Development of 3D Cadastre Strata Building Information Model: An Interactive Web-Based Prototype

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Abstract

The "3D cadastral strata building information model prototype" project aims to enhance land administration practices in Bhutan by developing a comprehensive solution for the digital representation of 3D land parcels. Through cadastral surveying, plot fragmentation analysis, and 3D building modeling, the project ensures the accurate depiction of land ownership information in compliance with Bhutan's Lagthram system and the Strata Transaction Guidelines of 2021. At present, the system operates within a 2D spatial framework, where cadastral objects encompass entire land parcels, strata such as apartment buildings, or subterranean parcels. However, both land and property owners' requirements reveal the inadequacy of solely relying on 2D cadastral parcel registration, as real estate assets inherently exist in three dimensions. Utilizing advanced surveying technologies and the Django framework, the project creates an intuitive website interface that facilitates seamless access and management of land data, enabling stakeholders to visualize landscapes and explore detailed ownership information, including airspace and subsurface rights, in 3D mode. By providing a holistic perspective on land parcels and property rights, the project supports informed decision-making, resource allocation, and sustainable urban development. In summary, the project presents a pioneering approach to land administration, aiming to improve transparency, efficiency, and equity in land management practices, thereby contributing to sustainable development in Bhutan and beyond.

Keywords— 3D Cadastre Modelling; Cadastral Surveying; Lagthram; Digital Terrain Model; CaesiumJS; Django Framework

1 Introduction

Urbanization, driven by industrialization, economic opportunities, and government policies, has accelerated rapidly in recent years, exerting immense pressure on land use and necessitating the construction of complex structures[1]. This surge in urban development, characterized by the widespread use of high-rise buildings and increasing above- or below-ground infrastructure, underscores the need for innovative methods to manage land property effectively. Moreover, in the dynamic landscape of urban planning and land administration, integrating advanced technologies has become indispensable[2].

One groundbreaking advancement in land administration practices is the development of 3D cadastral strata building information models (BIMs). This innovative system integrates cadastral mapping, three-dimensional modeling, and comprehensive building information to revolutionize how we perceive and manage urban spaces[3]. The success of 3D cadastral systems hinges on the establishment of institutional and legal frameworks, along with the application of efficient technical solutions[2]. Traditional 2D-based land cadastres may prove insufficient, particularly in multi-storied or high-rise buildings, to provide the necessary clarity regarding rights, restrictions, and responsibilities (RRRs) [3]. The transition to a 3D information-enabled representation of land ownership is essential to meet the needs of owners, valuers, insurers, and investors.

The term "cadastral" refers to the systematic recording of land tenure, including property boundaries, ownership, and land use[4]. When integrated into a three-dimensional framework, cadastral data transcend traditional flat maps, offering a dynamic and immersive understanding of urban environments. The addition of "strata" emphasizes the layered nature of this model, acknowledging the vertical dimension of buildings and structures[5].

Despite the potential benefits, many nations still rely on 2D documentation for registering three-dimensionally delimited property units, known as "3D property units." This limitation extends to the representation of legal property boundaries and RRRs, often described textually and depicted on 2D maps and drawings[6]. Various international examples demonstrate the transformative impact of 3D cadastres. For instance, Shenzhen, China, employs a 3D cadastre to manage limited urban space effectively, visualize individual properties within multistory buildings, and plan urban development[7]. Similarly, the Netherlands and Australia have implemented 3D cadastres to clarify property rights, responsibilities, and restrictions, leading to improved decision-making and economic benefits[8, 9, 10].

Bhutan, experiencing rapid socio-economic development and demographic changes, faces escalating pressure on the housing sector. The proliferation of multi-storied ownership flats in urban areas highlights the urgent need for advanced cadastral systems. While Bhutan currently operates a 2D cadastral system, the absence of cadastral information above ground underscores the necessity of transitioning to a 3D cadastral platform. Therefore, this study aims to develop a web-based prototype for a 3D cadastral stratum building information model tailored to Bhutan's needs. By enabling storage, visualization, editing, updating, and transactions of geometric and administrative data, this prototype seeks to address the challenges posed by modern urban environments and contribute to more efficient and transparent land administration practices in Bhutan.

