THE ROLE OF EFFICIENT ALGORITHMS IN OPTIMIZING COMPUTER RESOURCE AND ENERGY USE: DEVELOPING GREEN GIS TECHNOLOGY FOR HIGH-PRECISION CADASTRAL GIS, RENEWABLE ENERGY, LIDAR & REMOTE SENSING, TELECOMMUNICATIONS.

ADVANCING ACCURACY, LEGAL INTEGRITY, AND ENVIRONMENTAL SUSTAINABILITY.

The paper "The Role of Efficient Algorithms in Optimizing Computer Resource and Energy Use" highlights the critical role of algorithmic efficiency in the development of Green GIS Technology. By optimizing computational resources, efficient algorithms can significantly reduce the environmental impact of GIS applications while maintaining high levels of accuracy and performance. This work underscores the importance of sustainable practices in the evolution of GIS technology, offering valuable insights for future research and development in the field.

Keywords:Green GIS Technology, GIS, Software Development, Resource Management, Environmental Sustainability, Benefits, Strategies.

1. INTRODUCTION

The core of this research revolves around the concept of algorithmic efficiency. Efficient algorithms are designed to perform computational tasks with minimal resource usage, thereby reducing energy consumption. The paper presents several case studies where optimized algorithms have significantly improved the performance and sustainability of GIS applications. These case studies highlight the practical benefits of algorithmic efficiency, such as faster processing times, reduced energy costs, reduced overall costs, and lower environmental impact.

2. SGIS TECHNOLOGY INITIATIVE

2.1 THE GENESIS OF SGIS TECHNOLOGY AND PRODUCTS

When it comes to GIS technology and projects, we often deal with vast amounts of data—commonly referred to as big data. Big data is characterized by its volume, velocity, and variety, meaning large quantities of data are generated quickly and come in various formats (Big data and GIS, n.d.). Although GIS data and big data are not identical, they are closely related and frequently integrated. When combined, GIS and big data offer powerful insights into a multitude of real-world challenges. Examples of big data sources include satellite images and extensive graphical data containing complex attributes and metadata.

The rise of big data has revolutionized every industry - GIS is no exception. This shift has significantly changed how we acquire and use spatial information. Organizations are increasingly using geographic information science and technology. While government agencies were historically the main users of geospatial data, today, businesses across all sectors are adopting GIS at a rapid pace.

The most critical aspect of developing GIS technology is ensuring it can effectively manage these types of big data. This capability is fundamental to the success and efficiency of any GIS project.

Traditionally, we measure algorithm efficiency by how well it solves problems and how much computing power and storage it requires.

But with energy becoming a costly and limited resource, there's a new focus on the environmental footprint of algorithms. This shift reflects a broader awareness of energy's importance and prompts us to rethink how algorithms are designed and used.

3. TASK #1 GIS DATA CREATION: COMPARING OPEN-SOURCE TECHNOLOGY AND SGIS TECHNOLOGY

Data creation and digitization are essential tasks integral to any GIS. Therefore, our initial study will focus specifically on the algorithms that facilitate these processes. GIS software platforms like QGIS and SGIS offer distinct capabilities for data creation. While QGIS is widely used for its open-source nature, in our specific case, for the algorithm to be successfully executed, it requires additional steps like cleaning duplicate geometries and fixing errors when converting DXF file line entities into polygons. This can lead to inefficiencies and increased computational resource use.

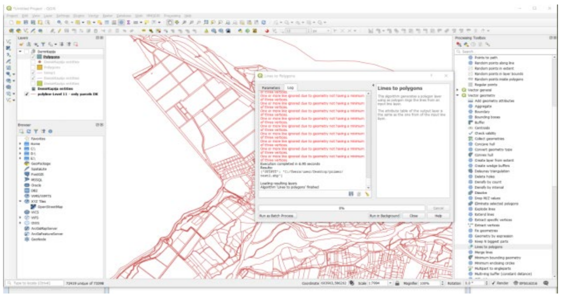

Figure 1. An error message appears when attempting to execute the Lines to Polygons command.

In contrast, SGIS streamlines this process with a single-click function to separate DXF layers, retaining original CAD properties, and converting lines to polygons without needing extra fixes. This efficiency reduces computational resources, aligning with Green IT principles.

