Smart Master Plan and 3D GIS Planning Support system—A Case of Chennai City, Tamil Nadu, India

Kusum Lata, Faiz Ahmed Chundeli, and Adinarayanane Ramamurthy

Abstract As 3D modeling tools and methodologies become more widespread, urban planners are beginning to think three dimensionally to address the ever-growing urban concerns, particularly in dealing with the built environment. In this chapter, the viability and necessity of using 3D GIS as a planning support system for smart master plan are examined. The interactive, dynamic, and information-rich 3D model used in this research provides an innovative method for sharing urban planning data with both urban planners and the general public. This study's methodological approach shows how 3D models can be employed as a smart master plan tool in regular urban planning activities. Every city has its planning procedure, and industry standards must be followed when integrating 3D models and 3D volumetric evaluation methodologies. More research into customization in the integration of 3D models is needed, from data collecting tactics through analysis and display. The research described in this chapter has aided in the expansion of 3D city model applications in urban planning toward a smart master plan approach. Although 3D city models improve analytical powers, adopting them into daily planning procedures necessitates more study in terms of greater analytical capabilities and adaptability. For the assessment and monitoring of growth and development, 3D technologies are an unavoidable prerequisite. Tools that are easy to use and free to download, as well as those that integrate spatial and non-spatial data more extensively. By combining 3D volumetric studies into day-to-day operations and planning processes to understand the threshold limits for growth and development, urban planners, city administrators, and lawmakers will be able to plan more efficiently.

Keywords 3D GIS · 3D city models · Urban planning · Decision support tool

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K. Lata
Indian Institute of Public Administration, New Delhi, India

F. Ahmed Chundeli · A. Ramamurthy (✉)
School of Planning and Architecture, Vijayawada, Andhra Pradesh, India
e-mail: adinarayanane@spav.ac.in

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1 Introduction

Numerous processes, techniques, and studies go into the planning of a metropolitan area. It necessitates a thorough awareness of issues in both horizontal and vertical dimensions. The failure to consider the vertical dimension of a city is currently one of the fundamental shortcomings in urban studies. Urbanization is increasingly taking place on a vertical scale, notably in Asian countries with significant vertical urbanization. The evaluation of the availability of (physical) infrastructural facilities for such an area is limited by a two-dimensional (2D) layout of a city center with skyscrapers. In actuality, 2D drawings rarely reveal an area's vertical volume and therefore put planners' imaginations to the test when imagining a "mental map" of a particular region. Traditional 2D plans limit planners' analytical perspective, and the limits of these designs become more apparent as cities get larger and more complex [1]. In general, urban analysis is limited to two dimensions, making it impossible to study a city's growth and development in three dimensions [2, 3]. Because of the complexity of data integration and modeling, as well as the absence of relevant skills for incorporating 3D models into everyday planning processes, urban planners are hesitant to employ 3D tools, affecting the efficiency and efficacy of the plans generated. This antiquated approach to urban planning and administration must be updated with technological breakthroughs that facilitate efficient planning (Xu et al. 2009). The use of 3D models in urban planning and design is a recent development in which "digital information is transformed into common graphical information," however most applications are limited to representations of the urban environment [4]. This graphical data allows urban researchers to depict and investigate urban characteristics in a variety of ways, including 2D (maps), 3D (built form), and four-dimensional (temporal) forms [5]. For urban planners, it is an opportunity to become familiar with and to integrate these tools for efficient analysis, planning, and designing of urban spaces.

3D models and visualizations are now thought to be more dependable than other traditional representations for gaining a better grasp of spatial data [6]. One of the key advantages of a 3D model is that it realistically depicts the world. Decision-makers and urban planners may get a good picture of how a city will look in terms of its spread and profile by employing 3D city models, which is not achievable with 2D map data. In actuality, 3D city modeling's applications are primarily limited to data visualization and communication. This study aims to include 3D models into everyday urban planning processes to improve urban analysis and planning. Urban planners use geographic information systems (GIS) extensively for planning and analysis utilizing 2D maps. They allow users to overlay data geographically and use it for effective analysis and management of urban space [5, 7]. A variety of analyses can be done using 3D city models created with ArcMap and ArcScene, including attribute and geographic queries, view-shed analysis, shadow analysis, and others [8]. 3D volumetric analysis as a smart city decision support tool for planning, analysis, and decision-making is discussed in this chapter. Furthermore, it has been discovered that the current plan development, implementation, and review mechanism does not meet the legislative criteria. To attain the required goals and objectives, the system also detects a strong requirement for an effective planning support system. This study intends to create such a planning support system, and it's important since it'll provide a methodological foundation for incorporating 3D models into everyday urban planning procedures for better analysis, planning, and decision-making. The potentials of 3D volumetric analyses, as well as their visualization benefits, will be revealed and demonstrated in this chapter.

2 City Planning and Development—An Overview

2.1 Urban Dynamics and Its Complexity

When compared to developed countries, the rate at which Asian cities are developing and the tremendous rate of urbanization are phenomenal. In these quickly rising countries, urban planners face a huge task in addressing the issues produced by fast growth. In places like Chennai, India, urban development plans are traditionally prepared and implemented by hand, utilizing traditional equipment and procedures. The application of CAD and GIS is restricted to mapping. In many urban centers, the inadequacies of traditional methodologies are visible in real development, which has a temporal and geographic irregularity or a temporal and spatial excess of planning. The traditional planning process has several flaws, including a shaky database for plan creation, a plan that isn't comprehensive or holistic, insufficient public participation, and a lack of monitoring and implementation mechanisms [9]. Urban planners are under increasing pressure to solve these difficulties and incorporate new tools and technologies into their daily work. Any technology designed to aid urban planners must be spatially contextualized. In these situations, the most often used applications by urban planners are CAD and GIS. While CAD and GIS systems can provide geographical qualities that aid planners in understanding development pressures, trends, and hotspots, their applicability is primarily limited by 2D designs. In recent years, Asian metropolitan areas have experienced more vertical expansion than horizontal development, necessitating the creation of tools and procedures to aid in the assessment of urban growth in the vertical dimension. When it comes to the provision of physical and social infrastructure, this becomes unavoidable [10]. Concentrated vertical developments imply difficult planning characteristics because voluminous activities must occur within a smaller spatial context.

2.2 City Planning and Development in India: A Glance

In managing growing urbanization, India is facing significant urban planning and development challenges. India's population is predicted to overtake China's by 2025, with more than 1.2 billion people. Existing megacities would account for a large amount of this increase, providing the greatest challenges to India's urban future [9]. The Ministry of Urban Development, the Ministry of Housing and Urban Poverty Alleviation, and the Planning Commission of India are all responsible for urban planning and development in India. These are the key agencies in charge of establishing policies, legislation, and development initiatives, among other things. Town planning departments are in charge of preparing master plans and development plans at the state level [11]. In India, the development plan directs city planning and defines land-use zones for residential, commercial, institutional, and industrial applications, among others [12]. The urban planning process is more or less the same throughout the country following the guidelines stipulated in Urban Development Plan Formulation and Implementation [13].