2 Materials and Methodology

2.1 Experimental location

The Jigme Namgyel Engineering College (JNEC) campus (Figure 1), which is situated at Dewathang under Samdrup Jongkhar Dzongkhag and has a geographical location of 26°51'06" N to 26°51'54" N and 91°26'48" E to 91°26'06" E and an elevation of 825 m (2600 ft) above sea level, was chosen as the study area.

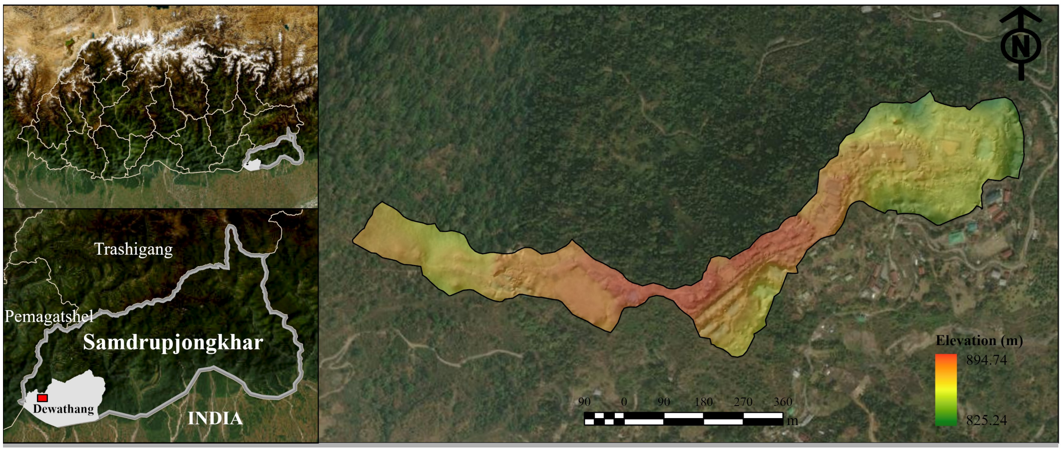

Figure 1: Experimental location depicting the elevation model generated through a ground-based topography survey

2.2 Methodology

The methodology encompassed in this study pertains to the development of physical modeling, which involves surveying and gathering both spatial and non-spatial features necessary for the storage of cadastral information pertaining to respective parcels, along with the incorporation of associated legal frameworks.

