Current Urban Studies, 2026, 14(2), 67-100
https://www.scirp.org/journal/cus
ISSN Online: 2328-4919
ISSN Print: 2328-4900

The Role of Artificial Intelligence in Urban Design Land Subdivision in Riyadh: A Case Study

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How to cite this paper: Alwadai, Z. H., Hallawani, M. M., Alabed, A. M., & Alhassan, A. M. (2026). The Role of Artificial Intelligence in Urban Design Land Subdivision in Riyadh: A Case Study. *Current Urban Studies, 14,* 67-100.
https://doi.org/10.4236/cus.2026.142005

Received: March 26, 2026
Accepted: May 25, 2026
Published: May 28, 2026

Abstract

This study explores the role of Artificial Intelligence (AI) in urban design processes related to land subdivision in Riyadh. It places this within the broader context of digital transformation and the increasing complexity of regulations. The research mainly focuses on two issues: first, the limited understanding of AI's current use in urban design and land subdivision, including identifying existing applications, comparing them with traditional methods, and documenting practices in Riyadh; second, the absence of a clear framework to effectively combine traditional procedures with AI tools within Riyadh's institutional setting. The study uses a descriptive-analytical approach that combines a review of existing literature with field-based data collection. The empirical part depends on semi-structured interviews with institutional actors involved in land subdivision in Riyadh. A three-point Likert scale serves as a descriptive tool to indicate the level of AI integration across various stages of subdivision. Findings show that land subdivision methods remain mostly traditional, with limited systematic use of AI tools. The study recommends practical guidelines to better combine professional expertise with AI technologies to enhance the efficiency and quality of urban design results in Riyadh.

Keywords

Artificial Intelligence, Urban Design, Land Subdivision, Riyadh

1. Introduction

Artificial intelligence is a crucial part of the modern technological revolution, referring to computer systems' ability to mimic human intelligence in complex tasks such as learning, analysis, and decision-making. Over the past few decades, its applications have expanded across sectors such as industry, healthcare, education, governance, and urban planning. AI plays an essential role in supporting decision-making in today's cities, especially as urban data grows and comes from multiple sources, requiring skills beyond traditional human capabilities (Russell & Norvig, 2020; Sadaia, 2023). As part of the global digital transformation, cities are adopting intelligent tools to manage growth, promote sustainability, and improve service efficiency, underscoring the importance of integrating artificial intelligence into urban design and planning strategies.

The use of artificial intelligence has gradually transformed traditional urban design practices. Urban designers no longer rely solely on personal experience or intuition; instead, they analyze large volumes of spatial and urban data with smart algorithms to support decision-making. Recent studies show that artificial intelligence in this field goes beyond simple descriptive analysis; it also generates design options, assesses scenarios, and enables interactive, creative design. This guides decisions toward more efficient and realistic solutions (Wang et al., 2025; Cugurullo, 2021). As a result, artificial intelligence has become a valuable tool in the design process, enhancing designers' ability to manage the increasing complexity of urban environments.

Based on that, land subdivision becomes a key focus of urban design, translating broad planning trends into detailed, actionable plans by shaping street layouts, land parcels, and the distribution of facilities and services. The land subdivision process aims to optimize land use and develop balanced urban environments that serve residents' needs. However, this process faces several challenges, especially in rapidly growing cities where economic, social, and environmental interests overlap, complicating decision-making (Alshuwaikhat et al., 2006). In this context, the need for analytical tools that can systematically and accurately address these challenges becomes clear.

In this context, artificial intelligence technologies have enabled advanced capabilities to simulate various land-use division scenarios, assess their potential impacts on traffic flow, the urban environment, and service distribution, and predict future demand for different land-use types. Smart algorithms also facilitate more efficient allocation of plots and spaces based on criteria such as population density, proximity to services, and sustainability considerations. This integration of artificial intelligence and land division highlights a shift in urban planning practices, moving from reliance on traditional methods to decision-support tools that use analysis and intelligent data processing.

Given the above, Riyadh serves as a prime example for studying this transformation due to its rapid urban growth and wide-ranging development efforts driven by Saudi Vision 2030. The Riyadh Municipality plays a crucial role in managing land subdivision, developing master plans, and enforcing land-use and infrastructure regulations. The municipality is also exploring ways to incorporate smart technologies, including artificial intelligence, into its operations, in partnership with the Royal Commission for Riyadh City, which has launched several projects aimed at increasing land-use efficiency, enhancing service delivery, and improving residents' quality of life (Royal Commission for Riyadh City, 2023).

The main research challenge is to understand how artificial intelligence techniques are currently used in urban design processes for land subdivision and to analyze the gap between traditional methods and the capabilities of smart technologies to support analysis and decision-making, without assuming the extent of this use or its outcomes.

The primary problem in the research is the lack of a clear, comprehensive understanding of how artificial intelligence technologies are employed in urban design and land division. This includes identifying the most prominent contemporary applications, comparing traditional land division methods with AI applications, and monitoring the current state of land division practices in Riyadh. This absence makes it difficult to assess the gap between available technical capabilities and actual practices and to understand the extent to which these technologies are integrated into current regulatory procedures.

The second research problem is the absence of a clear methodological framework for combining traditional land division methods with artificial intelligence applications in a way that conforms to Riyadh City's regulatory and institutional privacy standards. This hinders the creation of a comprehensive land-division process that blends human expertise with the analytical and predictive strengths of smart technologies.

Based on the research problem, this study aims to answer a broad question about how artificial intelligence techniques can improve the efficiency of urban design processes for land subdivision in Riyadh by addressing the following research questions:

1) What are the primary uses of artificial intelligence in urban design, and how can they be applied during land subdivision processes?

2) What is the current process of land division in the city of Riyadh?

3) What guidelines can be developed for combining human experiences and artificial intelligence applications to improve the land division process in Riyadh?

This study emphasizes the importance of applying artificial intelligence techniques to urban design for land subdivision, an area with a clear gap between theory and practice, especially in Riyadh. Its significance lies in focusing on a key stage of urban design—land subdivision—because it directly shapes the urban fabric, improves land-use efficiency, and enhances the quality of the urban environment.

The scientific importance of this study lies in its contribution to advancing Arabic literature within urban artificial intelligence by linking theoretical concepts and global AI applications to land division processes and examining them through urban design frameworks. It also shows how artificial intelligence techniques can improve design decision-making, highlighting the gap between traditional methods and the capabilities of smart technologies, supported by systematic analysis and field results.

Regarding practical significance, it focuses on providing a realistic assessment of the current state of land subdivision processes in Riyadh city and on analyzing the main organizational and technical challenges involved. This creates a knowledge base that relevant authorities, mainly the Riyadh Municipality, can use to develop work mechanisms and improve procedural efficiency. The study also helps establish guiding directives to better integrate artificial intelligence technologies with human expertise and regulatory frameworks, supporting the quality of urban outputs without compromising regulatory standards.

The study's significance also extends to planning and design, as it deepens understanding of the relationship between urban design and artificial intelligence technologies in land division. It promotes the adoption of more effective practices that address current urban challenges. Therefore, this research serves as a reference for future studies and for developing analytical frameworks that connect artificial intelligence and urban design in rapidly growing cities.

This study aims to clarify the issues raised in its introduction and research problem, and to review the scientific literature on the development of artificial intelligence applications in urban design. It also highlights the realities and challenges of land subdivision processes in Riyadh, aiming to achieve a set of interconnected objectives that integrate theoretical and practical aspects. These objectives focus on understanding the current state of land subdivision operations, analyzing the gap between traditional methods and the capabilities provided by AI technologies, and deriving guiding recommendations to improve the land subdivision process and increase the efficiency of its outputs. Therefore, the research objectives are as follows:

1) Highlighting the key artificial intelligence applications in urban design.

2) Monitoring the current land-division process in Riyadh City.

3) Extracting guiding instructions that integrate human expertise and artificial intelligence applications to enhance the land division process in Riyadh city.

This study employed a descriptive-analytical survey method, given the nature of the subject, which focuses on describing the current state of land subdivision operations in Riyadh and examining the technical shortcomings arising from the lack of artificial intelligence technologies.

Field surveys served as a primary method for gathering information through guided interviews with specialists from Riyadh Municipality. The goal was to examine the current land division processes, identify existing challenges, and evaluate the effects of not using artificial intelligence. This acts as an initial step toward shaping a preliminary vision for the future development of this field and understanding the role artificial intelligence could play in land division.

Beyond the introduction and conclusion, this study is divided into four sections: theoretical background and literature review, research methodology, results and discussion, and recommendations for improving land division and integrating traditional methods with AI.

2. Theoretical Background and Literature Review

This section first reviews the concepts, development stages, and applications of artificial intelligence. Next, it discusses artificial intelligence in urban design, including its concept and significance. Then it covers urban design theories and their application to land division, including morphological theory, analysis levels, and their implications. Afterward, it explores applications of artificial intelligence in urban design, emphasizing key areas where AI intersects with urban planning, and reviews AI tools and techniques used in urban design.