3 Conventional Plan-Making and Regulatory Mechanism

3.1 Conventional Plan Formulation Process and Regulatory Mechanism

In India, the traditional plan formulation process is represented in Fig. 1. The designation of the plan's goal, which is usually a policy note by the decision-maker based on people's desires, is the first step in plan formulation. The techniques and means of reaching the goal of the strategy are spelled out in objectives. The identification of expected requirements for various activities is the next significant step in plan formulation. Traditionally, the nodal body for collecting and compiling important information from other departments on their plans has been the Town Planning Department. This approach has been ineffective due to the lack of participation and cooperation across the departments [13]. To prepare a plan, urban planners seek information from numerous agencies, which makes the planner's function critical. Plan formulation considers planning theories and principles, planning tools and procedures, norms and standards, and evaluation processes, in addition to the preceding information. In Chennai, a similar plan creation procedure is used, and the booming metropolis is unable to keep up with improvements in the supply of long-term infrastructure to its residents. The advent of new economy bases necessitates a departure from traditional master planning tools and techniques to ensure Chennai's long-term and equitable growth. Though the previous master plan initiatives were successful in providing a strategic direction for the city's expansion, the new Master Plan must be examined for higher floor space index and density to meet the city's expanding demands. The conventional plan-making process has many shortcomings such as a weak database

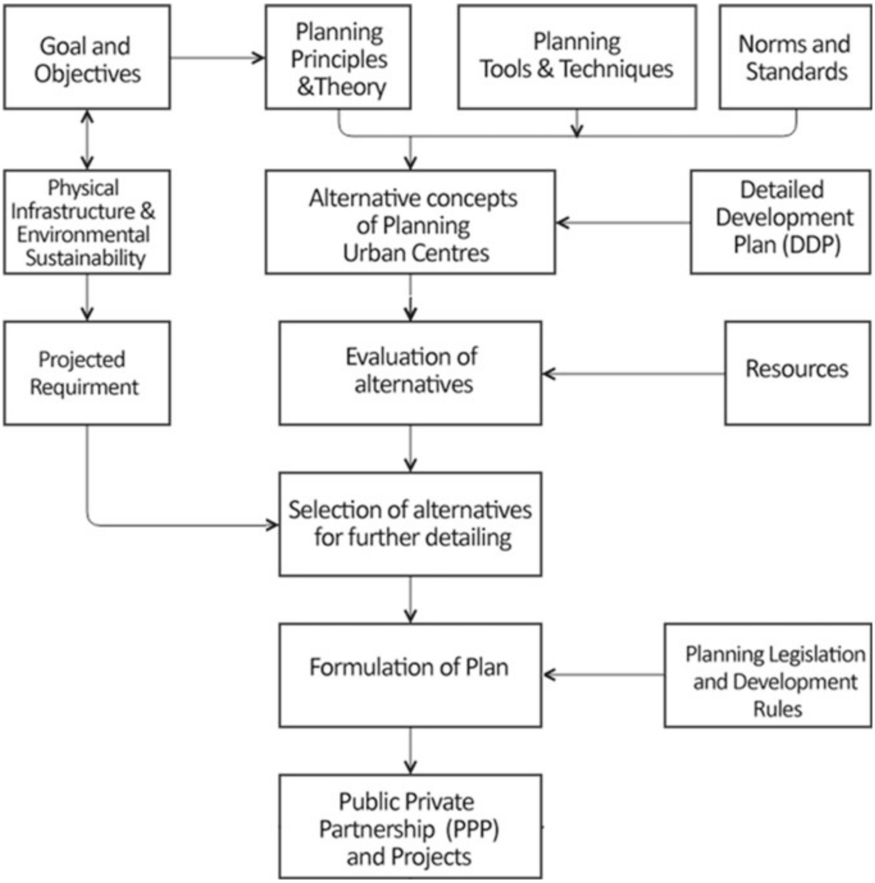


Fig. 1 Conventional plan formulation processes in practice, UDPFI-1996. (*Source* [13])

for plan preparation, the non-comprehensive and non-holistic nature of the plan, inadequate public participation, and lack of monitoring and implementation mechanism [9].

Zoning is a fundamental planning method used in Indian cities to manage urban development, with a set of restrictions affecting land use, density, form, and volume [14]. It's one of the legal tools for regulating urban development. Zoning improves city order [15], serves as an effective design control tool [16], and serves as a legal framework for guiding land use and protecting public health, welfare, and safety [13]. As a result, zoning is a set of requirements [17] that are utilized to implement master plans or development plans, and it is frequently regarded as a regulatory measure held by a city development agency. Zoning is determined by factors such as land use, bulk, height, and building shape [16]. However, traditional methods for developing zoning regulations, such as two-dimensional maps, fail to provide a platform for analyzing existing development and infrastructure. Zoning is the key planning strategy in cities like Chennai. As a result, urban planners must have a thorough understanding of the impact of zoning restrictions on city development. With today's tools and processes, which are mostly based on conventional 2D blueprints, planning for a better future is nearly difficult.

3.2 Overlapping Competencies and Clash of Authorities

The participation of state government agencies in the management of urban issues is a defining feature of Chennai's governance. Public Work Departments (PWD), Tamil Nadu Housing Board (TNHB), Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB), Chennai Metropolitan Development Authority (CMDA), and other organizations are involved in the planning and management of urban services. Due to overlapping abilities and authority conflicts, effective planning and management of urban services are almost impossible. Furthermore, to prevent cities from becoming increasingly unserviceable and unsustainable, India's urban planning and development authorities must embrace advances in planning tools and processes. One of the crucial tasks indicated in this study is the construction of an information-rich city database with dynamic and static city models, as well as cities' critical data that need daily updating. By applying dynamic information systems to existing planning processes that focus on urban-related concerns, urban planners will be able to plan more effectively. To develop such a digital database, Delhi adopted the Geospatial Data Infrastructure Act (2011). This 3D-built environment is included in the database, as well as the full physical infrastructure such as roads, water supply, wastewater, electrical lines, and so on. For cities like Chennai, an authoritative database of this type is critical, since it will prevent overlapping competencies and authority clashes over decision-making, as well as provide up-to-date information on city development.

4 Data Analytics and 3D GIS as Decision Support Tool

4.1 Planning and Decision Support Tool

Assessment of current conditions, generation of alternatives for future developments, and community participation are all frequent components of planning (Abdullah et al. 2005). Existing circumstances must be assessed not just for current development, but also for projecting future requirements, planning, and managing future developments [18]. The Indian planning system is traditionally based on experience and trend analysis rather than scientific planning tools and techniques,as a result, this traditional technique must be reassessed to fulfill modern planning demands with improved and efficient planning processes. Planners require a suitable instrument that can match the scale of their vision, which they have yet to find, for enhanced and efficient planning of urban spaces, which requires complicated processes and procedures [19]. Any decision that has a long-term impact on the built environment, according to Pullar and Tidey [20], must be rigorously assessed before implementation, and computer simulation is one such instrument for assessing the impact of such decisions. Planners rely on the availability, quality, and breadth of information to understand current events and make informed judgments. The final decision-makers in India are not usually urban planners, but urban planners may provide them with complete information in the form of a 3D information-rich city model to help them make better judgments [21]. The development of planning tools and procedures has opened up a world of possibilities for urban planners in terms of analyzing, planning, making decisions, and presenting geographically related data [18]. These advanced tools and methodologies will improve land-use planning decision-making and hence the social and economic elements of planning.

