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Project 3D-CLUP: 3D Simulation of Comprehensive Land-use Plan Maps Using GIS and Data Analytics to Promote Sustainable Development

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Project 3-Dimensional Comprehensive Land-use Plan (3D-CLUP) provides a community-based local WebGIS application that delivers visualization and simulation with integrated 2D maps and 3D scenes realized through SuperMap GIS technology. It provides information on a specific barangay about population, type of community, hazards, and potential resettlements. SuperMap GIS technology allows for the creation of detailed maps and models that can be used to visualize and simulate various land use scenarios, providing decision-makers with a thorough understanding of the potential outcomes of various development plans. Through the presentation of both 2D maps and 3D scenes, the application can increase public awareness of the disaster risk, and planners to easily communicate the impacts of different land-use scenarios. Moreover, it offers a more interactive and dynamic approach to view and comprehend the effects of planned changes on the environment, facilities, and communities. This increased engagement can lead to better decisions and more sustainable use of resources.

Keywords; ecology, GIS; land use; zoning map; simulation; planning

Article history

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Introduction

The overarching theme of the Philippine Development Plan (2017-2022) revolves around the strategy and goal of achieving inclusive growth, a high trust and resilient society, and a globally competitive knowledge economy. The strategies to achieve these are divided into three major pillars "Malasakit," "Pagbabago," and "Patuloy na Pag-unlad." The pursuit of inclusive growth is perceived as both a strategy and an end goal, therefore translating this concept into more concrete terms that can be understood and operationalized at the local government level is a crucial point. Comprehensive land-use plan maps developed through local government units (LGUs) play an important role as policy drivers, providing a guiding framework to address pressing issues and facilitate municipalities' physical and land use development. These maps cover the municipality's entire territorial jurisdiction, addressing a wide range of concerns across sectors. Furthermore, they promote inclusivity by translating development goals, objectives, and policies into spatial plans that ensure proper land resource allocation while focusing on sustainable development and environmental protection.

Land-use planning is an approach for ensuring safe and sustainable living conditions and livelihoods for the population while protecting important ecosystem functions through fair and transparent management systems that balance and reconcile conflicting interests (Lech & Leppert, 2018). Additionally, land use planning is crucial in addressing the scarcity of land and balancing competing land uses, as CLUP maps are mandated for all local government units in the Philippines. However, there is a need to assess the capacity of LGU planning teams, especially in areas affected by natural disasters. Backed by empirical data, the study conducted by Quitalig and Orale (2016) focuses on the Province of Samar, which faced the impact of Super Typhoon Yolanda ("Haiyan"). Through interviews and data analysis, the study examines the capacity of LGU planning teams in formulating CLUPs and highlights the need for capacity building, including expertise, staffing, equipment, and database management (Quitalig & Orale, 2016). To achieve urban sustainable development and promote livable communities, it is crucial to mainstream disaster risk reduction and climate change adaptation in the local planning processes (Raza, 2018).

Moreover, current comprehensive land-use plan preparations do not make use of high satellite imagery and hence do not reflect the true-existing land use condition. The process of generating the land use map from high-resolution satellite data is the most cost-effective, compared to the usual ground survey work and aerial photography (Bato et al., 2011). Through remote sensing, high-resolution datasets have been generated, and with the application of contemporary image-processing techniques, these datasets can be transformed into valuable products (Khan & Fatima, 2021).

With the application of GIS and data analytics, the resulting maps will have a scenario-based comprehensive plan, which is data-informed, shaped by diverse inputs from the community, adaptable, and highly responsive to changes occurring across all sectors.

This approach significantly contributes to sustainable development and policymaking in areas such as social, economic, infrastructure, local governance, and the environment, enhancing risk reduction and making communities more resilient to natural hazards.

Objectives

The objective of this research is to fundamentally enhance urban resilience by harnessing the potential of advanced three-dimensional (3D) visualization, geospatial research, and data analytics. This study aims to equip cities with a nuanced understanding of geohazards, facilitating proactive mitigation and effective response strategies that safeguard lives, critical infrastructure, and promote sustainable urban development against the backdrop of climate change and growing urbanization. Through the development of sophisticated 3D visualization tools and geospatial models, this research intends to augment urban stakeholders' awareness and preparedness for geohazard events, enabling proactive protective measures. Furthermore, it seeks to optimize resource allocation for disaster preparedness and response by analyzing extensive geohazard mapping and simulations, thus providing actionable insights for cities to enhance resilience and recovery processes following geohazard incidents.

Methodology

A meticulously outlined methodology is integral in the endeavor to craft impactful smart city projects, guiding the methodical establishment of urban digital models, meticulous data acquisition through the sensing layer, and strategic integration of GIS throughout multiple phases to achieve optimal results.

According to Shahrour (2018), a systematic strategy includes the construction of the urban digital model, data collection using the sensing layer, then data analysis, interactive data visualization and system control, as depicted in Figure 1. Additionally, for smart city projects, the geographic information system (GIS) provides advanced and user-friendly features (Shahrour, 2018).