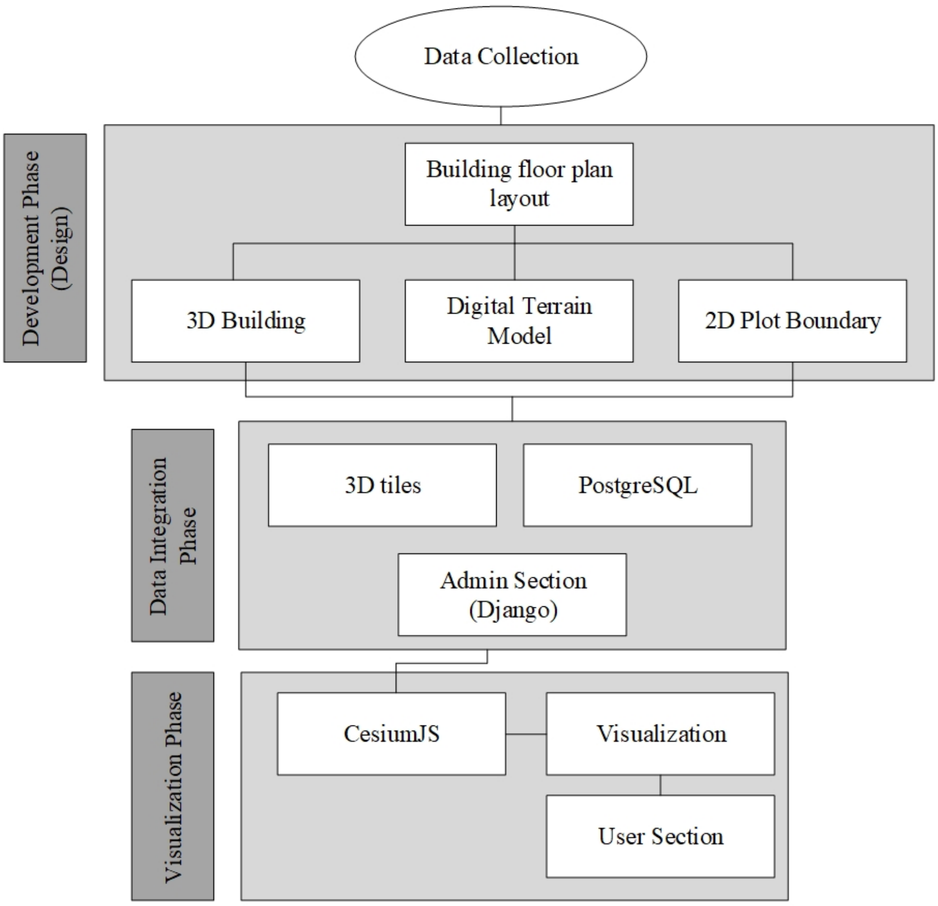

Figure 2: Methodological framework

Additionally, this section provides an overview of the imagery constructed through UAV-based photogrammetry for the delineation of Digital Terrain Models (DTM), which are instrumental in the construction of three-dimensional (3D) models of JNEC. The subsequent sections delve into a detailed exposition of the individual steps undertaken in the development of the 3D cadastre of JNEC (Figure 2).

2.2.1 Physical Modelling and Legal Framework

- **Physical Modelling**: In 3D cadastral modelling, a physical model represents the physical attributes of the built environment. Information about the geometry, location, and spatial relationships of parcels, buildings, and other land features is typically included. Pure physical models are not particularly designed for the purpose of mapping ownership arrangements and boundaries within multilevel buildings; however, they can be extended for representing and managing cadastral information, including the management of spatial and semantic information associated with physically existing objects at various levels of detail[11].
- **Legal Framework**: The laws, ordinances, and processes that control the ownership of land, property rights, and land administration make up the framework for 3D cadastral modelling. The 3D cadastral model accurately manages and represents the legal aspects of land. The legal definition of 3D objects and the registered rights in most countries are shown to be clearly impacted by the absence of clear legislation. Legal systems are primarily created in accordance with the local laws in each jurisdiction. Most legal models allow for the representation of ownership interests in two dimensions. The legal information for 3D cadastral buildings in Bhutan is represented based on the Strata Transition Guideline of Bhutan, 2021.

2.2.2 Analysis and Design

- **Data Acquisition and Data Processing Tool**: Data collection for 3D cadastral modelling involves gathering various types of spatial data to represent the physical and legal characteristics of properties and their associated rights, restrictions, and responsibilities (RRRs). For the 2D cadastral, the boundary was demarcated, plot fragmentation was carried out using an RTK instrument, and the individual plot parcels were assigned a plot ID. Additionally, the land parcel areas were calculated with LisCAD SEE version 12 software. The building floorplans were used to construct accurate 3D building models using SketchUp and AutoCAD version 2021. Using SketchUp 2021, a 3D model of the building was generated, incorporating interior design elements. To ensure comprehensive representation, the building model was designed floor by floor. The height of the building was determined based on precise measurements obtained from Total Station. The remote height feature of the Total Station allowed accurate height measurement data to be captured. By incorporating these data, the 3D model of the building was able to accurately represent the vertical dimension.
- **Digital Terrain Model (DTM)**: According to Hirt[12], a DTM is a digital representation of the terrain surface using a set of heights over 2D points. It approximates the continuous terrain surface by discretizing it into a collection of discrete points with unique height values. To obtain a detailed characterization of the landscape and enable proper visualization, a digital terrain model of the study area was generated. To create the DTM, aerial photographs were captured using a Metrice 300 drone. These photographs were subsequently imported into Agisoft Metashape, where the images were aligned. The next step involved georeferencing the images using the coordinates of the ground control points (GCPs). From the aligned and georeferenced images, a dense cloud was generated. This point cloud represents a three-dimensional representation of the terrain. The subsequent step involved removing surface features such as buildings, trees, and cars to focus solely on the terrain. Finally, a digital

terrain model with texture was generated, providing a realistic representation of the terrain surface. By following this process, the DTM provides valuable information about the topography of the study area, enabling further analysis and visualization for various applications.