4.2 2D and 3D GIS for Planning

In planning processes that utilize spatial data for analysis, planning, and decision-making, GIS plays an important role [22]. Planners prefer GIS because it can analyze both spatial and non-spatial data [23]. GIS considerably improves the handling of geographical data in planning and management, and it also serves as a useful tool for data sharing across departments. GIS is primarily utilized in India for the creation of maps. A GIS database comprises both spatial and non-spatial attribute data, such as land, buildings, roads, rivers, utilities, social amenities, and transportation. Since the 1960s, GIS has progressed from a 2D to a 3D depiction [24]. With limited analytical capabilities, the third dimension currently serves only as an add-on attribute to 2D designs. 3D GIS is frequently seen as a technical subject including 3D data organization, processing, and display [25]. Many researchers still regard 3D GIS as an extension of 2D drawings, and the traditional 2D database is one of the primary drawbacks of employing 3D city models in urban planning processes. For urban planners, effectively visualizing complex 3D constructed environments remains a difficulty. With the recent breakthroughs in GIS technology on quantitative urban planning and analysis [23], there is a large demand for effective and efficient 3D GIS integration for urban planning objectives for increased analysis, planning, and decision-making [26]. The ability to construct scenarios based on analyses and generate what-if scenarios is a significant aspect of 3D GIS [27, 28]. The data storage and retrieval capabilities of 3D GIS help spatial analysis, planning, and decision-making in two ways: first, they provide rapid and efficient data retrieval and sharing to support planning decisions. Second, it has a built-in 3D urban analytical capability that allows different options to be analyzed [28]. There are several approaches for creating 3D city models, all of which rely heavily on GIS data [29]. Traditional geometric modeling software, such as CAD, which is widely used in Indian planning, is incapable of visualizing big urban environments [30]. For generating volumetric blocks, extrusion techniques

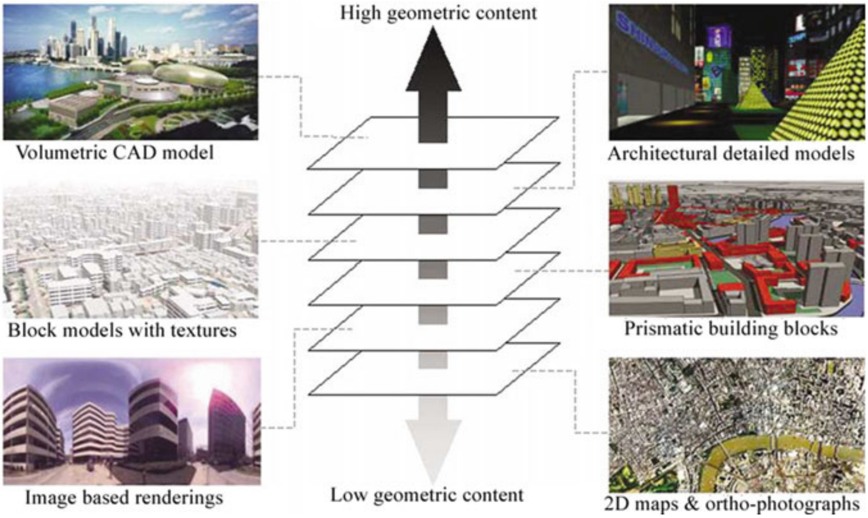


Fig. 2 Shinde's 3D city model typology, based on the degree of reality. (*Source* [28])

within GIS are the most popular approach of geometric modeling of the metropolis [31]. Combining 2D GIS and 3D visualization tools can make urban planning more effective and powerful as shown in Fig. 2.

4.3 Visualization Method for Linking Master Plan and Smartness

The use of 3D GIS has begun to have an impact on the planning profession [23, 32]. 3D GIS is now being used to model urban landscapes and investigate development scenarios, as well as illustrate alternative land-use plans and their influence on cities. 3D GIS models can connect past, present, and potential future developments in the built environment, closely resembling reality [33]. Yin and Hastings [23] demonstrated the use of 3D GIS in visibility analysis, and the model they created was used to evaluate zoning regulations in New York City concerning building height restrictions. Shiode and Yin [34] employed 3D GIS to analyze the built environment of cities from 1927 to 2000. By including zoning restrictions into the simulation model, development agencies all around the world have constructed virtual city models for controlling and managing urban development [35]. With its visual and analytical capabilities, a 3D GIS model will enable urban planners to effectively explain future development plans [28, 33]. 2D GIS maps provide for a wide range of geographical analyses [36]. GIS models are coupled with rich attribute data that can be utilized for spatial query and analysis. The application of geographic data in the form of 3D GIS has expanded as a result of the use of 3D data. Building height data is generally used to create 3D GIS models, which are normally created by 2D extrusions of the GIS dataset in the vertical direction [37]. Since 3D GIS is built on a 2D GIS database, a wide range of spatial analysis is made possible, such as view-shed analysis, spatial query, and 2D, 3D simulations [23].

4.4 Demands for 3D City Modeling and Types of 3D City Models

Urban planning entails several complicated processes and procedures. Planning involves assessing existing conditions, developing development plan concepts, and including the public in the planning process. Forecasting future development necessitates a review of current facilities and services to make plans. The methods and approaches used by Indian planners are still traditional, with several restrictions. Urban growth is a dynamic process, and city planners need better decision-making tools to keep track of current events and estimate the future [38]. Planners need an appropriate tool for analysis, planning, and decision-making to improve planning processes that entail complicated processes, procedures, and analyses [19]. Although the urban environment is 3D, human perceptions of it are either 2.5D or 3D, hence any examination of the built environment must be done in 3D [39]. 3D models and visualizations are now thought to be more dependable than other traditional representations for gaining a better grasp of spatial data [6]. One of the key advantages of a 3D model is that it realistically depicts the world. Decision-makers and urban planners may get a good picture of how a city will look in terms of its spread and profile by employing 3D city models, which is not achievable with 2D map data. According to Marr [39], the reasons for not using 3D city models in urban planning processes are either conceptual or technical. By conceptual, he means that 3D city models are not entirely necessary for explaining complex-built environments, and by technical, he means that there is a lack of data, data structure, and inadequate tools for integration. With advances in planning tools and techniques, one can say that there would be no more technical issues in nearby future and the only reason for not opting for 3D city models is conceptual in nature [25].

4.5 Applications of 3D City Models in Urban Planning

There has been a significant increase in the use of 3D city models over the last two decades [40]. Currently, 3D city models are used extensively in various fields of urban studies, for example, in the visualization of the urban setting [41, 42, 43, 44], urban land-use planning [45], 3D cadastral mapping [46, 47, 48], environmental planning and simulation [49, 50], and in studies of transportation [3], emergency response [1, 51], and the built environment [28, 52]. Although the application of 3D models to urban planning is not new, their application to the analysis of micro-level urban problems is a novel topic of research [45, 53]. A well-designed 3D city model improves the planning process, and with technological advancements, the 3D model appears to be more advantageous than 2D blueprints [54]. The use of a 3D city model allows for a more thorough investigation of the data. When compared to 2D layouts, the display of the current condition and predictions is easier and more instructive [54]. Cities can currently be modeled in 3D using a variety of techniques [55].

4.6 Current Research in Applications 3D City Models

While developing a 3D city model, the objectives of making such a model are very crucial. 3D models can be generated with distinct “levels of detail” (LOD) as required by the application and the users [43]. The concept of LOD is crucial in 3D city modeling,it indicates the real world and the data acquired for modeling [56]. An appropriate 3D city model should be chosen based on the purpose of a project. According to Shiode [28], the degree of reality is used as the important factor in creating a typology of 3D city models. Shiode [28] classifies 3D city models into six categories based on the degree of detailing, Fig. 3, which are as follows: (i) 2D digital maps and ortho-photographs,(ii) image-based renderings, (iii) prismatic building blocks, (iv) block models with textures, (v) architectural detailed models, and (vi) volumetric CAD models. Shiode [28] also classifies 3D city models into four categories based on their analytical capabilities, which are (i) aesthetic models are intended for illustration and aesthetic appreciations of development projects for authorities and the general public. Though aesthetic models are of the highest degree