2.1. Artificial Intelligence

Artificial intelligence is one of the most significant technological fields, experiencing rapid growth over recent decades and becoming a key part of many essential sectors worldwide. The interest in this concept in this study arises from its status as the broadest framework from which applications related to urban design and land division develop. This section provides a general overview of artificial intelligence, defining the concept, tracing its historical evolution, and outlining its main areas of application.

The idea of Artificial Intelligence (AI) refers to the ability of computer systems to perform tasks that typically require human assistance, such as learning, reasoning, problem-solving, and decision-making (Russell & Norvig, 2020). The European Commission has given a more practical definition of AI, describing it as "the ability demonstrated by technical systems to perceive their environment, analyze their inputs, and make decisions that help achieve specific goals" (European Commission, 2020).

As Cugurullo (2021) pointed out, artificial intelligence is "an independent cognitive structure based on analyzing big data with the aim of generating intelligent and behavioral responses within a specific context," thereby broadening the concept of intelligence to include interaction and self-adaptation to variables.

By comparing these definitions, the operational definition of artificial intelligence in this research is a cognitive and technical system capable of analyzing data, inferring patterns, and making decisions autonomously or semi-autonomously, thereby improving efficiency and increasing adaptability to changing environments.

2.2. Stages of the Development of Artificial Intelligence

Thoughts about artificial intelligence trace back to the 1940s, and the Turing Test was proposed in 1950 as a way to assess a machine's ability to mimic human thinking. In 1956, John McCarthy coined the term "Artificial Intelligence," a year widely regarded as the birth of the field in an academic and systematic way (Russell & Norvig, 2020).

After this announcement, artificial intelligence went through three main stages, which are as follows:

1) First Phase (1956-1974): It saw essential advances in theories and early software, but technical capabilities remained limited.

2) Second Phase (1980-1987): The beginning of the flourishing of machine learning, driven by the development of data-driven mathematical models.

3) Third Phase(1994-Present): The modern era of artificial intelligence, characterized by deep learning techniques and achieving tangible results in fields such as gaming, image analysis, and language interaction.

According to the Saudi Data and AI Authority, recent years have marked a turning point in the global development of artificial intelligence, with the rise of powerful applications such as "AlphaStar" (2019) and "GPT-3" (2020). Additionally, advances in text analysis tools and self-learning algorithms have confirmed that artificial intelligence has reached a stage of widespread practical maturity (SDAIA, 2023).

2.3. Uses of Artificial Intelligence

In recent decades, AI applications have grown substantially, making them a vital part of improving performance across key sectors. In healthcare, AI technologies are used to diagnose diseases and interpret medical images, achieving accuracies that sometimes surpass those of human experts, as demonstrated by programs that analyze X-rays and cancer cells (Wang et al., 2025). In industry, smart algorithms support automated control, fault prediction, and the enhancement of production efficiency within what is known as smart manufacturing (Quan, 2022).

In education, AI tools help create interactive learning content, analyze individual student performance, and tailor content to students' needs. Government and judicial bodies are increasingly using AI for document review, pattern prediction, and data-driven detection of manipulation or fraud (Surya, 2019). Its uses also extend to transportation via autonomous driving systems and traffic analysis, as well as to energy management, supply chains, and cybersecurity.

These examples demonstrate that artificial intelligence is highly flexible and adaptable to the specific needs of each sector, making its application in urban areas, especially in city design, planning, and land division, promising. The next section will discuss the role of artificial intelligence in urban design.

2.4. Artificial Intelligence in Urban Design

The field of urban design is experiencing significant growth in its tools and methods due to the rapid digital transformation happening worldwide. As the challenges faced by modern cities increase, it has become essential to develop analytical and design tools that keep pace with the complexities of the urban fabric and its many variables. Artificial intelligence is one of the most important technologies beginning to integrate into this field, helping to improve the efficiency of urban decision-making, process large amounts of spatial data, and generate design solutions based on accurate quantitative and qualitative standards.

In this context, this section examines the relationship between urban design, both as a conceptual and an applied discipline, and artificial intelligence as a supporting technology. It begins with a definition of urban design and then discusses its importance and role.

2.4.1. Concept of Urban Design

Urban design varies by academic perspective, but it is universally regarded as a science and practice that organizes urban spaces for efficiency, aesthetics, and harmony. Carmona et al. (2010) describe it as the arrangement of relationships among buildings, public spaces, and urban systems to improve urban life. Lynch (1984) calls it "the art of shaping a readable, integrated, and livable environment." Wang et al. (2025) see it as a strategic tool that turns planning into spatial practices.

This research defines urban design as an integrated process that shapes relationships among buildings, spaces, and infrastructure to enhance functionality, aesthetics, and urban life.

Urban design is essential for city efficiency, turning planning visions into practical spaces that address residents' needs for density, mobility, and services (Carmona et al., 2010). It improves quality of life by creating safe, comfortable public spaces that encourage social interaction and build a sense of community (Cugurullo, 2021). It also promotes spatial justice by enhancing access to services and organizing land uses (Huang et al., 2026).

It balances population densities by controlling block and facility distribution, reducing infrastructure stress, and improving efficiency (Wan & Ma, 2022). It organizes street networks and movement, connecting areas effectively (Quan, 2022).

Land subdivision is vital for planning, establishing plot boundaries and sizes, and connecting to services, thereby reflecting sustainable urban growth.

2.4.2. Urban Design Theories and Their Application in Land Division

Urban design literature classifies urban design theories into five types of theories (Cuthbert, 2007):

1) Theories related to the analysis of urban design components.
2) Theories synthesize the entire field of urban design.
3) Theories of pioneers in urban design.
4) Theories of urban design by individuals (unified theories).
5) Theories related to sustainability and post-urbanism (New Urbanism).

Researchers, as indicated in **Figure 1**, classify theories related to the analysis of urban design components into four categories: cognitive, intellectual, anthropological, perceptual, morphological, and behavioral (Alabed, 2020).

Among the previous theories, the following points review the morphological theory as the one most closely related to the formation of the city's physical structure in general and to land division, particularly the distribution of urban blocks.

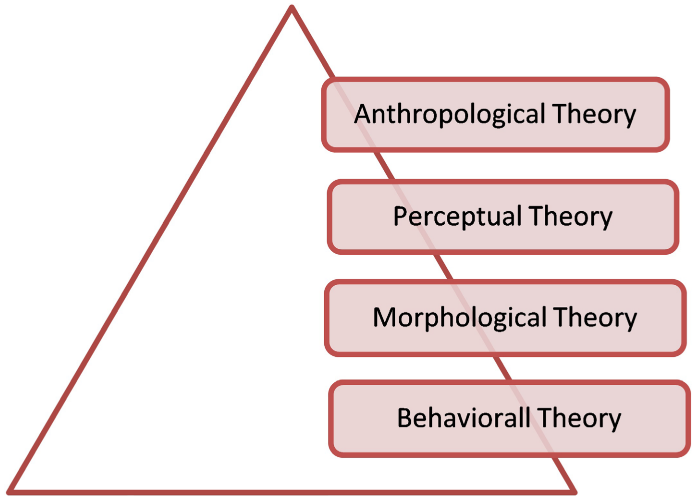

Figure 1. Cognitive and intellectual urban design theories.

2.4.3. Morphological Theory

Morphological theory is a key concept in urban design, as it examines urban form by analyzing the city's physical structure and breaking it down into different levels. This theory suggests that urban form is not created randomly but develops over time, guided by a logical framework that governs the relationships among elements. It is based on a fundamental principle: the city is composed of an "urban fabric" of interconnected elements, such as the network, the block, the lot, and the building. Each element has its own characteristics and role in shaping the city, but understanding urban form requires studying their relationships as an integrated whole rather than in isolation. This is known as the principle of "the whole and the part" or "composition from top to bottom" (Sitte, 1965).

2.4.4. Levels of Analysis in Morphological Theory

The morphological theory views the city as a complex network of interconnected elements, analyzing urban formation at four key levels. The broadest level is the urban context, which includes location, regional relations, natural features, and development factors, helping to understand growth patterns. Open spaces like plazas and gardens interrupt the urban fabric, serving roles in the environment, movement, and social life. Connection methods, such as street shapes, shape the framework by defining block boundaries. The network controls function and movement, with urban blocks composed of plots—the smallest units that influence density, form, and appearance. Buildings complete the urban composition, reflecting their uses and character (Alabed, 2020).

2.4.5. The Reflections of Morphological Theory on Land Division

Applying morphological theory to land subdivision offers a systematic way to understand cities as interconnected systems. It explains urban form, examines relationships among blocks and spaces, and identifies patterns. This theory guides plot distribution and shapes the urban fabric to align with spatial and social contexts (Venturi et al., 1977). It emphasizes the block as the primary unit of division, influencing usage density, building ratios, and pathways. Analyzing blocks informs road routing and the allocation of services and spaces, thereby shaping land division (Sitte, 1965; Venturi et al., 1977). Transitioning from blocks to smaller units creates a clear sequence in the urban fabric, linking to public spaces and reducing randomness (Venturi et al., 1977). Key outcomes include spatial organization through defined block boundaries, improved functional integration, site-specific adaptation, and the capacity for quantitative analysis to support AI optimization. Overall, morphological theory serves as both an analytical framework and a design tool, especially when integrated with GIS or AI.