2.2.3 Integration and Visualization

Integration involved connecting a PostgreSQL database system with the CaesiumJS platform to enable the visualization and analysis of geospatial data. When integrating a database with Caesium, the database served as a source of geospatial data, and Caesium provided the tools and capabilities to visualize and interact with that data in a 3D environment. The integration allows users to query, retrieve, and display geospatial information stored in the database within the Caesium platform. The 3D building models were stored in the presence of Caesium ions and were geo-referenced in the Caesium ion. The lagthram and ownership details are stored in PostgreSQL. Here, Caesium ion and PostgreSQL data were obtained from two databases. These databases are connected using the Django framework. Therefore, 3D visualization and an interactive interface are shown in CaesiumJS.

For the visualization of the 3D cadastre information, a website was created using HTML and CSS, providing a user-friendly interface. To further enhance the functionality of the system, an administrative section interface was developed. This interface empowered administrators to update and delete data in the PostgreSQL database. Any changes made through the administration section were automatically reflected in the CaesiumJS platform, ensuring that the information displayed remained up to date. The combination of the website, CaesiumJS interface, and Administ section provided a comprehensive and interactive visualization platform for the 3D cadastre information. Users could navigate and explore the 3D environment, visualize the terrain and buildings, and access detailed cadastral information. This approach not only improved the visual representation of land parcels but also facilitated a better understanding of property ownership and transactional details.

3 Results and Discussion

The results encompass several key components, including plot fragmentation analysis, the creation of DTM derived from photogrammetric processes, the development of 3D models, lagthram generation, the integration of 2D and 3D models within the Caesium environment, and web-based visualization that offers a user interface for viewing individual parcels in 3D mode discussed in following sections.

3.1 2D Plot Fragmentation

A 2D plot is crucial in the calculation of proportional land rights (PLR) for the subdivision of each plot into a required area based on the number and size of the flats owned by various owners within the plot since the project is prototype for creating a 3D cadastral strata BIM for residential buildings within the Jigme Namgyel Engineering College area. A total of 72 plot fragmentations were performed using an RTK instrument, as displayed in Figure 3, and the plot ID was assigned based on the division of the area into seven different zones.

3.2 Construction of 3D-DTM

The default Caesium terrain does not represent the actual topographical conditions, hence integration of the 3D-DTM accurately represents the surface overlyaing on the default caesium terrain. Figure 4 shows the DTM with a resolution of 10 cm created using UAV based-aerial photography from the Matrice 300 drone after processing in Agisoft Metashape software, and it was then uploaded to the Caesium ion to represent the surface.

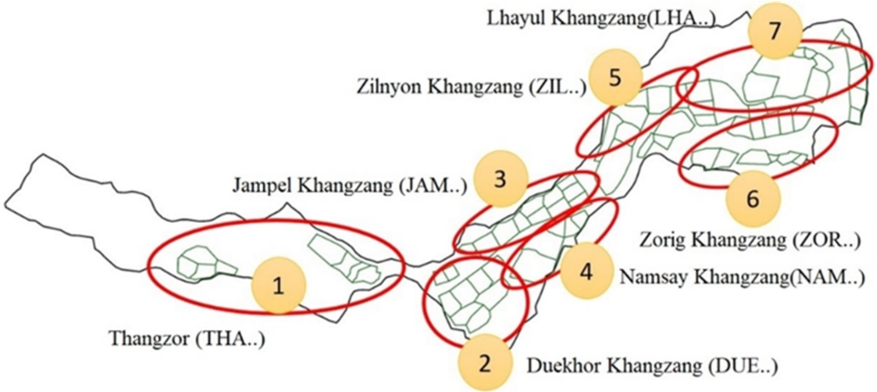

Figure 3: JNEC Plot fragmentation map

Figure 4: Digital terrain model with a 10 cm resolution and an integrated texture

3.3 Development of 3D Building Model

A 3D building for the representation of 3D cadastral strata BIM requires a building with an increased level of detail and an internal compartment, as well as an external representation.

