorithm) of each of these circles serves as a metro station. Thus, the distance between two adjacent stations comes out to be 1.6 km.

To deal with the inner gaps (which we call "packing left-outs") due to circle packing, which increases the station reachability distance for a person outside the 0.8 km radius of three adjacent stations, we reduce the diameter to 1.4 km. This is a significant finding backed by existing metro systems around the globe. According to the data analysis we performed on these metro systems, the average distance between two stations is 1.2 km [20].

6. URBAN LAYOUT

We studied various urban layouts and decided to use the grid plan and fused grid plan. A fused grid is a scaled-up version of a grid layout. Long, wide streets cut through the blocks to make transportation and navigation easier. In addition, each block was shaped into an octagon with chamfered corners to give the effect of being 'cut off'.

A. Grid Plan

Grid Plan also known as Grid Street Plan, Gridiron Plan is a type of urban planning technique where each street and road intersect at right angles thus forming a grid.

- Advantages
  - Cost-Effective as the cost is inversely proportional to the width of the street.
  - Maximum land use thus solving the packing problem.
  - Lower vehicle speeds due to frequent intersections result in fewer accidents.
- Disadvantages
  - Uneven landscapes restrict the model.
  - Less rainwater retention capacity (high as 30%).

- The frequency of intersections is a problem for pedestrians, bicycles, and people with physical limitations.
- Grid is considered to be the least safe with respect to other layouts.

B. Fused Grid

Fused Grids are a variation of Grid Layout with each grid larger in size and the grid consisting of cul-de-sacs or crescents. Each grid forms precincts or quadrants of the size of 40 acres or 400 m^2.

- Advantages
  - Increase in walkability compared to the conventional grid.[22]
  - Maximum land use thus solving the packing problem.
  - Neighbourhood streets exhibit low traffic volume thus falling in noise and air pollution.[23]
  - Traffic Congestion and the time delay are low during peak hours.
- Disadvantages
  - Uneven landscapes restrict the model.
  - Three-way intersection rather than a four-way intersection, thus being less safe. [24-26]

C. Concentric Zone Model

The Concentric Zone Model is one of the pioneering models to illustrate urban social structures. The model includes different zones in concentric circles such as Business District at the very centre, Factory Zone, Transition Zone mixed of residential and commercial uses, better quality middle class homes, and Commuter Zone at the outer circle of the city.

- Advantages
  - One of the simplest models to be designed.
  - Stress on economic development.
- Disadvantages
  - Uneven landscapes restrict the model.
  - The model does not fit the polycentric cities.
  - Intercity Transportation is difficult.

7. ALGORITHM

The project uses data acquired from Google Earth Engine, implementing a machine learning model for urban layout classification and Open Street Maps data for existing site edifices.

A. Geographic Coordinate and Landscape

The very first step includes fetching the landscape coordinates of the user's interest. The extraction process is carried out by Google Earth Engine API [27]. It provides the location geometry in the form of ee.geometry data type. Using this we extract the coordinates of the location and its bounding boxes for further planning and usage. As per the World Bank data [28] on population growth, we have considered the global average 2.5 %. This has been considered the bounding box of the city landscape for foresight expansion.

B. Examine Existing Edifice

While building a city, there can be existing settlements, forest areas, water bodies, and industries. For such situations, we either remove it if it is not contributing to the city or preserve it if it supports the sustainable mission. For identifying existing structures, the OSMnx library [29] comes in handy. OSMnx is a Python library for obtaining OpenStreetMap data and modeling, projecting, visualizing, and analyzing real-world street networks and other geospatial geometries using OpenStreetMap data.

Once data is fetched, we categorize each data variation separately. These locations are classified into ones that can be discarded and others that are to be preserved. We create a city-masked image by omitting those regions with edifices. This image is essential for Rail Network Generation (explained ahead).