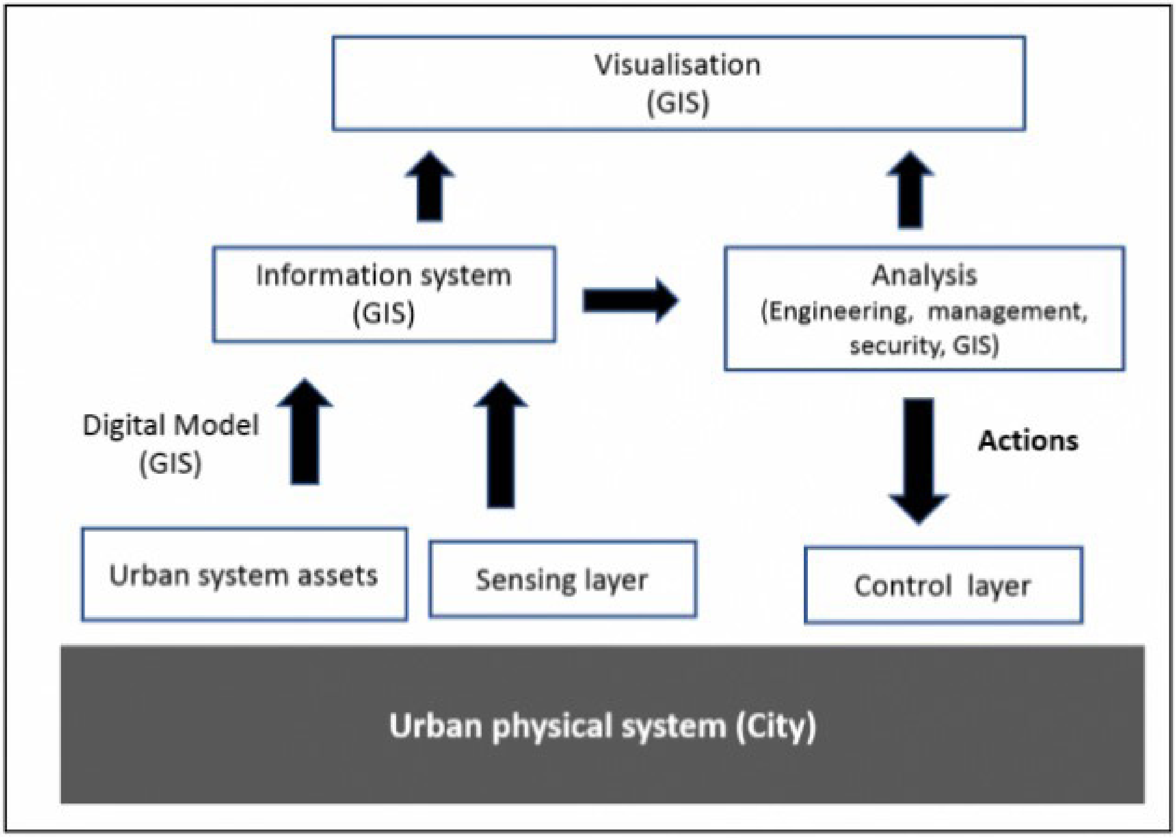

Figure 1. Implementation of Smart City Projects

While technology like GIS can provide valuable insights for land-use planning, effective implementation requires collaboration across key institutions. This collaboration is essential for ensuring that data is collected, analyzed, and used in a way that is both sustainable and transparent. In the Philippines, land-use planning underwent dramatic adjustments in the mid-2000s to address challenges of scattered processes and resource degradation. The significance of joint efforts across multiple ecosystems and authorities to overcome land scarcity and improve resource management became clear (Leppert et al., 2018). This shift highlights the importance of collaboration across important institutions to establish sustainable living conditions, improve local government transparency, and maintain a balance in land-use planning functions within the Philippine administrative system.

2D and 3D Mapping Approach

The project' approach utilizes land-use plan maps, demographic statistics, and hazard maps, enabling a holistic representation of the city's physical infrastructure, population density, and potential hazards as. This comprehensive approach aligns with the principles of integrated urban planning and sustainable development, ensuring that the model effectively supports smart city project implementation and land-use planning decisions.

The integration of these many data sources allows the researchers to produce a detailed and instructive 3D urban digital model. Figure 2 demonstrates the approach utilizing SuperMap GIS to deliver simulation and visualization of the project.

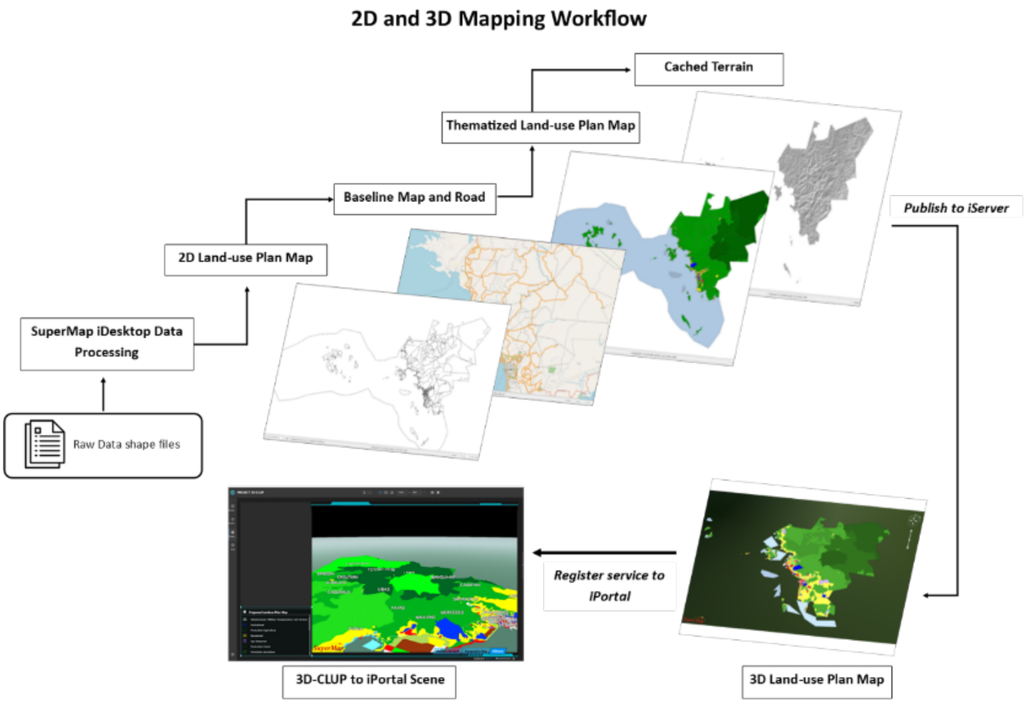

Figure 2. 2D and 3D Mapping Workflow

2D and 3D Mapping Approach

Data Collection and Preparation

This study employs geospatial data to craft detailed two-dimensional (2D) and three-dimensional (3D) maps, alongside simulations to bolster urban resilience strategies. Our data set, constructed within a geographical information system (GIS) framework, encompasses satellite topographical imagery, road networks, zoning boundaries, and hazard maps. Critical elevation, slope, and contour data, verified by the National Mapping and Resource Information Authority (NAMRIA), underpin our analysis. Zoning ordinances further detail land use classifications, delineating between developed areas (residential, commercial, industrial, institutional, educational facilities, infrastructure, and utilities) and undeveloped lands (agricultural, forest, barren land).