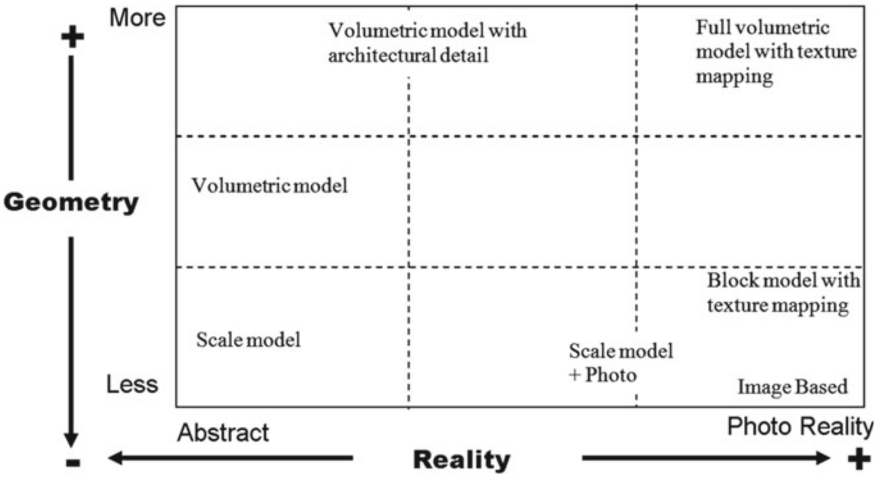


Fig. 3 Summary of types of 3D city models. (*Source* [57])

of reality, their analytical functions are very limited. (ii) Property models are models equipped with one or more analytical functions, for instance, the view-shed analysis, dynamic building blocks, and some basic querying functions. (iii) Full analytical feature models are the ones equipped with more multiple analytical functions, such as view-shed analysis, shadow analysis, scenario-based simulations, etc. (iv) Hybrid models are the combination of physical models and virtual reality models used for project appraisals.

As illustrated in Fig. 3, divides simulated 3D city models into three categories: volumetric model, image-based rendering, and hybrid model. The detailing of a volumetric model can range from simple geometric block models to intricate architectural detailing. Shiode [28] defined image-based rendering as "panoramic image-based modeling," in which a sequence of images is wrapped to form a viewpoint. Even though image-based modeling is less expensive and produces a more realistic depiction of the world, this model lacks 3D geometry. Hybrid models combine volumetric and image-based modeling approaches to generate realistic 3D city models, with a volumetric model covered with my texture mapping techniques. Based on the project's specifications, an appropriate 3D model with the required level of detailing is selected.

5 Application of 3D GIS and City Model for Smart Planning

5.1 3D Data Analytics and Simulation

There is a significant rise in the use of 3D city models in urban planning processes [33]. 3D models can be incorporated in several planning process stages, such as data collection and checking, analysis, prediction, and presentations, for superior understanding of real-world development. The modeling and visualization of different information and data at each stage of the planning process make modeling complicated and time-consuming. The application of 3D city models in the urban planning context varies from concept generation to decision-making and public participation. [36] explains the applications of 3D city models in 12 arenas such as (i) emergency services, (ii) urban planning, (iii) telecommunication, (iv) architecture, (v) facility and utility managements, (vi) marketing and economic development, (vii) property analysis, (viii) tourism and entertainment, (ix) E-commerce, (x) environment, (xi) education and learning, and (xii) city portals. Shiode [28] classifies the application of 3D city models into four broad groups, such as (i) planning and design, (ii) infrastructure and facility services, (iii) commercial sector and marketing, and (iv) promotion and learning of information on cities. The application of 3D city models in planning and design varies from site location analysis, community planning, and public participation. 3D city models are the best way for communicating with the general public, analyzing the data available for planning and design.

The provision of urban infrastructure services such as road network, water supply, sewerage, and other physical and social infrastructure facilities can be improved by applying 3D city models for planning, design, and maintenance [58]. 3D city models are also used for commercial purposes, such as to locate commercial and tourism spots, etc., and also in real estate businesses for selling and buying properties. 3D city models create a platform for people from different walks of life, to learn about cities. Kim [57] broadly categorizes the applications of 3D city models in urban planning and design into seven. (i) Public participation, 3D city models act as a communication tool to facilitate public participation in planning processes. 3D city models create a better platform for sharing information with the general public, on concepts, and design proposals. A better feedback mechanism for effective decision-making is made possible with the help of 3D city models. (ii) Visual impact analysis is another application of 3D city models, where it can facilitate the evaluation of design alternatives and attain the best solutions based on context and aesthetics. (iii) Development control, 3D city models have been used for controlling and monitoring development using visualization. (iv) Time-dependent phenomena, iconographic study, changes in the growth pattern of cities, shadows study, and distribution of population density are visualized using 3D city models for a better understanding of cities' growth. (v) Historic preservation, 3D city models are also used in historic preservation by adopting comparative analysis using visualization techniques of the proposed development and the existing historic sites. (vi) Dispute resolution, 3D city models can produce accurate visualization of a given development proposal to facilitate informed decision-making. This gives the user an accurate understanding of the size of the projects and their context and it helps in solving various disputes that arise. (vii) Environmental study, 3D city models can be used extensively for analyzing microclimates in built environment, in areas such as wind tunnel effects, humidity, sunlight, temperature variations, etc. It will also help in understanding the concept of the comfort factor in urban environments. However, most of these models can perform only limited analysis, despite being photo-realistic in nature and these models cannot provide additional spatial queries and analyses [28, 33].

5.2 3D City Models in Urban Planning

Non-specialists and the general public find conventional 2D plans difficult to understand, hence elaborate interpretations by professionals are required to comprehend the system [24]. According to current research, these restrictions can be overcome by incorporating advanced 3D city models into urban planning procedures [24, 59]. The use of advanced 3D city models for quantitative assessment improves comprehension of the complex urban system, as well as resolving urban planning difficulties and producing better planning outcomes [24]. According to the results of the tests, the visual preferences of designers and non-designers are similar since they both read 3D models in the same way. Planners and the general public can use a 3D city model to better understand complicated urban environments and the effects of anticipated future projects [23]. "A 3D city model speaks in common visual language, that people can understand" [23], as compared to conventional 2D maps [23, 59]. Indian cities need an efficient planning system that deals with rapid current and future urban developments [58]. There is a strong need to develop a planning support tool, to achieve desired goals and objectives, generate alternatives, and manage urban development. 3D city models with inherent visual and analytical capabilities are essential in today's planning practices for a better understanding of urban environments and enhanced decision-making [37, 60, 61]. 3D city model can contribute to bringing efficiency and effectiveness in everyday planning processes, by enabling urban planners to understand the present urban environment and envision an appropriate future [37]. 3D city model for spatial–temporal analysis that will support planning and design of urban environment has been recently developed [37]. 3D spatial–temporal model acts as a tool for representing urban growth change and performing spatial queries. Static models are interpreted by Yin and Shiode [37] as a single news chapter picture of the subject, representing a single point of view on the urban environment, whereas dynamic 3D cities are modeled as continuous television news feeds. Building a 3D city model that reflects the past, present, and future urban environment by giving information on built-environment intensity change [37] and information on physical and social infrastructure carrying capacity requires more research [58]. Such 3D models not only assist urban planners in performing enhanced analysis, planning, and decision-making but also aid in bringing planning transparency to the general public through effective dissemination of planning information. More research into the integration of data on population change in 3D databases will aid in the dynamic assessment of the relationship between population change and urban development [37]. This research attempts to integrate population data in a 3D city model for the quantification of physical infrastructure that will enhance urban planning processes.