C. TAGEE

TAGEE [30], an acronym for Terrain Analysis in Google Earth Engine, helps in calculating terrain attributes such as slope, aspect, and curvatures, for different directions and geographical extents. These attributes helped in understanding the terrain design and structure and its suitability for efficient urban layout. The landscape is divided into smaller sections using the Cut Polygon algorithm. We have taken into consideration the terrain analysis of the complete landscape and along with it the terrain analysis of smaller sections of the landscape. Using this algorithm, we have analyzed 18 major cities in the world and used the extracted data to train our machine learning model, explained in the next section.

D. Urban Layout Classification

Urban Layout is a very important aspect of Urbanization. The urban layout of the landscape area is decided based on its altitude, geographic conditions, and other terrain-related attributes using a machine learning model and data generation using the ResNet model.

The Cut Polygon algorithm explained earlier is also used for this process as well. For each small geometry of the landscape, the pre-trained ResNet model [31] is used to figure out the urban layout of 18 cities into smaller sections. The whole data includes around 88 features that can lead to multidimensionality problems. Thus, we used PCA or Principal Component Analysis for reducing features with similar trends and correlations. On applying PCA, 88 features boiled down to 13 features. Next, we applied different machine learning algorithms to our dataset. Amongst, Random Forest Classifier proved to be efficient with an accuracy of 64%.

When the user's landscape is provided, it will be divided into small sections with respect to the bounding region of the landscape. For each section, an urban layout - grid or radial is predicted using the Random Forest Classifier discussed earlier. Using the predicted data, an image is created with colors describing each urban layout. With the help of the computer vision technique, centroids of each color are calculated. These centroid values will be passed on to the next phase of city road generation.

E. Generative Tensor Field XStreamlines

Tensor fields are the basic building blocks of road network generation. Use of tensor fields is a procedural method for the generation of roads. A tensor field is a continuous function that associates a tensor T with every point p = (x, y) ∈ R^2. Eigenvectors decide the curve of the road. Major and minor eigenvectors are always perpendicular in the plane. XStreamlines are a very important concept that describes the curve along with the eigenvector fields. The frontend UI, City Generator Simulator [32] [33], we referred to is a city layout generation simulator that generates imaginary maps with no on-field points and attributes taken into consideration. It has provided a clear picture of the project. We have made remarkable changes as per our needs as our outputs are based on a range of different parameters as discussed in earlier sections.

As the City Generator Simulator provides a imaginary city map, we have normalized the whole coordinate system with respect to the bounding box of the landscape. The centroid values we have calculated in the last section for urban layouts are used for center, size, and decay value. The decay value denotes which centroid will be more powerful and have more impact on nearby tensor fields when two or more centroids are in the proximity of each other.

While researching the project, we came across GCPN, Graph Convolutional Policy Network [34]. GCPN uses a graph-based structure to optimize the provided goals with respect to a given pre-defined set of rules. Though the GCPN paper has a research study in chemistry and drug discovery, a similar use case can be applied to road network generation but due to a very handful of content is available on Graph Neural Network we are still understanding the concepts and will apply the same to the project in the future.

F. Rail Network Generation

Along with the road network, the railway network system is an important part of urban infrastructure. While planning the rail network, we encountered a few studies and derived a value of 1.6 kilometers for the distance between two stations. Thus, for generating a rail network we had stationary and fixed nodes and now the challenge was to connect these nodes. We first had thought of connecting each node to all other nodes and we'll be doing pruning to reduce complexity. Unfortunately, this method is computationally not viable as in a fully connected graph of 100 nodes, the edges would be around 5000 and will increase exponentially. Thus, we come up with a solution of using graph-based algorithms i.e., Dijkstra's Algorithm and MST Algorithm.

Dijkstra's algorithm is used to find the shortest path between the source node and the destination node based on some parameters such as distance or weights.

MST or Minimum Spanning Tree algorithm connects all the vertices together of the input graph. The solution graph avoids any cycle in the graph and provides an optimum solution for our problem.