Geospatial Data Processing with SuperMap iDesktop

Utilizing SuperMap iDesktop, a leading enterprise GIS application, we seamlessly integrated our geospatial data into a unified analysis and development platform. This process involved importing the collected data and standardizing the coordinate system to WGS-84 (EPSG 4326). Subsequent spatial analysis of both vector and raster datasets facilitated a deeper understanding of the inherent spatial characteristics and patterns, crucial for the nuanced development of our mapping initiatives. SuperMap's 3D GIS approach, embedded across their product suite, enhances our capacity for sophisticated data analysis and application development.

Implementation of the SuperMap iPortal Dashboard

The SuperMap iPortal platform was instrumental in enabling the creation of a versatile online mapping web application, without the need for coding. Featuring the Map Dashboard webapp, SuperMap iPortal offers a powerful tool for generating extensive visualization displays. This user-friendly interface supports the intuitive development of map visualization applications, integrating published data, services, maps, and scenes for comprehensive GIS spatiotemporal data visualization. Through DataVIZ, we crafted detailed census, land-use, and hazard maps, configuring thematic layers, base maps, and annotative elements to ensure clarity and effectiveness of our visual outputs.

User Interfaces

Graphical User Interface (GUI) The user interface for this local web application is created using Supermap iServer for datastore and Supermap iPortal which is a GIS portal platform for integrating, searching, sharing, and managing GIS resources and system monitoring dashboards. It provides fullfeatured web-side applications and brings very useful functions such as browsing 3D scenes, creating a practical dashboard, and building template-based applications.

Application Programming Interface (API)

Supermap iServer REST API – SuperMap iServer uses a REST architectural design and offers an HTTP-compliant iServer REST API. The GIS functionality is made available to clients as resources via SuperMap iServer.

Security Interfaces:

The frameworks listed below provide administrator and user privacy, data security, and site protection.

Central Authentication Service Single sign-on (CAS SSO) – Users must enter a username and password for verification before continuing to access the GIS services. The GIS server will forward the request to the authentication server for user authentication.

Secure Encryption Standard/HyperText Transfer Protocol Secure (SSL/HTTPS) – iPortal enables proxy service HTTPS protocol to provide encrypted communications and network server identity identification.

Security Module – Protect the GIS server allowing only trusted users and administrators to access it.

Lightweight Directory Access Protocol (LDAP) Account Login - SuperMap iServer supports login by LDAP authentication and achieves login and visiting iServer by using the user in the LDAP server.

Software Interfaces:

The frameworks stated below constitute the base for the entire development, design, and completion of the application.

1. SuperMap iDesktop – includes several 2D&3D integration functions such as data management and processing, editing, mapping, analysis, 2D/3D charting, and so on.

SuperMap 3D iClient for WebGL – a cross-browser client application that doesn't require a plugin in the service GIS architecture. It is built on the Cesium open-source framework and is geared for HTML 5.

This research develops a community-based local information system application integrating two-dimensional (2D) and three-dimensional (3D) visualizations and simulations to support hazard preparedness and environmental management within specific barangays (neighborhoods). The application provides critical information on barangays, including names, numbers, populations, and community types. It features 2D and 3D maps to identify areas at risk of natural hazards such as floods, landslides, and storm surges, highlighting constrained and other risk-prone areas to mitigate potential environmental impacts.

Furthermore, the system presents existing and proposed land-use plans in both 2D and 3D formats. This visualization aids in promoting suitable land areas for future development, encompassing settlement, agro-industrialization, eco-tourism, and urban use within the municipality. The application facilitates the identification of potential resettlement areas through spatial query and analysis, offering insights into verified available settlements as of 2021. Additionally, a 3D simulation employing hydrological analysis enables the determination of potential flood areas based on city topography.

Scope and Delimitation

This research develops a community-based local information system application integrating two-dimensional (2D) and three-dimensional (3D) visualizations and simulations to support hazard preparedness and environmental management within specific barangays (neighborhoods). The application provides critical information on barangays, including names, numbers, populations, and community types. It features 2D and 3D maps to identify areas at risk of natural hazards such as floods, landslides, and storm surges, highlighting constrained and other risk-prone areas to mitigate potential environmental impacts.

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2021. Additionally, a 3D simulation employing hydrological analysis enables the determination of potential flood areas based on city topography.

Limitations

The study's scope is confined to the application's capability to provide accurate visualizations and simulations based on available data of Catbalogan City as of 2021, specifically focusing on the barangay level. The effectiveness of hazard mapping and land-use planning visualizations may be limited by the quality and recency of the input data, including topographical images, demographic statistics, and land-use classifications. The study does not encompass real-time data analysis or the integration of dynamic data sources, which could further enhance the application's utility in disaster response and urban planning.

The application's performance in identifying potential resettlement areas and simulating flood risks is subject to the accuracy of spatial queries and hydrological models used. These models rely on historical data and existing environmental conditions, which may not fully account for future changes in climate patterns, land use, or urban development. Consequently, the application should be viewed as a tool for preliminary analysis and planning, rather than a definitive guide to hazard mitigation and land-use policy.

Results and Discussion

Project 3D-CLUP is Project 3D-CLUP: 3D Simulation of Comprehensive Land-Use Plan Maps using GIS and Data Analytics to Promote Sustainable Development is an online mapping solution based on SuperMap technology, designed specifically through the iPortal web application - MapDashboard. The dashboard is built by configuring and starting iServer, iPortal, and iServer Datastore. The base map used in the 2D maps is OpenStreet Map (OSM) and data sources for statistical presentation (census, urbanization level, and potential resettlements) are acquired from Catbalogan City comprehensive land use plan maps (2023-2033) volume 3 sectoral studies book. Figure 3a-8b shows the flow of the final and generated 2D maps and 3D scenes and simulations. To access the web application, users can access the iPortal homepage by using the GIS portal (http://<server>:<port>/iportal) provided by the administrator. Clicking the CLUP Dashboard button opens the Project 3D CLUP main page.