2.4.6. Applications of Artificial Intelligence in Urban Design

The field of urban design has recently undergone a qualitative shift driven by rapid digital transformation, as artificial intelligence has become a vital tool for decision-making and for improving the efficiency of analysis and design processes. Whereas decisions were once primarily based on designers' judgments and traditional planning models, AI tools can now analyze spatial patterns, generate design alternatives, and provide data-driven recommendations (Wang et al., 2025).

The role of artificial intelligence in urban design has evolved from a mere helpful tool to intelligent systems capable of generating initial designs, evaluating them, and adapting them to functional and spatial standards. This shift reflects the transition from traditional processing systems to machine-learning, intelligent modeling, and generative systems driven by intelligent algorithms (Huang et al., 2026). Notable examples include Urban GAN and Generative Urban Design, which demonstrate AI's ability to simulate design processes and produce urban plans that account for real-world constraints and environmental considerations.

The following sections highlight the main areas where artificial intelligence intersects with urban design, discuss the tools and software used worldwide, and link them to the potential for developing land subdivision mechanisms.

The main areas where artificial intelligence intersects with urban design:

Urban design has seen significant developments in its tools and methods with the advent of artificial intelligence, not only in analysis but also in supporting decision-making and generating design alternatives.

This part of the study reviews three areas of artificial intelligence that intersect with urban design: spatial analysis, usage prediction, and intelligent modeling.

1. First, Spatial Analysis

Spatial analysis is a fundamental field where artificial intelligence intersects with urban design. Its importance lies in describing the spatial relationships among components of the urban environment, such as land-use distributions, building densities, road network expansion, and access to services. In this context, artificial intelligence provides advanced capabilities for analyzing these relationships by processing large amounts of data, enabling the extraction of precise and impactful patterns for design decision-making (Cugurullo, 2021; Wang et al., 2025).

These analyses typically integrate artificial intelligence techniques, such as artificial neural networks (ANNs) and spatial classification algorithms (e.g., Random Forest and SVM), with Geographic Information Systems (GIS) to generate analytical maps that inform the formulation of design guidelines for urban plans. These tools enable the assessment of activity distribution efficiency and suggest design alternatives based on spatial balance and equitable access to services.

In this context, Wan & Ma (2022) developed a model that uses spatial data, such as density, land use, and road networks, to feed an AI-supported generative system that produces multiple comparable design schemes. The results showed that spatial analysis supported by intelligent algorithms improved land-use efficiency, identified movement paths, and more accurately distributed services.

2. Secondly, Predicting Uses

Predicting future land uses is a fundamental application of artificial intelligence in urban design, especially in cities experiencing rapid urban expansion. Machine learning algorithms are employed to analyze historical, geographic, and demographic data in order to identify patterns and forecast the distribution of future urban activities, including residential, commercial, and service areas (Wan & Ma, 2022). Common algorithms used in this context include artificial neural networks, multiple linear regression, and decision trees.

These models improve land-use efficiency by reducing undesirable overlaps, such as those between residential and industrial activities, and by promoting a balanced distribution of services and facilities. They also provide advanced capabilities for evaluating planning alternatives, supporting informed design decisions based on real data (Quan, 2022).

Some studies have shown that employing artificial intelligence in land-use modeling has improved the accuracy of planning decisions by more than 20% compared to traditional methods, especially in complex urban environments. These tools are also used to generate alternative spatial scenarios, allowing planners to test multiple models before finalizing the plan, thereby reducing time and cost waste and enhancing resource efficiency (Wang et al., 2025).

3. Thirdly, Intelligent Modeling

Smart modeling is a prominent application of artificial intelligence in urban design, enabling dynamic, interactive simulation of future urban network scenarios. Techniques such as genetic algorithms, neural networks, and multi-agent systems are used to model elements such as traffic flow, public service distribution, and projected population densities (Quan, 2022).

The importance of these models lies in their ability to predict the spatial and social outcomes of planning before implementation, which helps decision-makers test multiple planning alternatives and choose the most suitable one based on criteria such as reducing congestion, improving access to services, or achieving a balance between population densities and infrastructure (Wan & Ma, 2022).

The effectiveness of these tools is particularly evident in major cities, where they enable visualization of the complex relationships among urban components, as in the "Urban Network Analysis" model used to assess the flow and integration among urban network elements. Additionally, AI tools enable the development of urban designs that are better adapted to residents' actual needs by analyzing large volumes of data from sensors and smart systems (Huang et al., 2026).

2.5. Artificial Intelligence Tools and Techniques in Urban Design

Urban design is undergoing a significant evolution in its tools and techniques, with artificial intelligence playing an increasingly important role in supporting decision-making and generating planning alternatives. This progress includes the rise of specialized programs that enable the analysis of urban data, suggest flexible land divisions, and model the spatial impacts of projects before implementation. In this section, as illustrated in **Table 1**, the most prominent AI tools and techniques that have been applied in urban design projects will be reviewed, along with their application areas, mechanisms of operation, and supporting real-world examples and scientific sources, all in preparation for their use in land division.

2.5.1. First, TestFit

TestFit is a leading artificial intelligence application for urban design, specializing in generating land subdivision plans instantly from initial criteria such as location, uses, and regulatory constraints. Its significance lies in supporting early subdivision stages, especially in determining uses and developing the master plan, as well as testing plan compliance with local requirements for approval. By producing multiple alternatives in seconds, TestFit shortens planning time, reduces effort, and improves decision accuracy. Consequently, it has become a popular tool among developers and consulting firms involved in housing projects and urban planning worldwide (TestFit, 2023; Mahendra et al., 2025).

2.5.2. Second, Urban GAN

Urban GAN (Urban Generative Adversarial Network) is an advanced type of Generative Adversarial Network (GAN) created to aid urban design processes by learning from real urban data—such as satellite images, urban plans, and CAD/GIS maps. Its strength is in generating new design options that resemble the existing urban fabric and can be adapted to the specific traits of the target site. Urban GAN is directly connected to the land-use identification and master planning phases, and it can also facilitate community engagement by offering clear, comparable design alternatives for non-experts. These features enable Urban GAN to advance the use of artificial intelligence in urban planning, broadening the range of options available to planners (Quan, 2022).

This technique is based on the idea of GANs proposed by Goodfellow et al. (2020) for generating new data similar to the original data, making it an innovative tool for fields such as land division and neighborhood planning.

2.5.3. Third, Autodesk Forma

Autodesk Forma, formerly known as Spacemaker AI, is a cloud-based platform supported by artificial intelligence designed to facilitate innovative urban and architectural design processes. This tool helps gather and analyze site data, generate multiple design options, and compare them based on environmental and spatial performance indicators. Its role is closely tied to data collection, natural feature analysis, and master planning, enabling the integration of 3D models with real-world data, thereby improving design quality and reducing regulatory risks and costly late-stage modifications. Therefore, Autodesk Forma is a vital tool in the early stages of urban planning, especially for evaluating multiple options quickly and accurately (Azadi et al., 2023).

2.5.4. Fourth, CityEngine

CityEngine is considered one of the leading 3D urban design programs developed by Esri. It is widely used for urban fabric simulation, land subdivision analysis, and the creation of integrated planning models. The software relies on procedural modeling, where complete urban environments are built using CGA Rules that enable users to create road networks, divide blocks into parcels, and generate buildings or public spaces based on specific spatial properties.

CityEngine connects directly to various stages of land subdivision, including initial planning through simulation of network and block patterns, subdivision of blocks and parcels with precise procedural rules, and supporting plan review and approval by integrating Geographic Information Systems (GIS) with 3D visualizations. It also enhances community engagement by offering high-resolution visualizations that help facilitate discussion of alternatives. What sets CityEngine apart from other tools is its combination of GIS's spatial analysis capabilities and its ability to produce realistic visual models, making it an effective resource for supporting urban planning decisions related to land subdivision and development (Parish & Müller, 2001; Azadi et al., 2023).

Artificial intelligence tools and techniques in urban design have become central to supporting planning decisions, especially in land subdivision. The TestFit tool provides instant solutions for generating preliminary layouts and testing scenarios, while generative models such as Urban GAN enable the simulation of new urban patterns from real-world data. Cloud platforms such as Autodesk Forma offer an integrated analytical environment for studying design alternatives that consider environmental and spatial factors, while CityEngine is an advanced tool for 3D procedural modeling to support scenario visualization and urban subdivision planning.