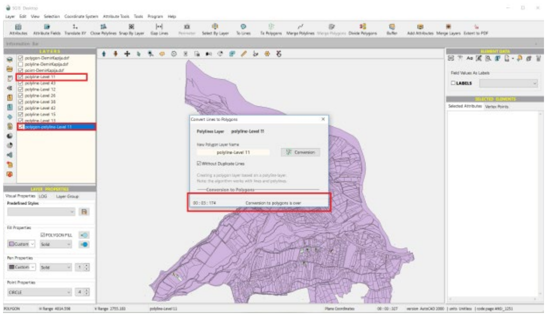

Figure 2. Polygons have been successfully created, appearing as a new layer in the Layers Panel.

4. TASK #2 LIDAR & REMOTE SENSING DATA MANAGEMENT

To conduct the second part of my research, I'll compare algorithm effectiveness and system requirements using a LiDAR dataset. I'll start by examining the open-source option, then compare it with the commercial alternative.

After importing the same dataset into both software, I've come to the realization that GIS software environments often don't integrate LiDAR tools.

One of the primary challenges lies in handling the massive datasets generated by LiDAR and Remote Sensing technology. These datasets consist of millions of data points, resulting in large volumes of data that can be cumbersome to manage and process.

For any GIS platform to effectively integrate LiDAR tools, it must possess the capability to handle such vast datasets without compromising performance. This entails efficient data storage, robust data management capabilities, and sufficient computing resources available to users. Additionally, the development of efficient algorithms tailored for processing LiDAR data is crucial for ensuring smooth integration and optimal performance.

In essence, while the integration of LiDAR tools into GIS software offers significant benefits, overcoming challenges related to data volume, storage, management, and computational efficiency remains critical for seamless functionality.

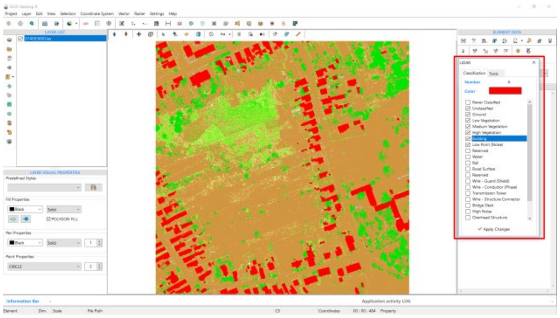

Figure 3. Displaying the seven active classifications in SGIS vR, with the others removed.

4.1.1. A Comparison Table

Table 1. A comparison table showcasing the efficiency of both GIS software for the second research task.

Criteria	QGIS	SGIS
Dataset Handling	Struggles with very large datasets; performance may degrade	Efficient handling of large datasets without compromising performance
LIDAR Support	Requires external plug-ins (e.g., LASTools); some tools need licensing	Built-in tools specifically designed for LIDAR data management
High-Resolution Data	Can experience lag with high-resolution data	Smooth handling of high-resolution data without significant lag
User Expertise Required	Users need to install and manage plug-ins; requires technical knowledge for optimal use	More user-friendly with intuitive tools and minimal additional installations
Workflow Efficiency	Additional steps needed for installing and managing plug-ins	Built-in tools for streamlined workflow
Export and Integration	Requires additional steps to isolate and export classifications	Direct export to new GIS layers

5. TASK #3 COLORIZE LAS

The third task in this research involves colorizing a LAS file, which means assigning RGB values from imagery to the corresponding LAS points.

While standard point clouds are highly useful, colorizing them significantly enhances their value. Adding colors and near-infrared values from images to LAS points creates an immersive, photorealistic display. However, this research reveals that the most commonly used open-source GIS software lacks an algorithm for this function. QGIS, for example, relies on LASTools for processing LiDAR data, including rapidlasso's closed-source tool, lascolor, which is specifically used to apply color to LiDAR points based on imagery.

In contrast, SGIS, as a GIS environment, possesses a built-in algorithm to colorize LAS files from images as well as from a Tile Map Service.

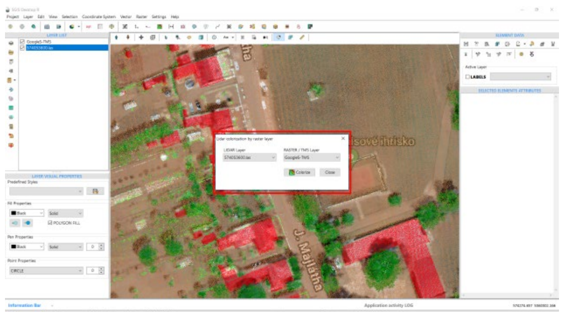

Figure 4. The dialog window for the 'Colorize LAS' function, allowing users to select their LAS layer and raster/TMS layer from the lists. Once selections are made, clicking 'Colorize' initiates the process.