Additionally, Figure 5b, 5c, and 5d present two-dimensional hazard maps for floods, storm surge, and landslide. These maps, like the demographic and land-use maps, provide details regarding the specific barangays affected by each hazard, with accompanying legends to aid in risk identification. Figure 5a encompasses potential residency data, including settlement availability and details such as lot numbers and area for the selected settlement. In Figure 6, the topographic map dashboard uses map swipe operation to view the two maps, the Catbalogan city terrain and city contour.

Project 3D-CLUP brings forward an innovative methodology, leveraging cutting-edge 3D visualization technology to craft immersive renditions of urban environments. These immersive representations are vividly portrayed in Figures 7a to 7e. Users have the capability to explore and engage with the 3D-transformed versions of the CLUP and hazard maps. Through this three-dimensional perspective, it goes beyond conventional two-dimensional maps and satellite images, offering a more in-depth understanding of urban vulnerabilities and infrastructure.

Most importantly, the system provides the capacity to simulate flood hazard scenarios with a remarkable level of reality, as shown in Figure 8a and 8b. This groundbreaking feature empowers cities to visualize and proactively plan for potential disasters, offering a critical advantage in the formulation of resilient strategies and infrastructure.

Finally, Project 3D-CLUP fosters collaboration among diverse stakeholders, including city planners, scientists, engineers, and policymakers. This multidisciplinary approach allows researchers to create a robust framework that can be adapted to various urban contexts. Furthermore, it's important to note that the system is designed to be fully customizable to different cities. This means that, with the necessary data and input from the new city client, we can create another personalized dashboard tailored to their specific needs and circumstances. This flexibility ensures that our program can accommodate the unique requirements of different areas and be a valuable resource for urban planning.

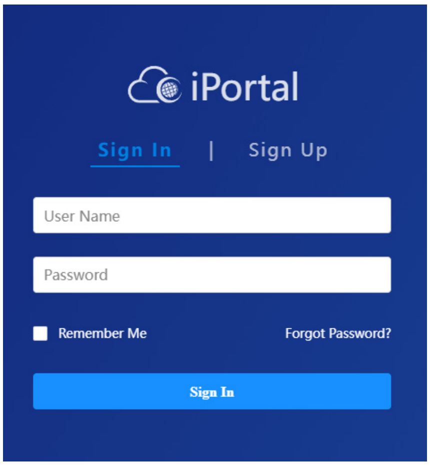

Figure 3a. Login Interface of the iPortal GIS

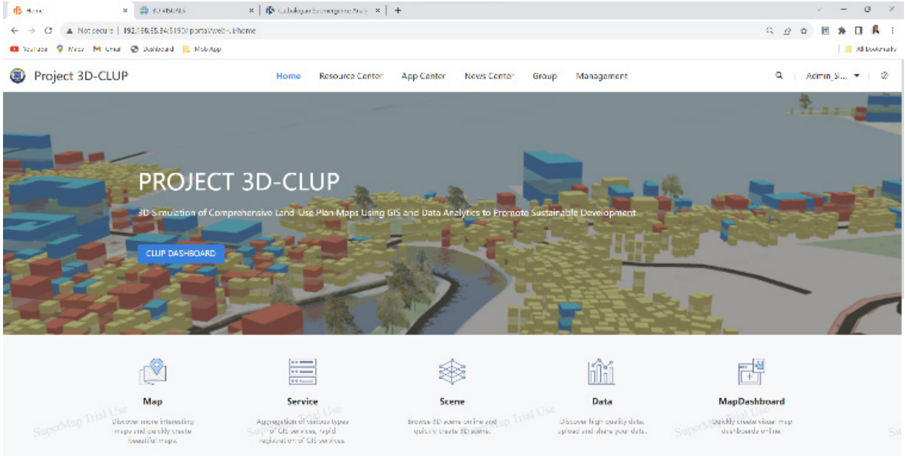

Figure 3b. User Dashboard of iPortal

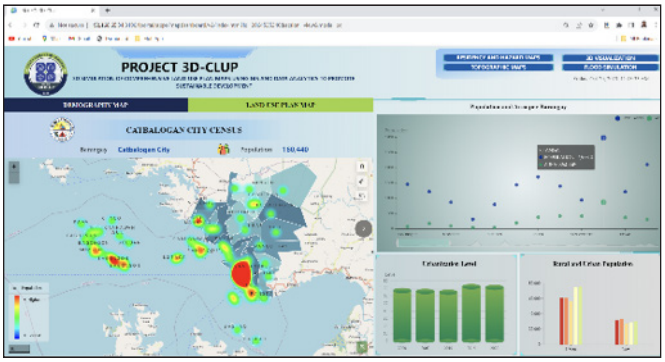

Figure 4a. Analytical Interface for Demographic Data Visualization in Catbalogan City