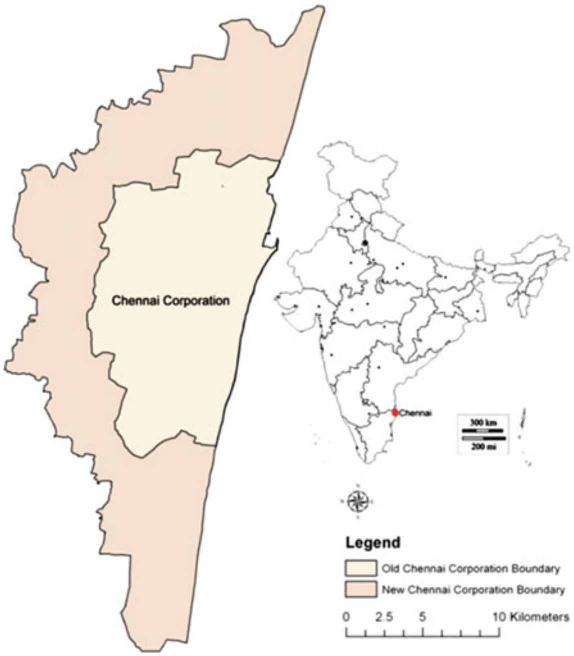
Planners have always used visual media to communicate with diverse persons involved in planning processes [36], and visualization has a long history in urban planning. There is a lot of use of city models in urban planning processes [62, 63]. Visualization has evolved as one of the most powerful decision support tools, thanks to recent improvements in digital computation techniques [24]. According to Langendorf [64], visualization has three purposes: first, to aid in the generation of alternatives,second, to aid in the understanding of complex urban systems,and third, to facilitate communication processes. 3D city models are useful for connecting with the real world [65]. Cities are thought of as living entities that alter and evolve [66]. The development of 3D city models is unavoidable, given its analytical capabilities in spatial analysis, planning, and decision-making [63, 65]. Expertise in the use of 3D city models for quantitative assessments of the built environment is required for improved analysis, planning, and decision-making [24, 58, 63]. This study is based on the preceding literature and aims to learn how to use 3D city models as a tool for quantitative assessments in urban planning procedures inside the Indian planning system. Today, many cities are actively involved in developing virtual city models for addressing various urban issues [24], and it is also anticipated that soon, there will be a further increase in the use of virtual city models in urban planning processes. The digital 3D city models in planning are expected to improve the planning processes, by making spatial and non-spatial data more accessible and easier to understand and engage by various stakeholders, including the general public [24]. The social applicability of 3D city models in urban planning processes is the essence of 3D visualization.

6 Dynamics of Chennai City Study Region

6.1 History of Urban Planning in Chennai

The Chennai Metropolitan Area (CMA) includes the Chennai Corporation's territory, as well as 16 municipalities, 20 town panchayats, and 214 villages [67]. As seen in Fig. 4, the CMA or Chennai District consists of the Chennai Corporation as well as portions of the Kancheepuram and Tiruvallur Districts. The Chennai Metropolitan Area (CMA) has a total administrative area of 1192 km^2, with a City Corporation area of 426 km^2 [67]. Before this, The Madras Town Planning Act was enacted in 1920, and it was used to plan the city of Chennai. Although the town planning legislation was passed in 1920, the first master plan for Chennai was not completed until 1975, and only a few Town Planning Schemes were developed (CMDA, Draft Master Plan-II for Chennai Metropolitan Area-2026, 2007).

Fig. 4 Study area location map. *Source* [67]



6.2 Critical Review of Urban Planning in Chennai

Chennai has a long and illustrious history of planning. In Chennai, zoning and building by-laws are still two of the most important tools for modern city planning [14]. In addition, master plans aim to create a physical pattern of land use and transit routes for the city and the surrounding metropolitan area. As a result, master plans serve as a template for other government bodies to create sector-specific plans [67]. The city of Chennai's second master plan was completed in 2008 and is currently being implemented. By 2026, the second master plan aims to make Chennai one of India's most livable cities, with a high quality of life and a sustainable environment. However, the rules and master plans for planning do not address how to achieve this aim. The master plan also fails to consider how Chennai's urban shape is changing. It also doesn't address how climate, landform, established urban fabric, existing physical and social infrastructure services, and other factors were considered when master plans were created. Various planning schemes, policies, two master plans, and development laws developed by the Development Authority over the past 53 years are understood to have governed the evolution of Chennai City. Chennai City planning began in 1957 with a basic town planning scheme and ended in 2008 with the second master plan, which included land-use zoning and development restrictions as a regulatory mechanism for the city's expansion. With two-dimensional plans, the master plan's spatial strategy and land-use planning adhere to zoning and development restrictions that apply to various zones. Urban planning and development were based on two-dimensional zoning and master plans.

6.3 Study Area Location and Selection

Chennai is one of India's major metropolises. It is the country's fourth largest metropolitan metropolis and is located on the Bay of Bengal's coast. The Chennai Metropolitan Territory (CMA) has a total administrative area of 1192 km^2, with a new Chennai corporation area of 426 km^2, as indicated in Fig. 5. In 2011, Chennai City Corporation had a population of 7.8 million people [68]. Chennai is South India's most important cultural, commercial, educational, and industrial center.

6.4 Profile and Land-use Classification

Kannadasan Nagar is one of Chennai Corporation's planning units [67]. As indicated in Fig. 5, it makes up the southeast corner of Chennai's Theagaraya Nagar (T. Nagar). T. Nagar is said to be India's largest retail district. Kannadasan Nagar is a residential activity facilitator. Commercial activities are restricted to the study area's outskirts. The planning units cover a total area of 0.69 km^2. The Kannadasan Nagar area's

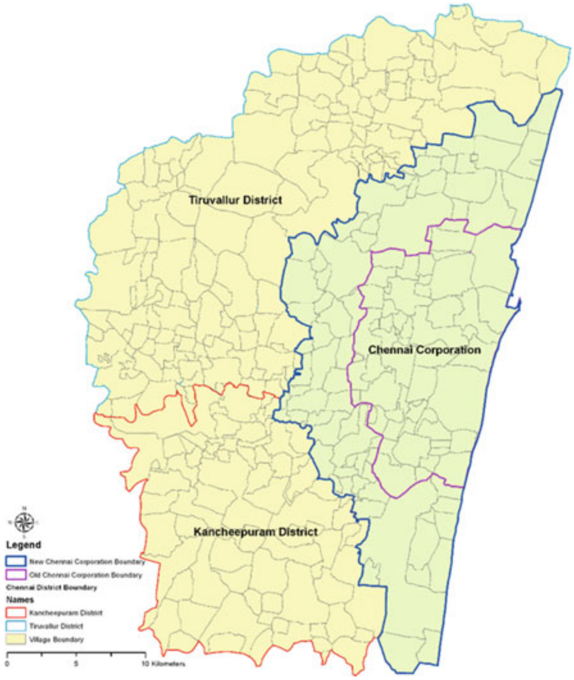


Fig. 5 Chennai metropolitan area—administrative boundary

Detailed Development Plan (DDP) was completed in 1980. According to the current field survey, the study area's population is around 77,270 people, with 917 various types of buildings. The research area is defined by two roads: South Boag Road on the east and Venkatanarayana Road on the southwest. There is also a neighborhood park called "Natesan Park" in the study area. As indicated in Fig. 6, the overall study area is 0.69 km^2, with 53% of plots being residential, 0.17% commercial, 18% mixed use, 8% institutional, and 2% parks and playgrounds [67]. Road and street networks take approximately 19% of the overall study area.