These applications demonstrate that integrating artificial intelligence technologies into land division not only speeds up plan preparation but also improves prediction accuracy, enhances resource utilization, and provides visual tools to aid decision-making. Therefore, these tools provide a strong foundation for modernizing traditional practices in fast-growing cities like Riyadh and for adopting more sustainable, locally adaptable solutions.

Overall, **Table 1** summarizes the most important artificial intelligence applications related to urban design, including global examples, the stages they can support in the land division process, and the mechanisms of each tool.

Table 1. Listing the applications of artificial intelligence in urban design and explaining their relationship to land division.

AI Tool	relationship to land division	Description of the tool/technique's operation	Reference
TestFit	Defining the uses, developing the master plan, and approving the plans	A rapid generative design tool for generating land division and building layout scenarios according to local regulations.	TestFit (2023)
Autodesk Forma	Gathering information, analyzing natural characteristics, and developing the general plan	An AI-powered platform for analyzing sites (noise, sun, wind, density) and suggesting design alternatives	Azadi et al. (2023)
Urban GAN	Defining the uses, developing the general plan	A generative adversarial network (GAN) for producing realistic urban design alternatives based on existing city data.	Quan (2022)
CityEngine	Developing the master plan, community participation	A generative program based on procedural modeling to produce viewable and interactive 3D urban zoning patterns.	Parish & Müller (2001)

2.6. Stages of Land Division and the Role of Artificial Intelligence

Figure 2 depicts the land subdivision process through several stages: starting with data collection, then analyzing natural features and determining land uses, followed by creating the master plan and dividing the blocks into smaller parcels. Next, the plan is reviewed in accordance with laws and regulations and with the community and relevant authorities before it is officially approved and implemented on the ground. The process ends with a stage of field implementation monitoring to ensure that what has been approved aligns with the actual situation. This sequence represents the main procedural framework to ensure that subdivision outcomes meet planning standards and support sustainable urban development (Wickramasuriya et al., 2011; Omollo & Opiyo, 2020).

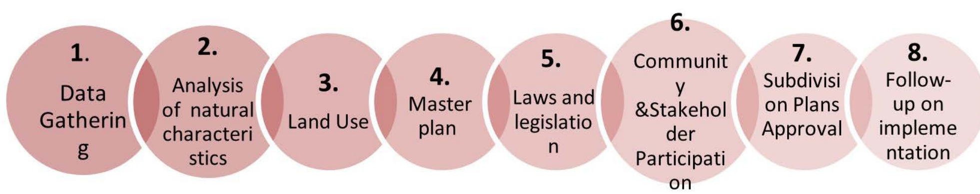

Figure 2. Land subdivision stages (Wickramasuriya et al., 2011; Omollo & Opiyo, 2020).

Table 2 shows the steps of traditional land division and compares it with land division using artificial intelligence techniques and tools, along with an overview of the best global practices that utilize these technologies and tools.

The stages of land division follow a sequence that begins with collecting and analyzing natural and regulatory data, then moves to defining uses and preparing plans, and finally culminates in approval and field implementation. The study clarified that incorporating artificial intelligence techniques into these stages not only reduces time and effort but also improves output accuracy and decision reliability. Based on global and regional experiences, it is evident that using these tools narrows the gap between the paper plan and practical reality, making them a promising foundation for supporting sustainable urban transformation in Riyadh.

Therefore, Table 2 supports the first research goal: to identify the most important applications of artificial intelligence in urban design and land division, clarify their relationship to land division, and serve as a methodological guide for the comparative analysis in the upcoming chapters.

Table 2. Land division stages.

No	Land division phase	Phase description	Traditional work (Human input)	Artificial Intelligence Applications (AI Input)	Best Practice	Reference
1	Data Gathering	Collecting spatial, environmental and social data (maps, satellite images, property records). human effort in compilation and review.	Manual field surveys, property reports, aerial photographs, and manual GIS analysis.	Predictive algorithms, optimization algorithms, and interactive modeling.	City of Helsinki Helsinki 3D project using LiDAR data.	(Omollo & Opiyo, 2020).
2	Analysis of natural characteristics,	Study of topography, soil, water resources, and environmental hazards.	Collecting geological data, conducting field surveys, and producing lengthy reports may be slow and prone to human error.	Remote sensing models, digital twins, and hydrological simulations	Singapore—Virtual Singapore project.	(Stevens & Dragicevic, 2007)
3	Land Use	Determining the most suitable uses (residential, commercial, service) and distributing densities, city data.	Planners rely on experience, population and economic surveys, and topographic maps manually to match population requirements with land possibilities.	Maps are prepared manually or using 2D CAD, relying on professional expertise without dynamic simulation or multiple alternatives.	Dubai—Dubai Urban Plan 2040 via the 3DEXPERIENCE City platform.	(Omollo & Opiyo, 2020).
4	Master plan,	Preparing a comprehensive plan for the road network, facilities, and services, and linking it to the infrastructure.	(Parish & Müller, 2001)	Generative Design, Urban Simulation, Multi-Objective Optimization	Dubai—Dassault 3DEXPERI-ENCity platform (experimenting with plans before implementation).	(Omollo & Opiyo, 2020; Stevens & Dragicevic, 2007)
5	Laws and legislation	Checking that the plan complies with the laws (setbacks, building ratios, ownership).	Manual reading of legal texts and building regulations by technical committees, review of plans on paper, and slow procedures.	Natural Language Processing (NLP), intelligent review systems.	New York—Port Chester via Gridics.	(Sun, 2014; Kitosi et al., 2024)

Continued

6	Community &Stakeholder Participation	Involving residents and service providers in discussing and approving proposals. Participation.	Public meetings, hearings, paper questionnaires, and presentation of plans in town halls.	Interactive engagement platforms, 3D models, chatbots.	Santiago, Chile via CityScope (MIT Media Lab).	(Innes & Booher, 2004; Rowe & Frewer, 2000)
7	Subdivision Plans Approval	Adopting the final plan and linking it to official laws and regulations. follow-up.	Manual review of documents and maps by technical and legal committees, one by one, on paper, with the possibility of delays and errors.	Verification systems such as Symbium.	California—San Jose using the Symbium platform	(Sun, 2014; Kitosi et al., 2024)
8	Follow-up on implementation	Monitoring implementation on the ground and addressing violations and deviations.	Periodic field visits by municipal inspectors, two-dimensional photography, manual paper reports.	Drones, Computer Vision, Propeller/Trimble Stratus.	Sydney, Australia via the Propeller/ Trimble Stratus platform.	(Yi et al., 2025; Omollo & Opiyo, 2020)

3. Research Methodology

This study used two main approaches to meet its three goals. First, a descriptive survey identified key AI applications in urban design and land division, comparing traditional and AI-based methods using secondary sources like books, research, and official reports. For the second and third goals, a field survey with semi-structured interviews evaluated land subdivision processes in Riyadh. These interviews, both direct and written, helped develop an analytical framework to understand AI's role in land division, with the aim of improving practices and urban quality.

The study adopted a descriptive-analytical approach, combining survey and field research, which is well-suited for analyzing complex urban phenomena in real-world contexts. It systematically describes planning processes from data collection to implementation, and monitors how land division evolves using natural, environmental, and regulatory data. This approach also examines technological shifts, exploring AI as a supportive tool alongside traditional methods, noting potential integration points and effects on urban design quality.

To deepen the analysis, a case-study approach was used, focusing on three land-division agencies in Riyadh with distinct roles. This allowed for a comparison of procedures and decision-making, reducing overgeneralization. This approach aligns with the complex urban process of integrating traditional and AI methods for land division, enabling a comparison of models and their impact on planning efficiency, flexibility, and accuracy.

By merging descriptive-analytical and case-study approaches, the study aims to develop a framework that explains how traditional tools and AI interact and to propose a model for better urban planning. The findings will support decision-makers in advancing planning practices.

3.1. Case Study (Riyadh City)

Riyadh, the capital of Saudi Arabia, has over 7 million residents and is the largest city, serving as the country's economic and cultural hub (Riyadh Municipality, 2023). Under Saudi Vision 2030, it is experiencing a development surge, with projects like King Salman Park, the 135 km Sports Path, and the Green Riyadh initiative planting 7.5 million trees to enhance urban life (Saudi Vision 2030, 2021; Royal Commission for Riyadh City, 2022). These efforts aim to transform Riyadh into a global city focused on economic growth and sustainability.

The city demonstrates how AI can help with urban land subdivision to address issues such as rapid population growth, land needs, and resource use. This study will examine land subdivision methods, evaluate AI readiness, and compare results from traditional and smart urban planning to promote sustainable growth and improve planning quality. The Riyadh Municipality oversees urban planning, land regulation, infrastructure, and law enforcement, playing a vital role in achieving Saudi Vision 2030's sustainable development goals.

There are three entities in Riyadh responsible for land subdivision in the city Figure 3.

Riyadh Municipality - Urban Planning Department.

Ministry of Municipalities and Housing - Urban Development Sector.

National Housing Company - Real Estate Development Sector.