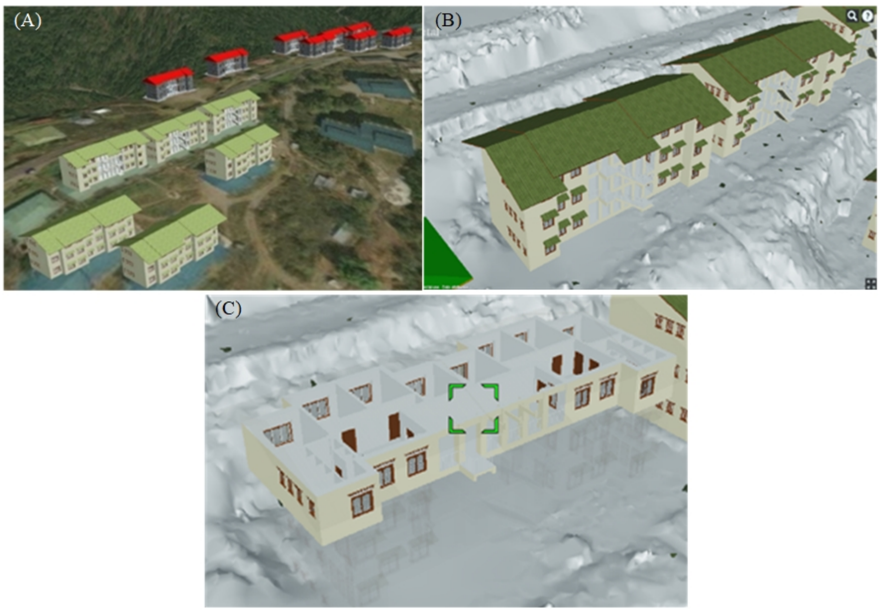

Figure 5: 3D buildings of JNEC, b) Exterior building Duelkhor Khangzang (DUE004), c) Interior flat of Duelkhor Khangzang (DUE004)

In line with the objective of the project, 3D buildings were generated using SketchUp software to develop the 3D model of the infrastructure. For residential buildings, each apartment and its internal compartments were generated separately and integrated to build a 3D building with an increased level of detail. The 3D buildings, exterior view of the Duekhor Khangzang (DUE004) building and its interior compartment are displayed in Figure 5.

3.4 3D Lagthram

In Bhutan, cadastral information about residential flats for multi-story buildings was still provided in 2D paper-based documents or a lagthram derived from the 2021 strata transaction guidelines. This project focuses on the 2021 strata transaction guideline (STG)[13] and the Lagthram for 3D cadastral information preparation, integration and visualization for each apartment. Figure 6 shows a sample 2D paper-based Lagthram prepared according to the STG 2021, and the Lagthram displayed on the JNEC eSakor website.