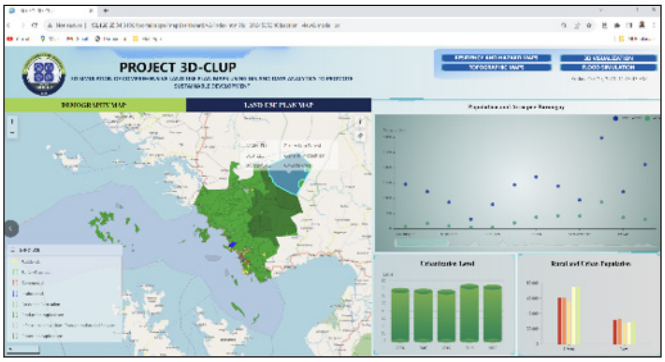

Figure 4b. Comprehensive Map of Current Land Use Patterns in the Municipality

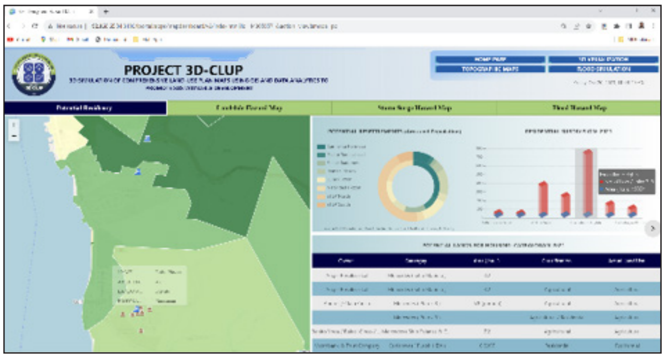

Figure 5a. Tab View of Potential Resettlement Areas

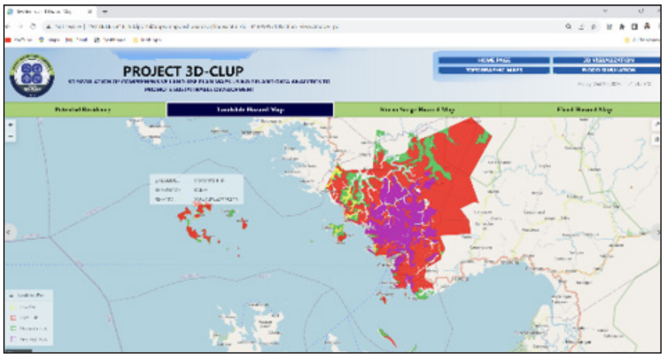

Figure 5b. Landslide Hazard Map Illustrating Susceptibility in Hilly Terrain

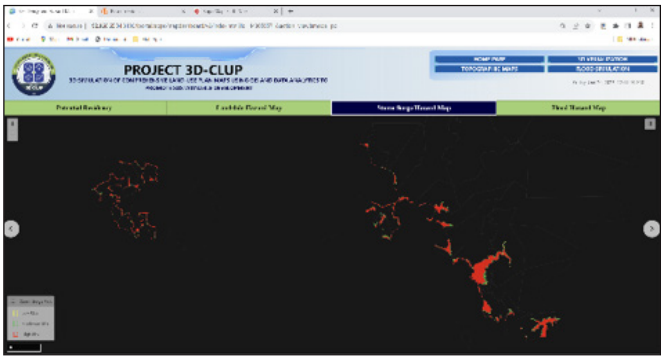

Figure 5c. Storm Surge Hazard Map Highlighting Risk Zone in Coastal Regions

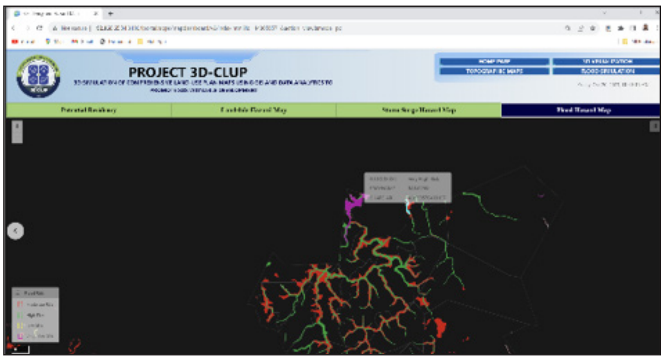

Figure 5d. Flood Hazard Map Displaying Vulnerable Areas within the Project Scope

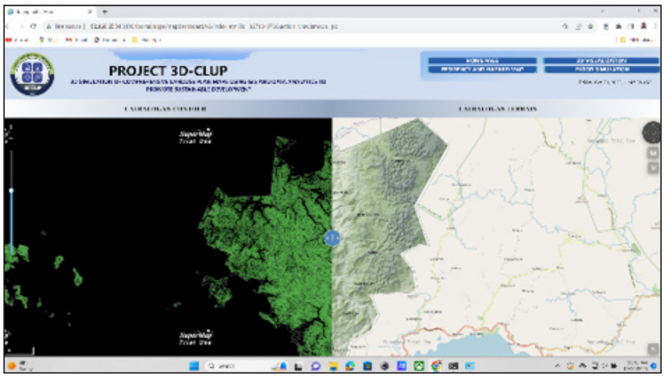

Figure 6. Interactive Topographical Mapping Dashboard

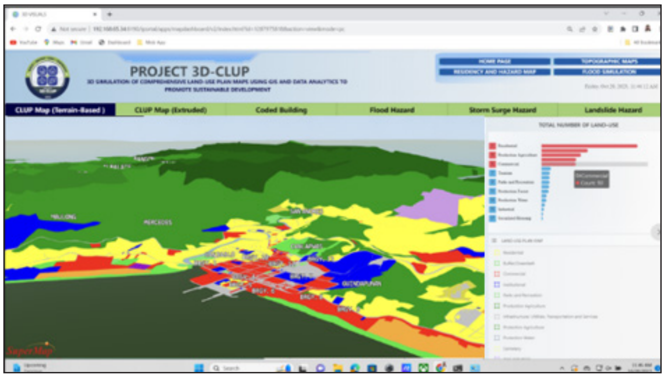

Figure 7a. 3D Visualization of Proposed Land-use Planning

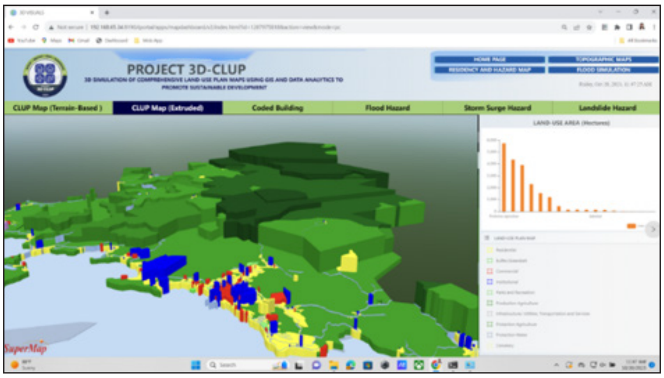

Figure 7b. Three-Dimensional Extruded Land Use Visualization

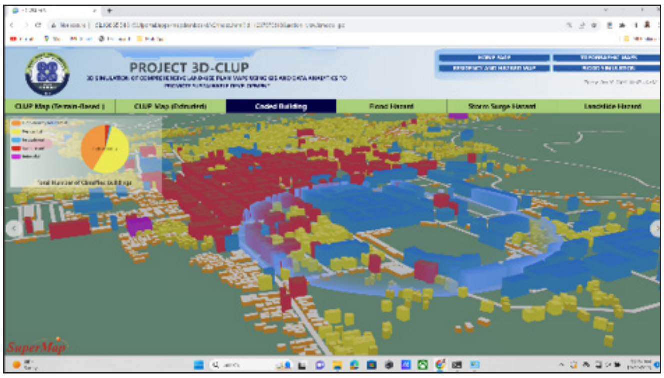

Figure 7c. Visual Codification of Building Structures

Figure 7d. Three-Dimensional Rendering of Flood Risk Areas

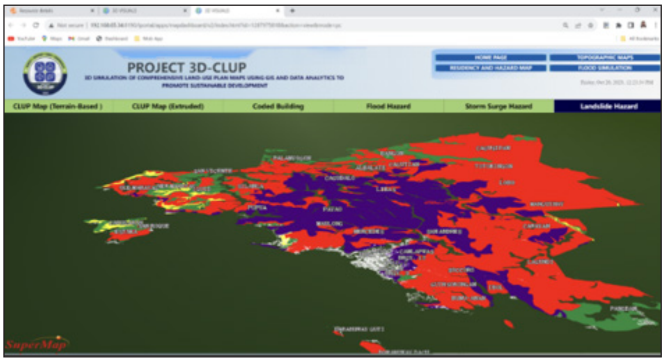

Figure 7e. 3D Visualization of Landslide Susceptibility

Figure 8a. Graphical Representation of Hydrological Data Analysis in iPortal

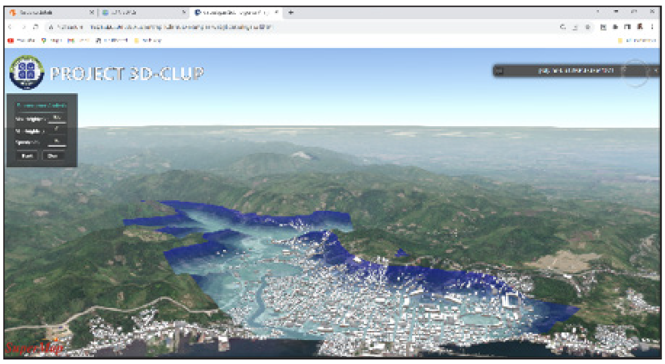

Figure 8b. Three-Dimensional Hydrological Simulation Depicting Flood Dynamics

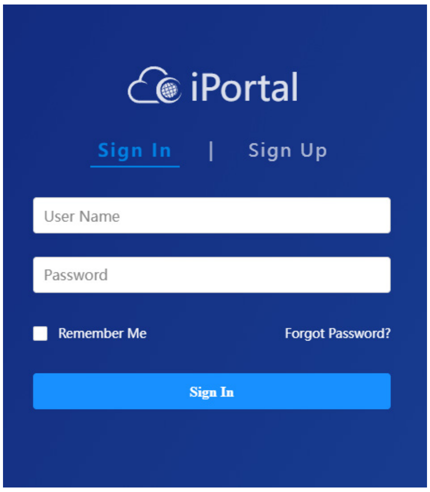

Figure 1. iPortal Homepage

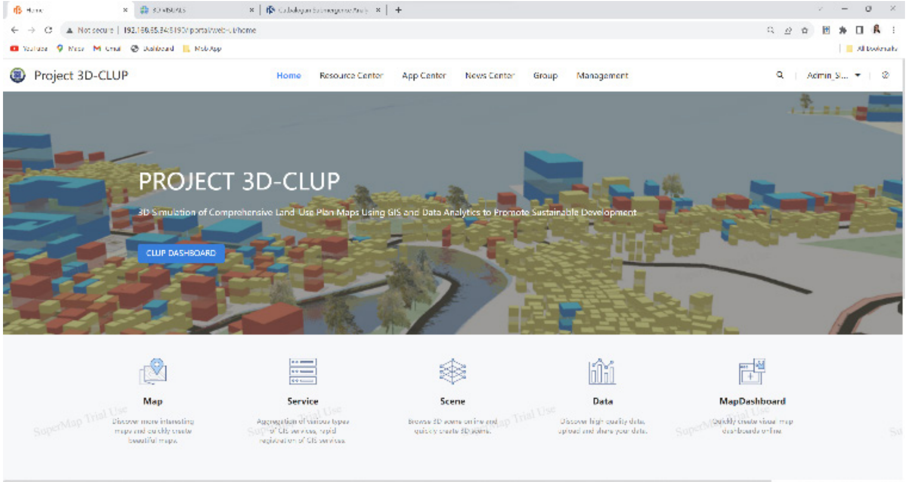

Figure 3b. iPortal User Homepage

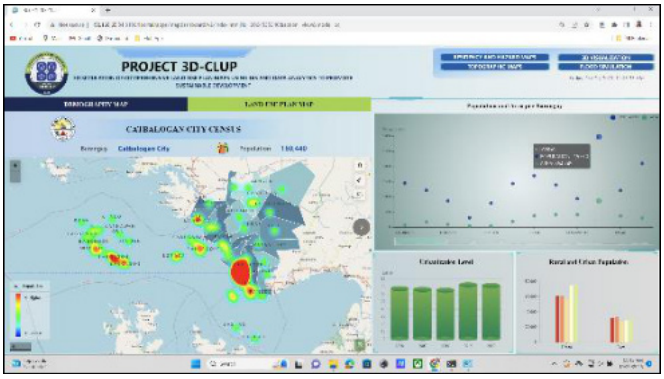

Figure 3. City Demography Interface

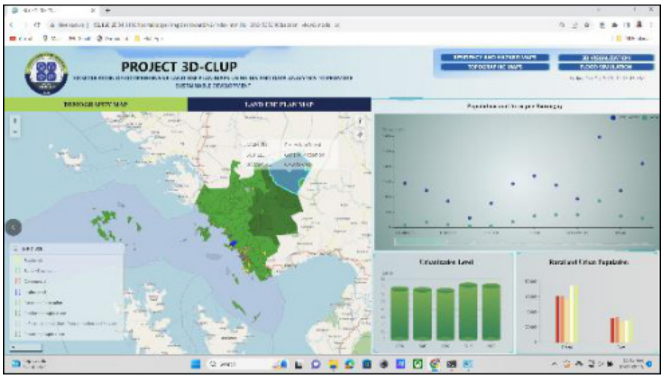

Figure 4. Existing Land Use Map

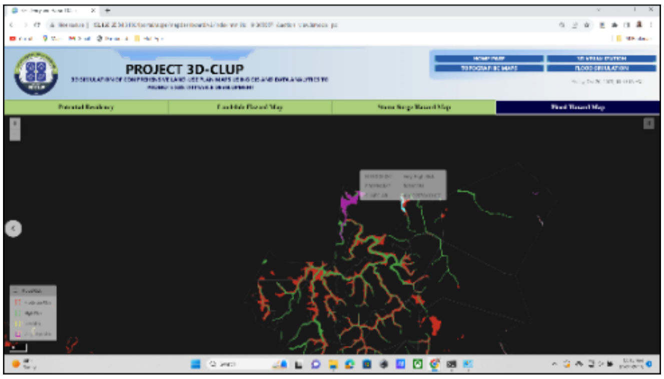

Figure 5. Flood Hazard Map

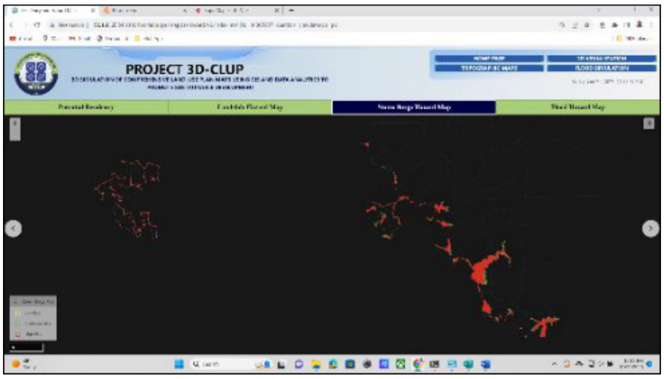

Figure 4. Storm Surge Hazard Map

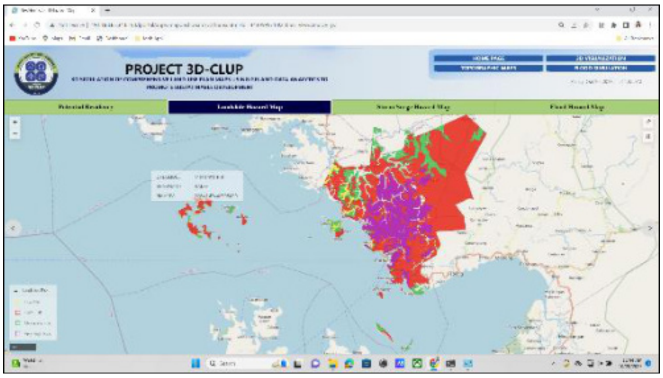

Figure 7. Landslide Hazard Map

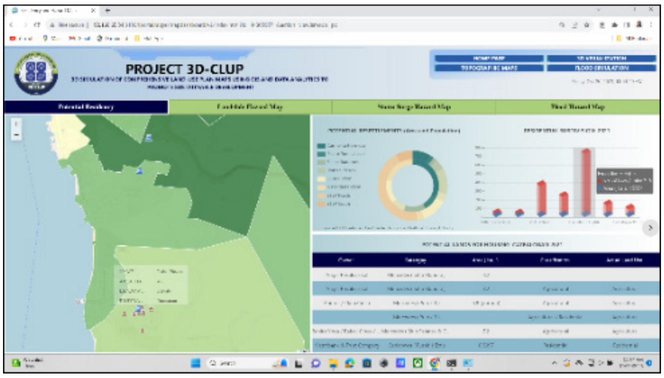