So, as we have the fixed nodes on the graph, we cluster the nodes into individual clusters. Now we select points in each cluster with respect to other clusters based on the Euclidean distance. So, for n clusters, there can be 1 node for all (n-1) clusters or (n-1) nodes, each for each cluster. For inter-cluster connections, we are using Dijkstra's algorithm. Now considering the connections within the cluster, we are applying the MST algorithm for efficient intra-cluster connections.

Another point to consider here is what if the node is plotted in place with some existing structure that can't be displaced such as a forest or historic place. For such a situation, we are using the city masked image mentioned in the Examine Existing Edifice section. This image will help in deciding whether to consider a point if it is in the core of the forest or shift that point, if placed on the edge of the forest or the historic place.

Keeping in mind the future expansion of the city, we have placed a few stations outside the user's region of interest within its bounding box.

While researching rail network generation, we came across Link Prediction using Graph Neural Network [35]. Link Prediction is helpful in predicting the edges between nodes based on parameters such as the number of adjacent nodes, the weight of nodes, adjacent edges, transitive edges, etc. We are working towards this by incorporating it into Urbanization.

7. IMPLEMENTATION

On covering the different algorithms used in Urbanization, let's look at the user implementation of it.

1. User Input

Users are provided with 3 different input options such as latitude-longitude of the location, search bar for the nearby region, and upload geojson file type of the location.

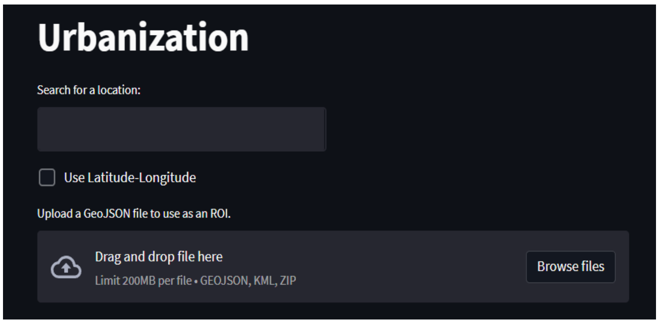

Figure 2: Urbanization UI

Next user can plot his region of interest on the earth engine embedded map. Along with the region of interest its bounding box is also captured and stored.

The coordinates and bounding box values are normalized between 0 and 1 for each migration to other sections of the project.

Figure 3: User Input on Earth Engine Map

2. 3E - Examine Existing Edifice

Looking for existing settlements or structures and creating a city-masked image required for Rail Network Generation.

Figure 4: City-Masked Image representing 3E

The white color indicates some kind of settlement, high altitude terrain, waterbody, or forest area. While the black region is one where we are going to plot our city.

3. TAGEE and Urban Layout Classification

Figure 5: Urban Layouts Heatmap

Now for the bounding box, the terrain details and attributes are extracted using TAGEE. This data is further used for predicting urban layout. Ahead we are generating an image describing urban layout distribution. Orange, blue, and green denote grid, organic and radial layouts. Centroids of each layout are stored in JSON data type.

4. GTX - Generative Tensor Field XStreamlines

As discussed in the earlier section about GTX, it plots a landscape wide tensor field as shown in the figure. The red dots on the tensor field are the centroids calculated for urban layout prediction. These dots will form the center for each layout and can influence the tensor fields in its proximity.

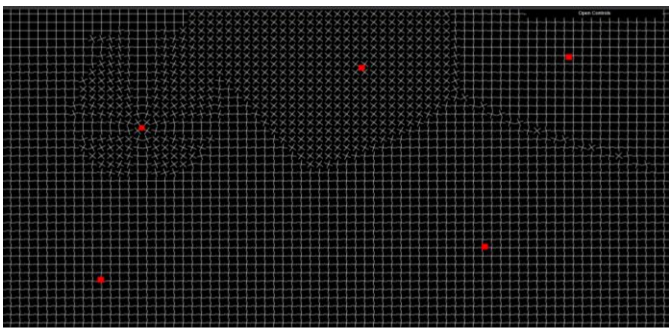

Figure 6: Tensor Field with urban layout centroids

5. Optimized Blueprint Cartography / Output

Optimized based on different parameters taken into consideration right from the beginning, the following city blueprint is generated using Urbanization. It has included all types of buildings, major and minor roads, parks and forest, and water bodies with appropriate and efficient road designing and building placement.