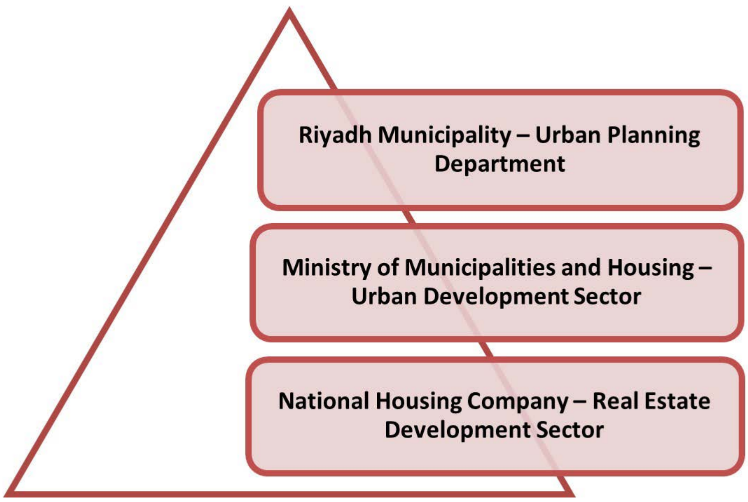

Figure 3. Three entities in Riyadh are responsible for land subdivision.

3.1.1. Riyadh Municipality

As part of this study, data were collected from the Urban Planning and City Development Agency at Riyadh Municipality, which handles creating urban policies, overseeing development projects, reviewing and approving urban plans, and monitoring their implementation in line with sustainable development goals and the city's vision for the future (Riyadh Municipality, 2023).

The interview was conducted with the Urban Planning Department within the Assistant Agency for Urban Planning.

3.1.2. Ministry of Municipalities and Housing

The study also involved the Ministry of Municipal and Rural Affairs, the Assistant Agency for Housing Supply and Real Estate Development, and the General Directorate of Urban Development, which is the regulatory body responsible for establishing policies and standards for urban planning and development across the Kingdom. It oversees the implementation of housing and urban plans and ensures they align with national development programs. Additionally, the General Directorate of Urban Development conducts relevant studies and regulatory initiatives for city planning and monitors the implementation of technical requirements for land subdivision and residential projects (Ministry of Municipal and Rural Affairs and Housing, 2024).

3.1.3. National Housing Company

The study also included the National Housing Company (NHC), which is one of the national companies owned by the Public Investment Fund. The National Housing Company encompasses several sectors, including real estate development. The real estate development sector is considered the core of the National Housing Company and the solid foundation upon which most of its work is based. It is one of the main sectors responsible for planning and implementing urban projects, subdividing land, and developing residential plans in accordance with sustainable urban development principles (National Housing Company, 2024).

These entities were selected because they represent the key sectors involved in land subdivision operations and in applying smart technologies to urban management. They also have field experience and development plans that help explain how traditional methods can be integrated with artificial intelligence tools in urban design and planning. **Table 3** lists the participating entities in the study and their roles in the land subdivision process in Riyadh.

Table 3. Three entities in Riyadh are responsible for land subdivision.

Entities in Riyadh are responsible for land subdivision	Main field	The main role
Riyadh Municipality - Urban Planning and City Development Department	Urban planning and design and land use regulation	Preparing and reviewing detailed urban plans, implementing municipal requirements, and following up on the approval of residential, commercial, and industrial plans in order to achieve urban balance within the city.
Ministry of Municipalities and Housing - Urban Development Sector	Urban policies and legislation, and oversight of regional and structural urban planning and design works.	Developing national guidelines and standards for urban planning, reviewing laws regulating land division, and adopting master plans at the urban area level.
National Housing Company - Real Estate Development Sector	Real estate development, management and design of major housing projects	Designing and implementing model residential plans, coordinating infrastructure work in cooperation with municipal authorities, and applying urban quality of life standards.

3.2. Data Collection Tools

The study used semi-structured interviews to collect field data, focusing on the urban land subdivision process in Riyadh. It aimed to analyze the procedures, identify challenges, and evaluate the use of artificial intelligence techniques at different stages of subdivision. The questions targeted organizations directly involved in land subdivision, such as the Riyadh Region Municipality, the Ministry of Municipalities and Housing, and the National Housing Company.

The interview questions were aligned with each stage of the land division process, with specific questions designed to reflect the unique technical and organizational procedures at each point. During development, the research considered the varying complexity across stages, assigning more questions to stages involving multiple procedures and roles across different entities. In contrast, stages with simpler procedures had fewer questions. Table 4 presents the five questions asked of participating entities, their objectives, and how they monitor current practices, identify challenges, and assess the level of digital technology integration at each stage.

Table 4. Semi-structured interviews.

Land division stage	Questions		The extent of integration of artificial intelligence technologies		
Stage name	First question	1.1. What are the traditional methods of data collection in the .... stage?	Riyadh Municipality	Ministry of Municipalities and Housing	National Housing Company
	Second question	1.2. What artificial intelligence techniques are used in the .... stage?	No sue /to some extent/ full use	No use /to some extent/ full use	No use /to some extent/ full use
	Third question	1.3. To what extent are artificial intelligence technologies relied upon? (No use/To some extent/Full use)			
	Fourth question	1.4. What are the obstacles to using artificial intelligence technologies at the .... stage?			
	Fifth question	1.5. How long does this stage take?			

The interview responses were gathered through official written correspondence with specialists at the participating entities, as well as face-to-face interviews when available. This approach helped document the responses and improve the accuracy of their interpretation. It is also noted that the interviews were conducted with the entities in their organizational capacity, not with specific individuals, because the procedures under study are organizational and administrative in nature and relate to the entity itself.

To ensure the organized collection and official documentation of information, the participating entities were contacted via facilitation letters issued by the university. These letters were intended to facilitate interviews and the collection of responses from relevant specialists. Table 5 shows the participating entities, facilitation letter numbers, their dates, and the methods of information collection.

Table 5. The participating entities and facilitation letters issued by the university.

Entities in Riyadh are responsible for land subdivision	Facilitation letter	Date of letter	Method of collecting information	Date of obtaining the answers
Riyadh Municipality	141685/81/7	8/12/2025	An official meeting with the entity	19/12/2025
Ministry of Municipalities and Housing	141741/81/7	8/12/2025	Official correspondence	24/12/2025
National Housing Company	141760/81/7	8/12/2025	Official correspondence	29/12/2025

A QR code related to interview questions, shown in Figure 4, has also been included. It allows viewing the question form that was sent and actually used for data collection, aiming to clarify the adopted research tool, standardize the format of questions asked to participants, and improve the accuracy of the methodology followed in the study.

Figure 4. A QR code related to interview questions.

4. Research Findings

This section explores the land subdivision process in Riyadh, using field data from the Riyadh Municipality, the Ministry of Municipal and Rural Affairs and Housing, and the National Housing Company. Its aim is to present research findings on current practices and technical and regulatory procedures, and to evaluate the level of technical integration and the application of artificial intelligence tools at each stage. This directly helps assess the current status of land subdivision in Riyadh.

Supporting this, the analysis of the eight stages in Riyadh's land subdivision process shows how three main entities—Riyadh Municipality, the Ministry of Municipal and Rural Affairs and Housing, and the National Housing Company—operate across these stages. Reviewing their responses indicates that the process relies primarily on traditional methods for data collection, analysis, review, and approval, with only limited use of digital technologies at certain points. Notably, artificial intelligence technologies are absent at all stages.

The data indicate that the initial data collection phase, analysis of natural features, and development of the master plan all rely on field visits, surveys, and traditional engineering methods, without the use of smart analytical tools. Moreover, the three entities stated that reviewing regulations and legislation, as well as meeting organizational requirements, are conducted through manual auditing. This process also affects the community and service sector participation stage, which mainly depends on paper correspondence and coordination meetings.

The final approval stages and monitoring of plan implementation still rely on traditional methods. Plans are manually checked against municipal requirements and then sent to service agencies for review, without using automated systems to read or assess compliance. Agency feedback indicates that monitoring relies on field supervision and periodic reports, lacking intelligent tools to track progress or automatically identify discrepancies between design and execution.

This overview indicates that artificial intelligence is still used only minimally across all stages, with human expertise and manual review primarily guiding decision-making. Intelligent technologies are largely absent from most current phases. This overall view provides an essential understanding of Riyadh's land subdivision process and serves as the basis for evaluating technological integration, as shown in Figure 5.