Figure 8. Potential Resettlement Tab

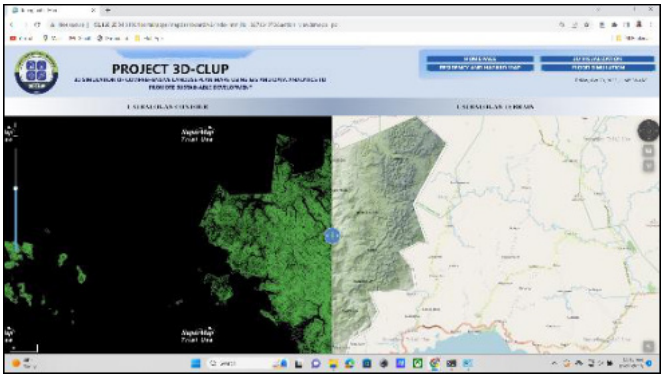

Figure 9. Topographic Map Dashboard

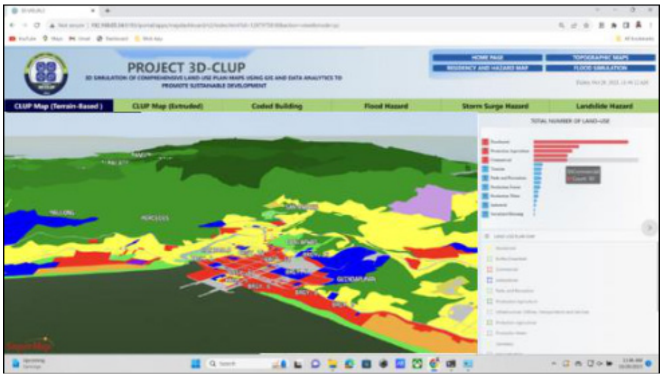

Figure 10. Proposed Land Use in 3D Scene

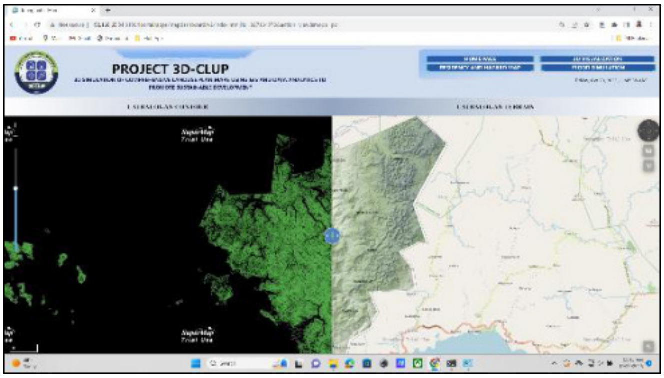

Figure 11. Extruded Land Use in 3D Scene

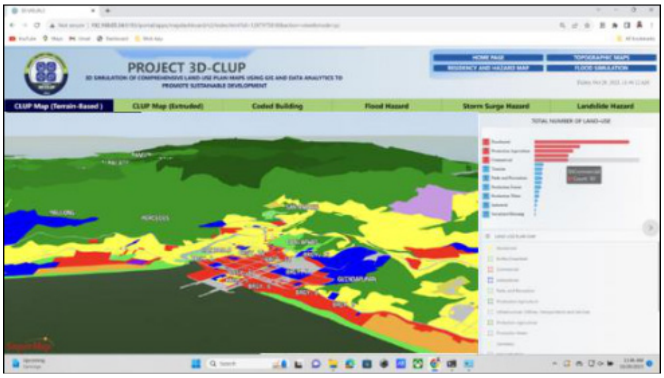

Figure 12. Coded Building Visual

Conclusion

The Project 3D-CLUP web application creates a detailed 3D model of land-use plans using GIS data to enhance visualization and simulation. With the help of this application, urban planners, especially those in Catbalogan City, can better understand the spatial relationships between various land uses and come to wise land-use management and development decisions. Additionally, it offers a venue for stakeholders to communicate and take part in the planning process. Likewise, it is meant to analyze and assess various land use and development scenarios, assisting them in making decisions about the most effective use of resources and land. It offers a more interactive and dynamic approach to for viewing and comprehending the effects of planned changes on the environment, facilities, and communities.

Most importantly, using SuperMap GIS technology allows for the creation of detailed maps and models that can be used to visualize and simulate various land use scenarios, providing decision-makers with a thorough understanding of the potential outcomes of various development plans. This can assist in ensuring that resources are used efficiently and sustainably, while also reducing negative effects on the environment and local communities.

Recommendation

The proponent made the following recommendations to improve the web application's overall functionality to maximize its use:

1. Creating more functions. It might be necessary to modify the map to reflect the qualities and requirements of the local area while keeping in mind the local context, including local land use regulations, zoning laws, and other pertinent factors. Adding landmarks, travel routes, or locally distinctive natural features may be a part of this customization process.

2. The use of high-end terrain mapper drones ensures that data accuracy and quality are significantly improved, resulting in a reliable and precise mapping results. Since the current data used to form the 3D terrain is solely based on the elevation file of the city, the technology will allow the collection of high-resolution images and data, which can be used to create detailed maps and models.

3. Implement a mobile version of the web application. With the help of this platform, users will be able to access and use the same information and features on the go.

Acknowledgement

The project proponents would like to thank Samar State University, particularly the Samar Island Geographic Information System staff, whose expertise and assistance were crucial to the project's success. The funding provided by the DOST-NRCP NSTEP, which enabled this project, is also very much appreciated. Lastly, the local government entities that provided the data and information required for the project's completion are also recognized for their contributions, without which this project would not be feasible.

Declaration of Conflict of Interest

We declare that, to the best of our knowledge and belief, there are no potential conflicts of interest that could compromise the objectivity or integrity of our work on the Project 3D CLUP web application. Our involvement in this project is solely motivated by the pursuit of advancing knowledge and contributing to responsible land-use planning practices. I have no financial or personal relationships with any individuals or organizations that could influence or perceived to influence the outcomes of this research. Our commitment is to the unbiased and ethical exploration of Project 3D-CLUP. GIS and SuperMap technology for the betterment of urban planning, with a focus on Catbalogan City.