6.5 Data Collection Techniques

Plot and building-level data are two types of attribute data connected with 3D information-rich base models. The plot border, area, frontage, land uses, acceptable floor space index (FSI), maximum permissible building height, road connectivity, utilities (water supply and wastewater network data), and so on are all included in plot-level data. As indicated in Fig. 7, plot-level data for the research region was acquired from secondary sources in the Chennai master plans [67]. The footprint of the building, the number of levels, and the purpose of each floor are all included in the building-level data. As illustrated in Fig. 7, the footprint data was gathered

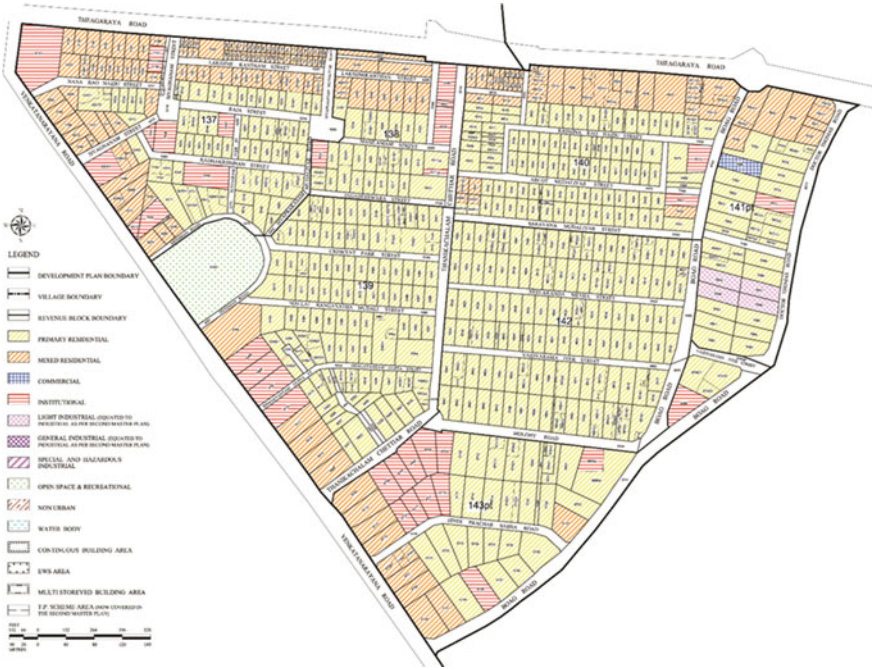


Fig. 6 Kannadasan Nagar area, DDP. *Source* [67]

using Google Images (2013 data), and the number of floors and uses at each level were estimated using primary survey data. To reduce the errors when representing the realistic built environment, complete enumeration of the study area is carried out. Table 1 shows the total residential, commercial, and institutional built-up area at each floor level, which was obtained from a primary survey and was also used to quantify the water supply and wastewater.

7 Area-Specific Analysis of the Study Region

7.1 *Building Footprint Analysis*

Using 1980 and 2013 datasets, a similar technique as depicted in Fig. 7 was adopted to create a 3D information-rich model of the study region, Kannadasan Nagar. To assess the intensity of developments and their impact on the carrying capacity of the physical infrastructure (water supply and wastewater) network in place, a status analysis of both the 1980 and 2013 datasets was conducted. The goal of this research's conceptual framework is to create a model that evaluates the relationship between physical development and all other physical and social infrastructure needs in the

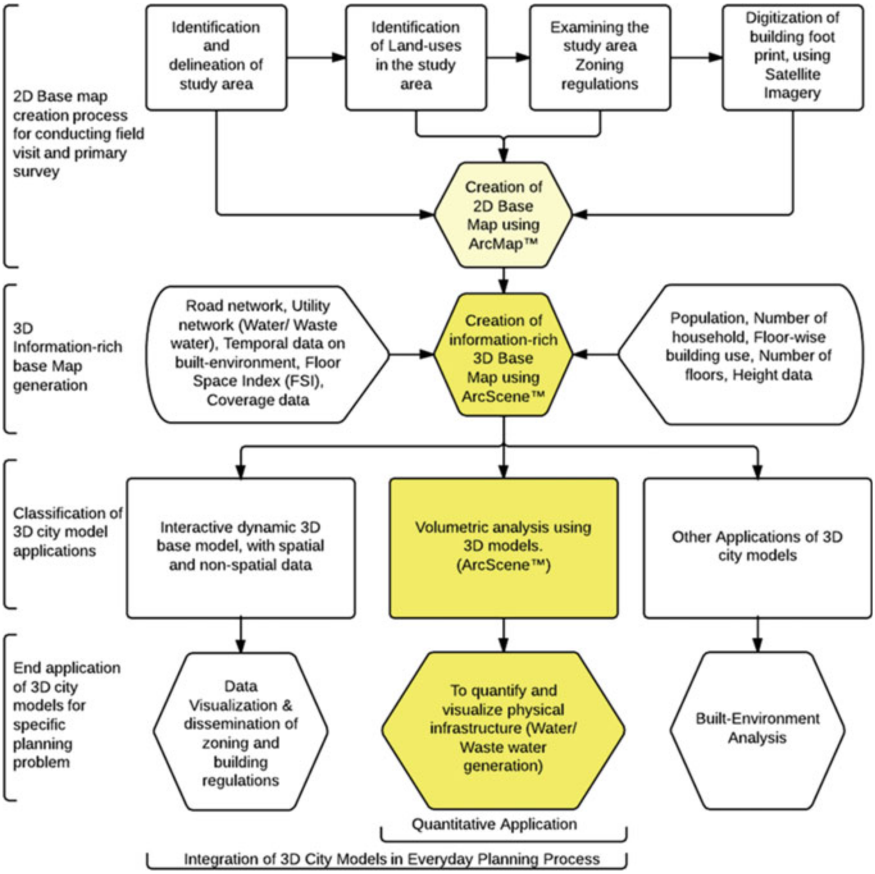


Fig. 7 Conceptual frameworks for creating 3D information-rich models and for performing the volumetric analysis

studied area. As indicated in Fig. 6, the total study area is 0.69 km^2, with 53% of plots being residential, 0.17% commercial, 18% mixed use, 8% institutional, and 2% parks and playgrounds [67]. Road and street networks take approximately 19% of the overall study area. The DDP for the Kannadasan Nagar region was prepared in 1980, and since then, there has been a substantial change in building activity and intensity throughout Chennai and inside the study area. An old aerial photograph (1980) of the research area was received from the Institute of Remote Sensing (IRS), Chennai, to measure the change in intensity of developments over three decades. The footprints of the study region in 1980 were digitized and confirmed using DDP supplied by CMDA for structures and land uses. For the current year (2013) status on the intensity of development, a primary survey was carried out using a digitized base map prepared using the current year Google Images.

Table 1 Floor-wise area statement of the study area, 2013

Floors	R-count	R-area (m^2)	C-count	C-area (m^2)	I-count	I-area (m^2)	Total count	Total area (m^2)
I	713	188,580	169	65,742	35	16,866	917	271,188
II	675	184,844	153	60,664	25	13,343	853	258,852
III	279	105,411	66	32,850	8	5847	353	144,107
IV	136	58,836	33	20,461	2	1613	171	80,910
V	36	18,962	22	14,705	1	1070	59	34,738
VI	11	6724	12	9565	0	0	23	16,288
VII	4	3648	4	4240	0	0	8	7888
VIII	3	3018	4	4240	0	0	7	7258
IX	3	3018	2	1974	0	0	5	4992
X	1	1360	0	0	0	0	1	1360
		574,401		214,440		38,740		827,580
		69%		26%		5%		

Source Primary survey by the author

7.2 Quantification of Development Intensity

In 1980, the study area's footprint was marked in yellow, blue, and red, with road networks, residential, commercial, and institutional building footprints indicated in yellow, blue, and red, respectively. The 1980 planned open space is also depicted in Fig. 8. Outside the research area, gray footprints have been noted. According to 1980 data, the total available land for development is around 0.55 km^2, with a building footprint size of approximately 0.13 km^2. There are 709 structures in the study area, with residential usage accounting for 80% of the footprint and commercial and institutional use accounting for 10% each. The study's net footprint coverage (excluding road and street networks, parks, and playgrounds) is around 24%, with a gross coverage of 19%. In other words, in 1980, approximately three-quarters (76%) of land was available as net open space, while around 81% was available as gross open space. In 1980, Fig. 8 depicts the total intensity of development in the study area, which includes residential, commercial, and institutional growth. With 709 buildings, the overall volume of the built environment is 911555 cubic meters, with residential activities shaping 71% of the intensity, 15% commercial, and 14% institutional. Figure 8 depicts the intensity of development in 1980 for specific uses such as residential development, commercial development, and institutional development.