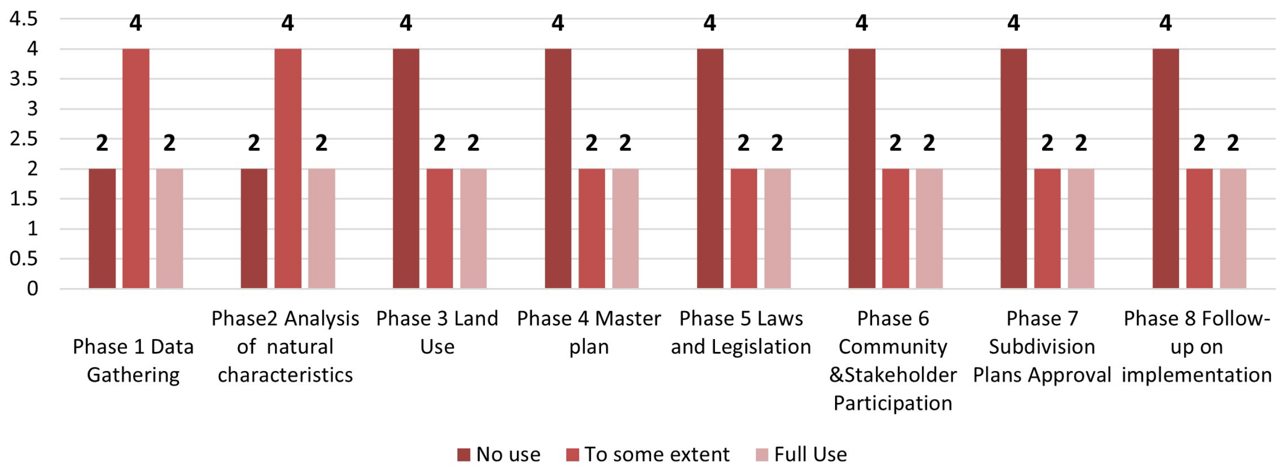

Figure 5. The extent of reliance on artificial intelligence technologies.

Figure 5 illustrates how artificial intelligence methods are incorporated across the eight land division stages in Riyadh, based on feedback from three participating organizations. It shows that most stages still rely on traditional approaches, with many indicating "no use" of smart technologies, underscoring the procedural focus of planning, auditing, approval, and implementation.

Figure 5 shows limited variation at certain stages, with weak signs of digital adoption or only partial benefits from technological tools. Nonetheless, this usage remains below full integration with artificial intelligence technologies. Overall, the data suggest that segmentation still relies mainly on traditional methods, such as human expertise, field visits, and manual reviews, with smart technologies not yet fully or clearly embedded across different stages.

This diagram provides a clear overview of current technological integration and serves as a key starting point for identifying the gap between current implementation and the potential of artificial intelligence technologies. The next chapter will build on this analysis by presenting results and exploring future pathways.

5. Results and Discussion

The study demonstrates how Riyadh Municipality, the Ministry of Municipal and Rural Affairs and Housing, and the National Housing Company operate by examining their methods, challenges, and the extent of digital tool integration at each stage. It also offers a clear, step-by-step overview of managing subdivision operations within the regulatory and technical framework, including start-up procedures, coordination with service agencies, plan review, and approval in accordance with urban planning standards.

Table 6 analyzes the stages of land subdivision and the elements associated with each stage, aiding in organizing and understanding the process and its sequence, in preparation for a detailed explanation of each stage in the following sections.

Table 6. Stages of land subdivision and the elements associated with each stage in Riyadh.

No	Land division phase	Current situation in Riyadh	Challenges	Artificial Intelligence (AI Technique) Tools	Artificial Intelligence (AI) Applications	Applied example
1	Data Gathering	Spatial, organizational, and environmental data are collected from multiple sources using traditional GIS tools, with a significant reliance on human in compilation and review.	The inconsistency in data quality and updating, the multiplicity of information sources, the weak integration between spatial and organizational data, and the reliance on manual procedures.	Computer Vision, LiDAR, Machine Learning for Spatial Data	LiDAR-based Mapping Systems, ArcGIS (GeoAI), Propeller/ Trimble Stratus	Helsinki—Using 3D LiDAR data; Singapore—AI-powered spatial databases
2	Analysis of natural characteristics,	An AI-powered platform for analyzing sites (noise, sun, wind, density) and suggesting design alternatives		Remote Sensing Analytics, Digital Twin Modeling, Machine Learning for Terrain Analysis	Digital Twin Platforms (مثل Virtual Singapore), GeoAI Tools, Google Earth Engine	

Continued

3	Land Use	A generative adversarial network (GAN) for producing realistic urban design alternatives based on existing city data.	(Quan, 2022)	Generative Design, Predictive Analytics, Spatial Optimization	TestFit, Autodesk Forma, AI-enabled GIS Planning Tools	United States (multiple cities)—Using TestFit to generate alternative uses and densities; Singapore—Land use analysis within a digital environment
4	Master plan,	A generative program based on procedural modeling to produce viewable and interactive 3D urban zoning patterns.	(Parish & Müller, 2001)	Generative Design, Urban Simulation, Multi-Objective Optimization	Autodesk Forma, TestFit, CityEngine	European and American countries—using Autodesk Forma and TestFit to generate and analyze alternative schematics before adoption
5	Laws and legislation	The plan is reviewed manually to verify its compliance with approved urban planning regulations and requirements through several entities, and based on human inspection and regulatory documents.	The length of the review period, the number of participating parties, the possibility of discrepancies in interpreting the requirements, and the high percentage of repeated comments on the plans.	Automated Compliance Checking, NLP (Natural Language Processing)	Symbium, Rule-based AI Systems, AI-enabled Compliance Tools	United States (California)—Using Symbium for automated verification of urban planning regulations
6	Community & Stakeholder Participation	Community engagement is limited by coordination meetings and stakeholder feedback, rather than by interactive digital platforms that enable broader stakeholder participation.	Limited channels for participation, difficulty in collecting and analyzing feedback, weak representation of beneficiaries' opinions, and lack of tools for immediate assessment of the impact of proposals.	Sentiment Analysis, NLP, Participatory Urban Platforms	AI-enabled Public Participation Platforms, Map-based Feedback Tools, NLP Analysis Systems	Helsinki—Using interactive digital platforms to engage the community and analyze
7	Subdivision Plans Approval	Subdivision plans are adopted after a series of reviews and approvals by multiple parties, involving the exchange of documents and technical reports and a heavy reliance on manual procedures and administrative follow-up.	The length of the approval process, the duplication of feedback between parties, the difficulty in tracking the application's status, and the delay in making the final decision.	Workflow Automation, Decision Support Systems, Predictive Analytics	AI-enabled Workflow Management Systems, Smart Approval Platforms	Estonia—Automated digital approval systems in government services
8	Follow-up on implementation	The implementation of the subdivision plans is monitored on the ground and periodically through supervisory reports and field visits, with limited reliance on digital systems for tracking and documentation.	The difficulty of continuously verifying compliance with approved plans, the delay in discovering violations, the weak time-based tracking of implementation, and the varying accuracy of field reports.	Computer Vision, Progress Monitoring using Aerial Images, Anomaly Detection	Drone-based Monitoring Systems, OpenSpace AI Vision Platforms	United States—Using OpenSpace and aerial monitoring technologies to track the implementation of urban projects

5.1. Data Gathering

The study demonstrates that data collection forms the foundation of Riyadh's land subdivision urban design, relying on gathering spatial, regulatory, environmental, and ownership data from multiple sources, primarily using traditional GIS tools and human effort. This influences the quality of input for later stages.

Current data collection relies on multiple sources and manual methods, which are effective but slow, less accurate, and difficult to integrate. Challenges include inconsistent data quality, diverse data sources, weak connections between spatial and organizational data, and manual steps that lead to errors and delays in site analysis.

Interview results show that data accuracy and update frequencies vary, and that multiple sources sometimes lack integration, which impacts early understanding of spatial and urban relationships.

Limited use of advanced analytical tools keeps urban design descriptive rather than analytical, which reduces decision-making flexibility in later subdivision phases, as noted in recent literature.

Studies show that using AI for data collection offers significant advantages over traditional methods. Computer Vision techniques rapidly and accurately extract urban features such as roads and buildings from aerial and satellite images (Lu & Weng, 2025). Deep Learning assists in classifying topographic data, detecting urban changes, and updating spatial databases efficiently, which reduces human error and improves reliability (Buslaev et al., 2018). Literature emphasizes the importance of combining LiDAR and UAVs with AI to create precise 3D models of urban features, including heights, slopes, and voids, which are often difficult to identify with conventional methods (Wang et al., 2025). Comparing these findings with Riyadh's current practices highlights a gap between AI's potential and its actual application.

The literature indicates that AI techniques used globally for data collection differ based on urban settings and levels of digital transformation, with notable examples:

1) Finland (Helsinki): Using high-density LiDAR with AI algorithms for detailed 3D mapping.

2) Singapore: Using smart geospatial databases with GeoAI for urban density analysis and land data updates.

3) United States: Using ArcGIS GeoAI and Google Earth Engine for satellite imagery analysis and tracking urban changes.

4) Australia and Canada: Processing drone and LiDAR data using platforms like Trimble Stratus and Propeller for land subdivision and infrastructure.

5) China: Applying machine learning in smart planning systems using big data and high-resolution satellite images.

These examples demonstrate that AI not only speeds up data collection but also improves integration and transitions the process from descriptive to analytical.