Figure 7: City Blueprint generated using Urbanization

6. Rail Network Generation / Output

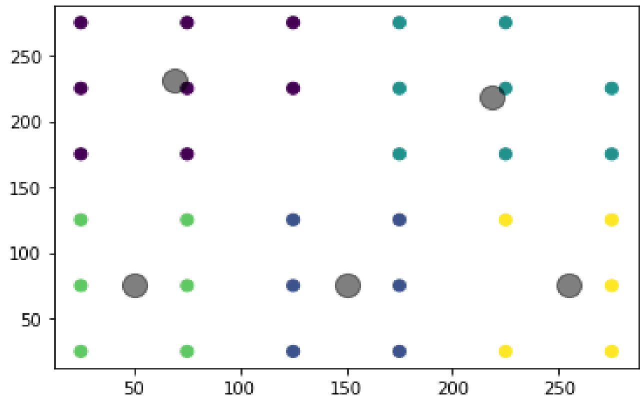

Figure 8: Nodes with their centroids for rail network

As explained earlier in Algorithms section, we have plotted the centroid of each cluster. Based on these centroids Dijkstra and MST algorithms are applied for the final result presented below. Currently we have demonstrated the algorithm on a example set in prototype phase and we are working on its full-scale deployment into Urbanization.

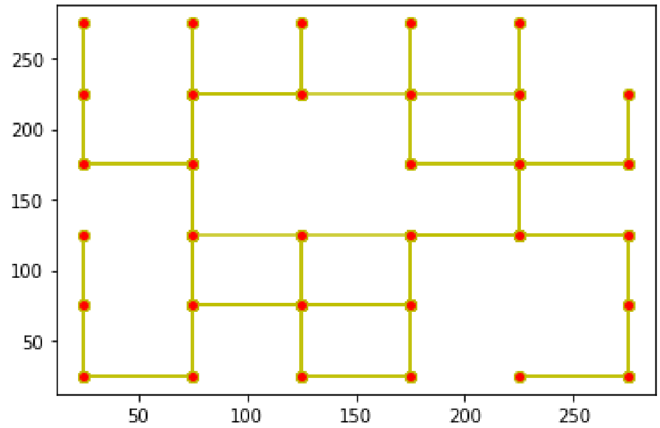

Figure 9: Rail Network Generation in Prototype Phase

8. CONCLUSIONS

To summarise the findings of the study, the problem of unplanned city transits is a huge setback for the urban cities, and it must be addressed as soon as possible. Urbanization is an online application that aids the urban planners to design and plan transit systems of city with more sustainability. Urbanization - Smart City Smart Planner employs Generative Tensor field Xstreamlines (GTX). Urban Planners using Urbanization, provide the geographical area. The data is sent on to the GIS for area specifications and GTX for road planning and micro blocks designing. Taking into account all the elements stated above regarding technology implementation and ecologically soundness, Urbanization builds a blueprint for the region provided and suggests some guidelines that can benefit the planner. Urbanization does not replace the role of urban planner but instead it aims at reducing the burden and designing more sustainably.

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BIOGRAPHIES

	DILIP JAIN BE Computer Engineering, SIGCE
	SIDDHESH KADAM BE Computer Engineering, SIGCE
	ADITYA MAHIMKAR BE Computer Engineering, SIGCE
	PROF. VAISHALI YEOLE Computer Engineering Dept, SIGCE