A single-story building makes up 30% of the study area, while two-story buildings make up 26%, three-story buildings make up 32%, and four-story buildings make up 12%. Level I (ground floor) accounts for 57% of total activity volume, followed by 26% on level II (first floor), 14% on level III (second floor), and 3% on level IV (fourth floor). On the level I floors, residential activities account for 80% of the activity,

Fig. 8 The intensity of development—building use classification of the study area in 1980

with commercial and institutional activities accounting for 10% each. Residential activities account for 69% of activity on level II floors, followed by commercial activities (13%) and institutional activities (18%). In level III, residential activities account for 53%, commercial activities for 18%, and institutional activities for 29%. 90% of the activities in level IV are commercial and 10% are residential, Fig. 9.

7.3 *Land Use and Functional Dynamism*

All 675 plots in the research region are divided into three categories based on development regulations. (i) Plots on which conventional buildings may be constructed. (ii) Plots on which exceptional structures are permitted to be built. (iii) Plots where multi-story buildings are allowed to be built. The criteria for plot classification are listed in Table 2.

This is as per the rules outlined in the city of Chennai's second master plan [67]. The image depicts the classification of 1980 plots according to the development standards outlined in the Chennai master plan [67]. According to the classification, 75% of the total plots available in the study region in 1980 were acceptable for conventional building constructions, 23% for special buildings, and 2% for multi-story buildings, as shown in Fig. 10. Based on secondary information from IRS and CMDA, Fig. 10 depicts the real development that occurred in 1980. Except for a few buildings shown in red, which are not compatible with the proposed land uses, the bulk of the buildings is consistent with the proposed land uses. According to available

Fig. 9 The intensity of development—building use classification of the study area in 2013

data, 97% of structures built in 1980 fit into the categories of regular buildings, 1% special buildings, and 2% multi-story buildings, as illustrated in Fig. 10.

7.4 Volumetric Assessment and Built Form

An FSI audit was conducted based on the available data. The study area's net FSI, which excludes roads and street networks as well as parks and playgrounds, is around 0.42, with a gross FSI of 0.33. For the city of Chennai, the general FSI is 1.5 [67]. FSI is one of the most important planning instruments utilized in Chennai for current and future development planning and design, as well as the supply of related infrastructure services. The graphic depicts the FSI audit of the study area's buildings. Buildings are divided into three categories: those with an FSI of less than 1.5, those with an FSI of 1.5–1.75, and those with an FSI of more than 1.75.

Table 2 Criteria used for classification of plots

Classification of plots	Road width	Plot size
Ordinary buildings (G + 1 building)	Less than 9 m	Less than 200 m^2
Special buildings (G + 3/Stilt + 4 building)	9–12 m	200–1199 m^2
Multi-storied buildings (above G + 3/Stilt + 4 building)	12 m and above	1200 m^2 and above

Source [67]

Fig. 10 The actual intensity of development in 1980

8 Results and Discussion

8.1 Comparison of Developments Intensity Between 1980 and 2013

In 1980, the study region's overall net footprint coverage was nearly a quarter (24%) of the whole study area. In other words, as indicated in Fig. 11, about three-quarters of the land was available as net open space in 1980, and about 81% was available as gross open space. By 2013, a fifth of the study area had been added as built fabric over a three-decade period. The entire footprint coverage for 2013 is 50% of the total study area, and the intensity of development has doubled in terms of footprints throughout this period. The footprints of the 1980 and 2013 datasets are compared in Fig. 11. The footprints of buildings in 1980 are represented in yellow, and the footprints of buildings in 2013 are overlapped on the 1980 dataset and shown in red. It also shows that 26% of the study area is eaten away by the building fabric in a span of three decades.

8.2 Comparative Building Footprint Analysis

Between 1980 and 2013, there was a minor rise in the number of new buildings added to the study region, according to the volumetric intensity of development. In

Fig. 11 Footprint comparison 1980–2013

1980, there were 709 structures in the study area; in 2013, there were 917 buildings, a 28% increase. This increase in the number of buildings represents the addition of a new structure during a three-decade period. Buildings that are reconstructed on the same plots are not included. On the other hand, the study area's footprint has nearly doubled from 129418 m^2 to 271188 m^2, a 110% increase in footprint area since 1980. However, a staggering 263% increase in the amount of intensity is discovered. In 1980, the total volume of buildings was 911548 cu.m, and in 2013, it had increased by 263% to 3310320 cu.m, as shown in Fig. 12. According to the findings, the research area has experienced extraordinary vertical growth. This is also obvious from the literature, which shows that most Asian cities have expanded vertically rather than horizontally, with a similar pattern in Indian cities. Figure 12 depicts the 1980 building volume overlapping with the 2013 building volume, which is colored yellow and red, respectively.

8.3 Comparative of Volumetric Intensity on Development

The outcomes of a comparison of 1980 and 2013 activity studies suggest that residential activities have increased by 254%, while commercial activity has increased by a staggering 449%. The use of institutions has increased by 46%. The physical infrastructure requirements are greatly influenced by changes in activities or building usage. The 1980 activity analysis, such as residential, commercial, and institutional, overlapped with the 2013 dataset, as seen in Fig. 13. Between 1980 and 2013, an

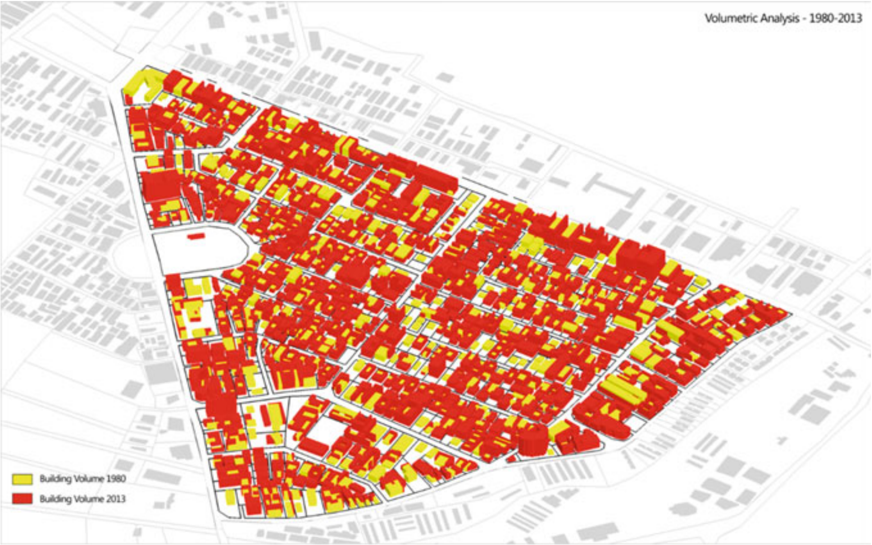


Fig. 12 Comparision of building volume 1980–2013

FSI audit was conducted, and the findings revealed that no new buildings with FSI 0-1.5 were built; however, there was a 716% increase in various buildings with FSI 1.5–2.5, and a remarkable 2400% increase in new buildings with FSI 2.5 and beyond. The findings suggest that there is a strong desire to create multi-story buildings in the research area.