Authors' Contributions

Engr. Raven C. Tabiongan (Project Leader) – meticulously planned its scope and aligned it with stakeholders' goals, all while ensuring effective team collaboration. He formed critical partnerships with Catbalogan City officials and the SuperMap GIS Sales Team, making significant contributions to the project's memorandum of agreement. To meet project objectives, his leadership prioritized continuous communication and quality control.

Engr. Jan Floro S. Bautista (Project Staff L3) – focused on the WebGIS application's sustainability, addressing maintenance, updates, and community engagement. He also tackled intellectual property protection and facilitated the technology's commercialization, ensuring a strategic approach to technology transfer and application viability.

Engr. Merry Chris D. Margarico (Project Development Assistant) – played a crucial role in the creation of the WebGIS application, establishing a strong system architecture designed for advanced spatial data analysis and simulations. Her commitment to user-centric design and interactive GIS technology facilitated community engagement and ensured the system's reliability and adaptability through comprehensive testing and feedback integration.

Engr. Stephanie E. Tan (Admin Staff Clerk) – managed the financial and procurement aspects of the project, ensuring resources were allocated efficiently and processes remained transparent. Her meticulous approach to financial management supported the project's infrastructure needs and operational integrity. Tan's efforts in audit preparedness and fiscal management underscored the project's commitment to accountability and compliance.

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