5.2. Natural Characteristics

Analyzing natural features is crucial in urban land subdivision, connecting initial data gathering to the design phase. It emphasizes site characteristics, such as topography, slopes, soil types, water sources, and environmental hazards, which affect land use, road design, and parcel layout. In Riyadh, current practices rely on traditional tools such as topographic maps, environmental data, field surveys, topographic reports, satellite imagery, and GIS. While these tools provide general insights into the site, they are limited in their ability to analyze complex spatial relationships.

Challenges include outdated data, repeated field surveys, poor data layer integration, and lengthy analysis. AI techniques like remote sensing, digital twins, and machine learning, demonstrated by the Virtual Singapore project, show promise for enhancement. Riyadh officials confirm that manual methods are still used for terrain and slope analysis, with no AI integration yet. AI could help analyze satellite and elevation data in the future. The site analysis process remains manual—dependent on field visits and reports—causing delays and data-update issues that affect decision-making. Literature supports early inclusion of natural factors for reliable land division, though traditional methods are slow and prone to errors, especially on complex sites.

The literature in the second chapter shows that remote sensing, digital elevation models, and AI enable more accurate, quicker terrain and environmental risk analysis, producing natural constraint maps almost instantly (Azadi et al., 2023; Wickramasuriya et al., 2011). The Virtual Singapore project demonstrates that digital twins, which combine high-precision LiDAR data with hydrological analysis, better support land division and land-use planning (Biljecki et al., 2015; Kitchin et al., 2021). Comparing this to interviews from Riyadh reveals a gap between AI's potential to analyze natural features and its current applications, highlighting the need to further develop this technology to improve urban planning and reduce reliance on traditional methods.

5.3. Land Use

The study indicates that land-use decisions greatly influence urban design in Riyadh, with decisions largely driven by regulatory controls, expert knowledge, and traditional GIS tools. This approach reduces flexibility because decisions rely on predefined plans, templates, and manual analysis. Challenges include limited scenario testing, difficulty forecasting effects on density and traffic, and weak assessment tools. Although advanced methods such as AI and generative design could improve planning, current practices primarily rely on regulations and experience. This traditional reliance on human judgment may limit adaptability and the ability to respond to future changes.

This phase's results align with Chapter Two's literature, which confirms its importance in balancing urban growth with sustainability by integrating traditional knowledge and innovative AI tools, such as predictive models and optimization algorithms. While the literature highlights that reliance on traditional methods is slow and limits the accuracy of scenario simulation, it emphasizes that AI-driven methods forecast demographic and economic shifts, guide spatial planning, and enable testing multiple alternatives to improve decision quality.

When comparing these theoretical proposals with interview results in Riyadh, it becomes clear that a gap exists between the potential of artificial intelligence technologies in land-use planning and their current level of use. This highlights the need to advance this stage through intelligent analytical tools that support decision-making and minimize reliance solely on human judgment.

5.4. Master Plan

The master planning phase combines previous outputs into a comprehensive urban vision, serving as an essential step where land use, natural features, and transportation plans are integrated into a spatial plan that defines urban relationships in Riyadh. Currently, the practice relies on a single final plan developed after decisions on land use and roads are made, which limits opportunities to test multiple alternatives.

Planning primarily relies on 2D maps and CAD, heavily depending on human interpretation and lacking tools to simulate different scenarios or predict future impacts. Challenges include limited simulation capabilities, difficulty in assessing effects on traffic and infrastructure before implementation, and lengthy review processes. There are opportunities to incorporate AI tools such as digital twins and generative design, as demonstrated by AI-supported platforms. Interviews reveal that Riyadh's master plan development still relies on traditional methods, using 2D plans and expert review, leading to slow processes and limited testing of alternatives. The absence of smart simulations causes delays in impact assessments on infrastructure and traffic, reducing the plan's flexibility and ability to adapt to future needs, especially in large projects.

This phase's results align with the literature in Chapter Two, demonstrating that it impacts the long-term urban development framework through road networks, service distribution, and infrastructure connectivity (Stevens & Dragicevic, 2007). Traditional two-dimensional design tools restrict testing scenarios and dynamic simulations (Omollo & Opiyo, 2020). In contrast, using AI techniques such as digital twins and generative design allows for the creation of virtual urban models to simulate movement, energy, and water flow, as well as to generate multiple planning options for efficiency and sustainability (Azadi et al., 2023). These tools decrease planning time, improve output quality, and support environmental and social standards in decision-making.

When comparing these theoretical proposals with the results of interviews in Riyadh, it becomes evident that a gap exists between the potential offered by artificial intelligence technologies during the master planning stage and their current level of use. This underscores the need to advance this phase with intelligent tools that support the planner's flexibility and enhance the efficiency of urban design for land subdivision.

5.5. Laws and Legislation

The review of laws and regulations is a crucial step in land subdivision and urban design to ensure adherence to rules and codes, including land-use regulations, building ratios, setbacks, heights, and infrastructure requirements. It connects technical planning to legal considerations and supports the assessment of AI use across Riyadh's land subdivision stages.

Currently, laws are reviewed manually by technical committees that compare plans to regulatory texts, relying heavily on human effort and expertise. Challenges include slow processes, errors, varied interpretations, and multiple authorities delaying approval. AI tools such as NLP and verification systems could automate and accelerate this process, as demonstrated by example tools. Interviews confirmed that Riyadh's review mainly involves manual checks by technical committees, which cause delays. Multiple review levels and the lack of automated systems further slow decision-making, especially for complex projects.

This phase aligns with literature in Chapter Two, emphasizing its role in ensuring urban plans comply with laws, protect rights, and promote justice (Sun, 2014; Kitosi et al., 2024). Manual reviews are slow and error-prone, leading to delays and re-approvals. The literature highlights that AI, especially NLP, can automate the conversion of legal text into digital rules, thereby speeding up reviews, reducing mistakes, and increasing transparency (Chalhoub et al., 2021). Intelligent systems can also detect conflicts between plans and regulations in real time and assist decision-makers more effectively.

When comparing these theoretical proposals with the results of interviews in Riyadh, it becomes clear that a gap exists between the potential offered by artificial intelligence technologies in the review phase of laws and regulations and their current level of use. This highlights the need to develop this phase using intelligent verification systems that help reduce review time and improve the quality of regulatory decisions in land subdivision projects.

5.6. Community and Stakeholder Participation

Community engagement in Riyadh's land subdivision is currently limited in scope and impact, relying mainly on traditional methods such as meetings and correspondence. Challenges include weak community involvement, difficulty representing diverse groups, and limited tools for analyzing feedback. AI tools such as 3D platforms, text analysis, and chatbots could improve participation and feedback processing, as demonstrated in a digital participation example. Officials confirm that engagement mostly occurs through official channels, which delays feedback and project phases. The lack of interactive tools hampers understanding of community input and reduces the benefits for plan quality.

The results align with Chapter Two and the research on community and stakeholder engagement. Studies confirm that involving the community is essential for successful urban planning and social acceptance, especially when using interactive channels for clear communication (Innes & Booher, 2004). Traditional methods like public meetings and surveys provide limited interaction and are difficult to analyze (Rowe & Frewer, 2000). In contrast, AI techniques such as 3D models and text analysis enhance participation by converting feedback into data for analysis and supporting transparent planning decisions (Evans et al., 2016). Smart tools like CityScope allow for instant testing of planning scenarios, boosting participation and improving urban design outcomes (Vergara-Perucich, 2025).

When comparing these theoretical proposals with interview results from Riyadh, it is clear that a gap exists between the potential of artificial intelligence technologies for community engagement and their current use. This highlights the need to create participation mechanisms using smart digital platforms that support transparency and improve the quality of planning decisions in land subdivision projects.

5.7. Approval of Subdivision Plans

The study indicates that the plan approval stage is the critical turning point in Riyadh's land subdivision process, marking the final step after technical and regulatory reviews. This stage follows a specific process involving several parties, as detailed in Chapter 4, which illustrates the approval mechanism and sequence.

Currently, plan approval in Riyadh is conducted through manual reviews by specialized committees to ensure regulatory compliance. This process involves multiple stages of review and coordination, leading to delays caused by lengthy procedures and multiple entities. Repeated reviews and varying interpretations of regulations often delay final approval, with limited use of digital systems for automation.

However, AI tools such as automated verification and digital accreditation platforms can accelerate the process and minimize errors by transforming requirements into digital rules, as shown by a practical example of an intelligent system application.

Officials from Riyadh Municipality and the Ministry of Municipal and Rural Affairs confirmed that typical approval involves multiple sequential reviews, which can take considerable time due to regulatory comments and technical feedback. Repetitive review cycles and inconsistent interpretations can further delay approval. The absence of integrated digital verification systems relies heavily on manual checks, limiting decision speed. Implementing AI-based systems could streamline procedures, enhance accuracy, and reduce delays.