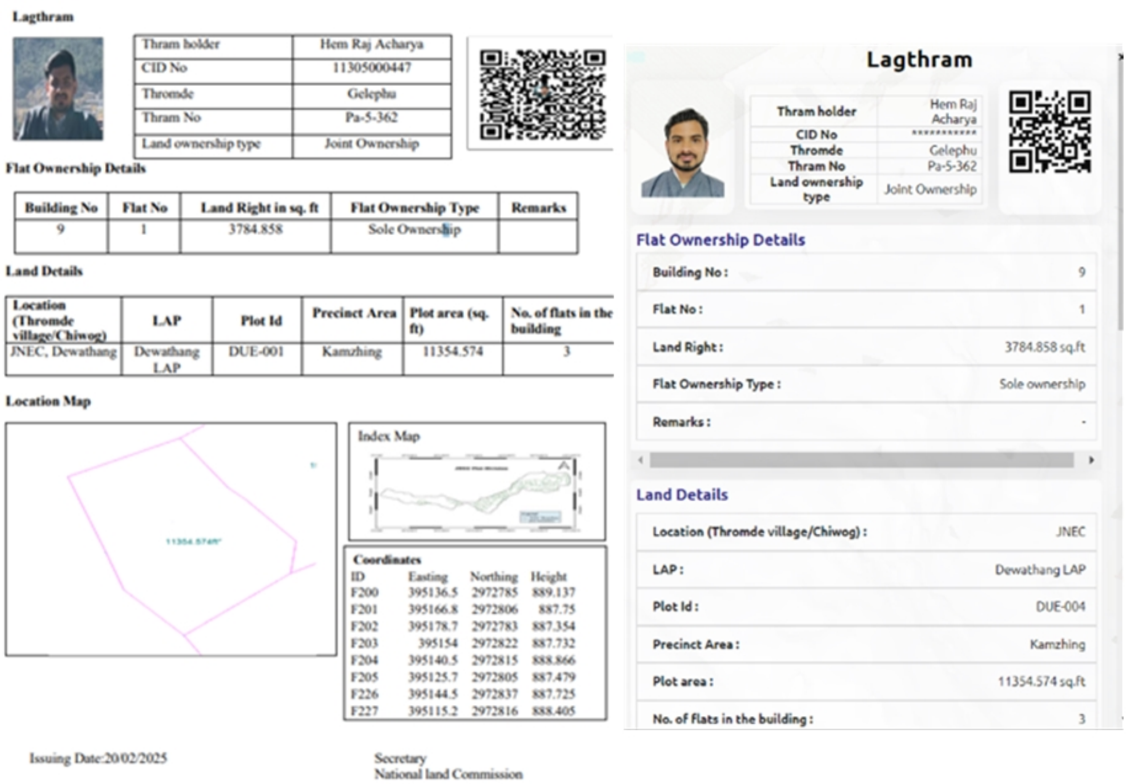

Figure 6: Existing lagthram

3.5 3D building, digital terrain model, 3D lagthram and 2D plot integration

As part of the integration, legal attributes are linked to corresponding physical features, such as building components and cadastral parcels, as well as specific model components with ownership rights and restrictions. The finalized 3D model offers a comprehensive view of the property, enabling several uses in land administration, property valuation, urban planning, and legal disputes.

In this prototype, physical models such as 3D buildings and DTMs were converted to 3D tiles, which were subsequently stored in the Caesium ion database, whereas legal boundaries such as 3D Lagthram details and 2D plot boundaries were stored in the PostgreSQL database. The two different databases were then integrated and visualized in CaesiumJS, as shown in Figure 7 and Figure 8.

Figure 7: Integration of the 3D building, DTM and 2D plot boundary in CaesiumJS

Figure 8: 3D Cadastral Strata information of Duekhor Khangzang-A building of different flat owners for a) second floor b) first floor and c) ground floor

3.6 Strata Transition Platform (JNEC eSakor)

JNEC eSakor comprises an urban land transaction system, a rural land transaction system, a land mortgage system, a land-related grievance redressal system and an online land tax payment system. The prototype JNEC eSakor(Figure 9 was created with the addition of a strata transaction platform, as shown in Figure 8, for the user to register, view and access services related to 3D cadastral strata transactions. It also provides the admin in updating and deleting the 3D buildings and other spatial related features.