Fig. 13 Comparision of residential activity 1980–2013

The findings also suggest that the FSI was around 0.42 (net FSI) and 0.33 (gross FSI) in 1980, and is now 1.52 (net FSI) and 1.20 (gross FSI) in 2013. Even though the intensity of development has increased dramatically, the FSI for the entire study region has just recently surpassed the commonly adopted FSI of 1.5 in Chennai City. As a result, the impact of increased development intensity on physical infrastructure services has been established. The infrastructure services supplied and the intensity of development are clearly out of sync. The results of the 3D volumetric analysis are critical in places like Chennai, where there is an insufficient and inefficient supply and demand of physical infrastructure services, particularly water supply and wastewater generation. Densification of urban centers occurs without first measuring the intended intensity of development concerning the infrastructure services available, resulting in unsustainable urban development. For example, according to the findings, the study area's overall FSI in 1980 was around 0.42, but it was 1.52 in 2013. FSI, on the other hand, has climbed by 266% in the last three decades, Fig. 14. Contrary to popular assumption, the overall FSI has slightly crossed its upper limitations of 1.5 FSI, although most of Chennai's planned areas have exceeded their FSI restrictions. The city becomes chaotic and deformed due to infrastructure failure that is not strengthened to match the increasing intensity of development. Furthermore, utilizing traditional tools and methodologies, proactive, dynamic quantification, and visualization in everyday planning and decision-making is almost difficult. Before making judgments about increasing the density of development or proposing new developments, urban planners must analyze the infrastructure services available. Based on the carrying capacity of the infrastructure services in place, such analyses will assist identify zones where the intensity of growth can be raised or restrained.

Fig. 14 Comparison of FSI 1980–2013

The findings of this study are restricted to an examination of key physical infrastructure factors including water supply and wastewater generation. Other physical and social infrastructure criteria must be incorporated in volumetric evaluations, in addition to the parameters listed above, for more informed decision-making.

9 Recommendation and Conclusion

Urban planners are beginning to think three dimensionally to address the ever-growing urban problems, particularly in dealing with the built environment, as 3D modeling tools and approaches become more popular. The possibility and need for incorporating 3D GIS as a planning support system for smart master plan are discussed in this chapter. This study's interactive, dynamic, information-rich 3D model demonstrates a novel technique for disseminating urban planning data for the benefit of both urban planners and the general public. Planners can use this 3D information-rich model to get up-to-date information on city development for better analysis, planning, and decision-making. Sharing 3D information-rich models in the public realm improves transparency in planning processes. One of the most significant benefits of having a 3D city model is the capacity to quantify the activities that occur in a specific location, not only in two dimensions but also in three dimensions. Planners can use volumetric data to quantify and assess activities in terms of volume against infrastructure services available.

This study also demonstrates the usage of 3D models to compare envisioned growth plans to present development trends. When there is an increase in built-environment intensity without a simultaneous enhancement of existing infrastructure services, certain zones within the study area critically overshoot the network's designed carrying capacity. The methodological framework created in this study demonstrates how 3D models can be used as a smart master plan tool in everyday urban planning operations. The main critical planning factors (physical infrastructure) that can be obtained using 3D city models have also been found in this study. Apart from zoning restrictions, all physical and social infrastructure elements must be analyzed holistically for informed planning and decision-making. 3D volumetric analysis is one such technology that can integrate all of these parameters into daily urban planning operations, allowing for improved analysis, planning, and decision-making. Furthermore, 3D volumetric assessments that are within the designed carrying capacity of the entire in situ infrastructure can be used to determine the study area's appropriate development intensity.

The process of 3D modeling and analysis is time-consuming. Integrating 3D models into urban planning processes necessitates substantial study into a variety of topics, including modeling approach simplification, data integration, and enhanced and simplified analytical techniques, among others. Furthermore, the 3D volumetric analysis used in this study is based on static 3D models created with ArcScene. The dynamic nature of the urban planning process necessitates dynamic 3D volumetric analyses. More study into 3D dynamic volumetric measurements is needed. Every city has its plan-making process, and integrating 3D models and 3D volumetric evaluation methodologies must be done by industry standards. From data collection strategies to analysis and presentation, more study on customization in the integration of 3D models is required.

The research presented in the chapter has helped to broaden the applications of 3D city models in urban planning toward a smart master plan approach. Although 3D city models provide enhanced analytical capabilities, incorporating them into everyday planning processes requires additional research in terms of superior analytical capabilities and flexibility. There is an inevitable requirement of 3D tools for the assessment and monitoring of growth and development. Tools that are simple to use and freely available, and that integrate spatial and non-spatial data more thoroughly. Urban planners, city administrators, and policymakers will be able to plan more efficiently by incorporating 3D volumetric analyses into day-to-day affairs and planning processes to understand the threshold limits for growth and development.

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Kusum Lata was awarded Ph.D. in Urban Planning from the School of Architecture and Planning (SPA), New Delhi. Her Ph.D. on "Monitoring Urban Development, Case Study: Water Supply System of Ghaziabad" suggests a result-oriented approach for monitoring urban development at city level, which has been defined as "System of responses of city managers to the process, parameters and products of urban development observed through a set of filters". Her post-graduation in Regional Planning is also from SPA, New Delhi. She completed her graduation in Civil Engineering from Government Engineering College, Raipur (currently NIT-Raipur, Chhattisgarh). Dr. Kusum is currently the faculty of Urban & Regional Planning with Centre of Urban Studies at Indian Institute of Public Administration (IIPA), New Delhi, a premier Institute under the Department of Personnel and Training (DoPT), Government of India. She as the Program Co-Director, successfully conducted the IIPA's flagship program, the 44th Advance Professional Programme in Public Administration in 2018–19. During her twelve years at IIPA, she has conducted numerous capacity building programmes for functionaries of central, state and urban government. She has also conducted several research studies related to urban, social and cross-cutting issues, policies and schemes of various departments and ministries of GoI (like Ministry of Housing and Urban Affairs, Ministry of Tribal Affairs, Ministry of Sports and Youth Affairs, Department of Posts and Ministry of Development of North Eastern Region). She has experience of over 30 years in the academic, research, and professional field of Engineering and Planning. She has published couple of books, authored peer-reviewed research papers, book chapters and has presented papers at national and international conferences.

Faiz Ahmed Chundeli is a researcher and built-environment analyst, with a specialization in modeling and simulation of built-environment. After obtaining a Bachelor's degree in Architecture and a Master's degree in Planning, he went on to pursue M.S. (Research) degree at Polytech Tours, France. He holds a Ph.D. in simulation and modeling of built-environment for quantitative urban analysis. Dr. Faiz teaches at the School of Planning and Architecture, Vijayawada, India (An institute of national importance under the Ministry of Education, Government of India). He has authored several peer-reviewed research articles, book chapters, and presented papers at national and international conferences. Dr. Faiz is currently developing a high-resolution micro-scale meteorological simulation of the urban environment for measuring and modeling the wind environment, heat and carbon fluxes, daylight availability, heat island effect etc.

Adinarayanane Ramamurthy acquired Ph.D., a degree in Urban Studies and Planning from the School of Architecture and Planning, Anna University, Chennai. He holds Ph.D., in simulation and modeling of Energy Efficient Sustainable Development of Metropolitan cities for quantitative urban analysis through System Dynamics. He completed post-graduation in Urban and Rural Planning from the Indian Institute of Technology Roorkee (IITR), Uttarakhand State. He received his Bachelor's Degree in Civil Engineering from Annamalai University, Tamil Nadu State. He has experience of over 27 years in the academic, research, and professional field of Planning and Architecture. He has published a book authored over twenty peer-reviewed journal research papers and has presented in several international conferences. Dr. Adinarayanane is currently heading the Department of Planning and He is also holding the position of Dean (Planning and Development) at the School of Planning and Architecture Vijayawada (An institute of national importance under the Ministry of Education, Government of India).