The results align with the literature in Chapter Two on plan approval stages, confirming its importance for ensuring the legality and enforceability of plans. Traditional approval methods are slow and manual, increasing the risk of delays and regulatory misunderstandings (Sun, 2014; Kitosi et al., 2024). Conversely, Chapter Two emphasizes that incorporating AI, especially NLP-based automated verification linked to spatial data, accelerates approval processes, improves transparency, and reduces human error by matching plans with systems in real-time (Symbium, 2021). These systems also enable more accurate and reliable regulatory compliance assessments, especially for complex projects.

When comparing these theoretical proposals with interview results in Riyadh, it becomes clear that a gap exists between the potential of artificial intelligence technologies during the planning approval stage and their current level of use. This highlights the need to develop approval systems on smart digital platforms that enable faster procedures and enhance the quality of organizational decisions in land subdivision projects.

5.8. Follow-Up on Implementation

On-ground implementation follow-up is the final stage of urban land subdivision, ensuring that work adheres to plans and regulations. It connects theory to practice through ongoing field monitoring, supporting the third study objective of evaluating AI in land subdivision in Riyadh.

Table 6 presents Riyadh's current follow-up approach, challenges, and potential AI tools, such as drones and digital platforms, for real-time monitoring. Current practices involve site visits, reports, and photos, which are basic and rely on human effort, making it hard to detect small deviations early.

Challenges include slow procedures, difficulty tracking changes, and delayed detection of violations, all of which increase costs. Limited data integration hampers quick comparisons between completed work and plans. Interviews reveal deviations are usually minor (under 5%), often caused by errors, overlaps, or infrastructure updates.

AI tools like drones with computer vision, As-Built/Design comparison platforms, digital twins, and IoT enable real-time monitoring, automatic deviation detection, and precise reporting, as shown in smart platform examples.

Currently, oversight relies on routine site visits and traditional documentation, both of which are time-consuming and lack real-time tracking. Delays in identifying deviations may lead to rework, affecting schedules and costs. Limited use of analytical tools hampers proactive decision-making.

This phase's results align with the literature in Chapter Two on ground monitoring. Studies show that traditional methods relying on field visits and paper reports limit monitoring efficiency and delay error detection (Yi et al., 2025; Omollo & Opiyo, 2020). Limited visual and analytical documentation affects oversight quality and infrastructure sustainability. Conversely, Chapter Two highlights that AI techniques—such as drone-supported computer vision, Digital Twin, and IoT—improve accuracy and enable real-time comparison with plans (Batty, 2018). Smart platforms like Propeller and Trimble Stratus help track progress and detect deviations early, reducing errors and ensuring plan compliance.

When comparing these theoretical proposals with the interview results in Riyadh, it becomes obvious that there is a gap between the potential offered by artificial intelligence technologies during the implementation monitoring phase and their current level of use. This highlights the need to adopt smart monitoring tools to improve oversight efficiency and enhance the quality of land subdivision projects.

The results of phases seven and eight show that the absence of artificial intelligence technologies not only lengthens the approval process for plans but also carries over into the implementation follow-up stage, where reliance on manual work increases as adjustments and discrepancies are managed, impacting the continuity of the design vision between the approval and implementation stages.

6. Recommendations

This section directly links the study recommendations to the analytical framework of land subdivision phases shown in Table 4. By matching each recommendation with its corresponding phase, the study explains how urban design interventions—supported by AI tools—can address identified challenges and enhance procedural efficiency and planning quality in Riyadh.

6.1. Data Gathering Phase

Based on the analysis, the main challenges are scattered data sources, inconsistent data quality, and heavy reliance on manual work. Therefore, the recommendation to enhance the data collection phase directly addresses these issues. Improving the integration of spatial, organizational, and ownership data—using AI techniques such as machine learning and LiDAR-based mapping—can significantly enhance data accuracy and interoperability. This reduces uncertainty in early decision-making and the need for later corrections.

6.2. Analysis of Natural Characteristics Phase

The study identified the underutilization of environmental and topographical data despite the availability of advanced analytical tools. The recommendation to systematically incorporate natural site characteristics into urban design decisions addresses this gap. AI-powered platforms, including digital twins and remote sensing analytics, enable comprehensive evaluation of environmental factors such as solar exposure, wind patterns, and terrain conditions. This supports more responsive land-use allocation and infrastructure planning, reducing conflicts and inefficiencies in subsequent stages.

6.3. Land Use Phase

The analysis highlighted the need for more flexible and exploratory planning methods. Recommending a flexible land-use framework aligns with the capabilities of AI-driven generative design tools (e.g., GAN-based systems, TestFit, Autodesk Forma). These tools allow planners to create and evaluate multiple land-use options, optimizing spatial distribution and density while ensuring regulatory compliance. This approach enhances adaptability and promotes evidence-based decision-making.

6.4. Master Planning Phase

The findings showed a tendency toward planning based on a single scenario with limited comparison of alternatives. The suggestion to test multiple design options directly addresses this problem. AI-powered generative modeling and multi-objective optimization tools enable the simulation and comparison of different master plan configurations. This enhances spatial integration among transportation networks, public spaces, and parcel structures, resulting in more efficient and unified urban layouts.

6.5. Laws and Legislation Review Phase

The analysis identified delays, inconsistencies, and repeated feedback as key challenges in regulatory review processes. The recommendation to better integrate urban design considerations into regulatory evaluation corresponds with the adoption of AI-based compliance tools, such as NLP-driven systems and automated rule-checking platforms. These technologies can standardize the interpretation of regulations, accelerate approval timelines, and reduce discrepancies between reviewing entities.

6.6. Community and Stakeholder Participation Phase

Limited participation mechanisms and weak feedback analysis were key issues identified in this phase. The recommendation to involve the community early in the design process is supported by AI-enabled participatory platforms and sentiment analysis tools. These systems facilitate broader engagement, enable real-time collection of feedback, and allow planners to assess public responses to design proposals more effectively. This results in more inclusive and context-sensitive urban outcomes.

6.7. Subdivision Plans Approval Phase

The study highlighted inefficiencies in long approval cycles, duplicate reviews, and limited transparency. The suggestion to support and streamline the approval process involves using AI-driven workflow automation and decision-support systems. These tools improve coordination among stakeholders, enhance tracking of application status, and reduce administrative delays, ensuring greater consistency in preserving the original design intent.

6.8. Implementation Follow-Up Phase

The analysis revealed that monitoring processes depend heavily on manual inspections with limited digital assistance. Linking implementation tracking to urban design outputs addresses this gap. AI technologies such as computer vision, drone-based monitoring, and anomaly detection systems enable continuous, real-time comparison between approved plans and actual ground execution. This allows for early detection of deviations, supports corrective actions, and maintains urban design quality throughout the process.

7. Conclusion

This study examined how artificial intelligence (AI) can improve the urban design process of land subdivision, using Riyadh as a case study of rapidly growing cities facing complex regulatory and technical issues. The research was driven by the need to shift from traditional, labor-intensive methods toward more adaptive, data-driven approaches that enhance both efficiency and the quality of planning results.

To achieve its objectives, the study adopted a comprehensive methodological approach that combined theoretical exploration and empirical analysis. The literature review explored key AI applications in urban design and land subdivision, emphasizing their functional roles at various stages of the process. This was supplemented by a comparative framework showing the differences between traditional practices and AI-enabled methods. Additionally, an in-depth evaluation of the current land subdivision process in Riyadh was conducted through document analysis and field observations, revealing critical procedural gaps, inefficiencies, and decision-making challenges.

Building on these findings, the study developed a comprehensive, stage-based framework that shows how AI techniques can be systematically integrated into the land subdivision workflow. The framework highlights the strategic role of AI in data integration, predictive analysis, scenario creation, and decision-making support. It also offers practical recommendations to enhance professional expertise with intelligent tools, improve data reliability, and streamline procedures, while aligning with Riyadh's institutional and regulatory environment.

The findings confirm that AI should be viewed not as a replacement for human expertise, but as a complementary tool that enhances analytical ability and supports more informed, accurate, and context-aware design choices. By redefining land subdivision as a collaborative process between human judgment and machine intelligence, the study promotes more resilient, efficient, and future-ready urban practices that can keep pace with Riyadh's rapid growth.

8. Research Limitations

While this study offers a thorough framework for incorporating AI into Riyadh's land subdivision process, it has certain limitations. Firstly, the research concentrates on a single case study of Riyadh, which may restrict the generalizability of its findings to other cities with different regulations, cultures, or technologies. Secondly, the empirical analysis primarily involved document review and field observations; without real-time testing of the proposed AI tools—such as generative design or automated compliance systems—in an active municipal setting, practical issues like data privacy, required computational infrastructure, and institutional resistance could not be fully assessed. Third, the study did not provide a detailed cost-benefit analysis or a quantitative evaluation of time savings and accuracy gains from AI adoption. Lastly, given the rapid evolution of AI technology, the specific tools discussed may soon become outdated, emphasizing that the framework's value lies in its stage-based procedural logic rather than its particular technological components.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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