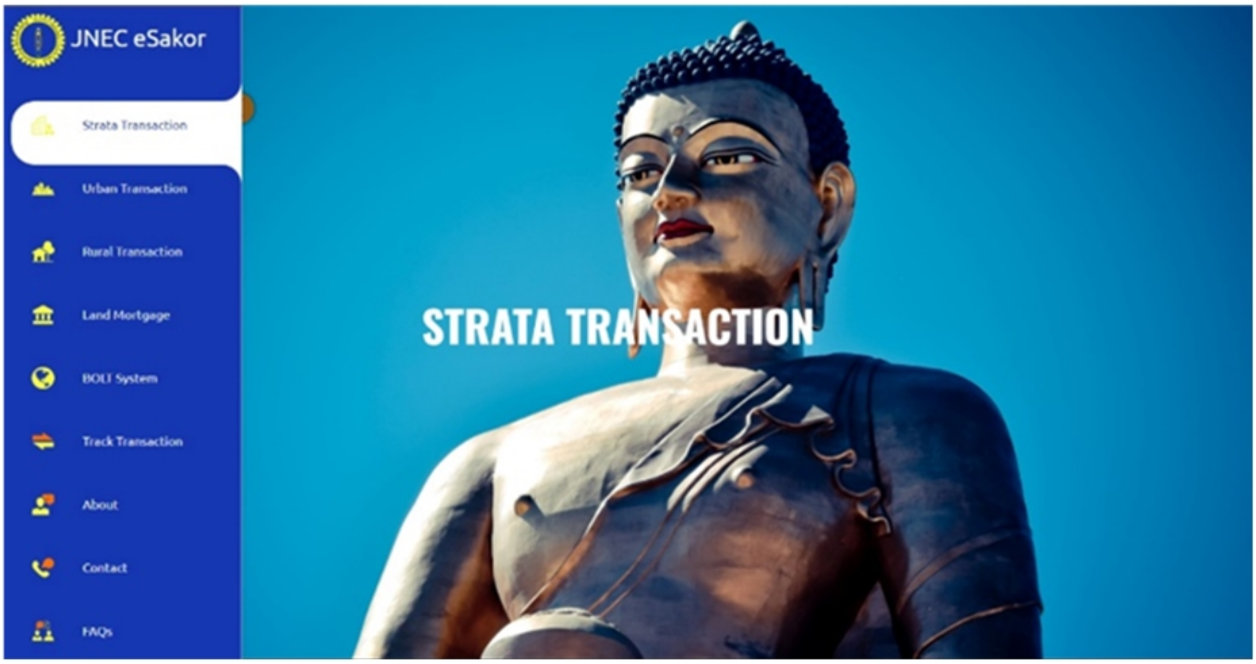

Figure 9: JNEC eSakor website

4 Conclusion

In conclusion, the "3D Cadastral Strata Building Information Model (BIM) Prototype" offers a comprehensive solution for digitally representing and visualizing land parcels in three dimensions. By integrating 3D modeling techniques, it aims to redefine traditional cadastre systems, providing more accurate depictions of land ownership and property rights. This approach facilitates better decision-making in land management and urban planning. The project implemented a website interface for accessing transaction details, effectively integrating lagthram and flat ownership data with the CaesiumJS platform. The administrative section ensures data integrity and enhances system usability. While challenges such as data accuracy and technology complexity were encountered, the potential of 3D cadastres to revolutionize land management systems remains evident. Improvements in data quality assurance, integration procedures, and user experience are recommended to enhance the prototype's effectiveness. Ultimately, 3D cadastres offer stakeholders a deeper understanding of land-related information, leading to more informed decision-making and improved land management practices.

Future works: Future research could focus on improving data collection methods to ensure the accuracy and reliability of information. Conducting case studies and real-world pilot projects to assess the practical implementation and effectiveness of 3D cadastre systems in different contexts could provide valuable insights. Moreover, to refine user interfaces and make them more intuitive and user-friendly, understanding user needs and preferences through usability testing and user feedback could guide the development of more efficient interfaces for accessing and interacting with 3D cadastre information.

Recommendation: The NLCS has been working to increase the effectiveness and efficiency of putting online systems in place to provide services to Bhutanese citizens, and with more experience, the NLCS has greatly improved over the years[14]. With the introduction of the Rural eSakor and Urban eSakor systems, the NLCS left the traditional way of processing land transactions in Bhutan. However, many improvements need to be made in the systems. The study recommended the incorporation of 3D models representation in NLCS eSakor in easy perception to the users regarding their percels information including transactions.

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