6. TASK #4 CADASTRAL DATA INTEGRATION FOR URBAN PLANNINNG: UTILIZING UAV-SOURCED ORTHOPHOTOS AND POINT CLOUD DATA

In North Macedonia, the Republic's Agency for Real Estate Cadastre maintains precise building data, crucial for urban planners. Since 2012, the Agency has provided digital cadastral plans, available for professional purchase, covering the entire country. These plans include vector data in GIS zip archives with SHP files rich in polygonal data and attributes. Overlaying these building polygons with current point cloud and orthophoto data is essential for extracting diverse information. Our research focused on validating property boundaries and cadastral parcels against real-world conditions, crucial for urban planners, particularly in areas like Radozda village in Struga municipality. To enhance the accuracy and currency of the housing database, we assessed existing buildings using point cloud models, orthophoto maps, and supplementary materials. This involved correcting building geometries and adding new buildings as necessary, with drones extensively used for data capture and UAV data manipulation. Drones significantly lower costs and enhance data collection accessibility (Quamar et al., 2023).
Using GIS throughout the process enriches the final data with detailed attributes, avoiding the need to switch between different platforms. This approach saves time and resources while simplifying the learning curve. Our focus was on comparing the open-source ‘Magic Wand’ tool in QGIS with SGIS’s original algorithm for segmenting pixels based on color technology. Both algorithms process pixel data from images, allowing users to select areas based on color similarity within raster layers. However, the Magic Wand displays vector outlines with questionable accuracy, whereas SGIS outputs raster footprints that can be saved as backdrop images, offering better precision and smaller file sizes.

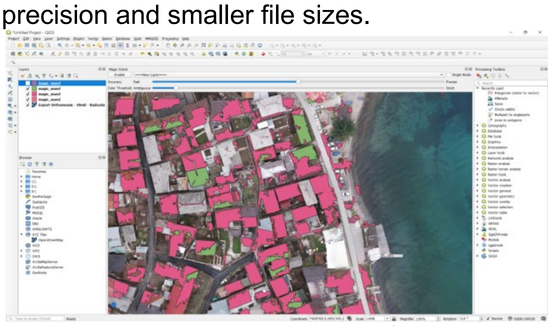

Figure 5. ‘Magic Wand’: Result with Color Threshold set towards ’Ambiguous’.

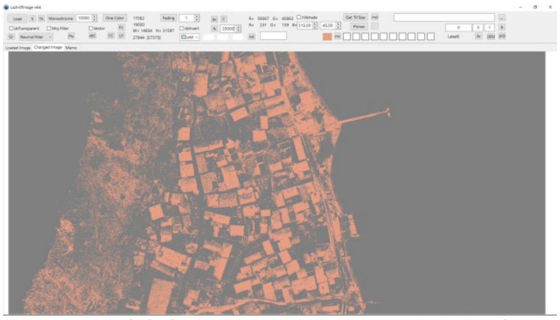

Figure 6. SGIS: The output is a raster image file containing the building footprints needed for the overlay. These image files take up much less storage space and are very useful in batch processing, especially for large projects covering extensive areas.

7. RELYING ON THIRD-PARTY CODE LIBRARIES

One important aspect of green software development is creating innovative solutions with original algorithms that are entirely independent of external libraries. Unlike most GIS software that relies on frameworks like GDAL, PROJ, .NET, and JAVA runtime environments, green software development emphasizes self-sufficient algorithms.
Why is that?
When you add a third-party library, you're taking on responsibility for code you didn’t write. This can introduce potential liabilities and complexities. Every new piece of code increases overhead, whether in load time or complexity.
Third-party libraries often contain more code than necessary because they’re designed to handle a wide range of use cases. This extra, unused code can make your project more cumbersome and introduce more opportunities for bugs. Plus, each library may have its own dependencies, creating a complex web of code to manage and maintain.

8. WHY ALGORITHMS MATTER FOR EFFICIENCY?

In my research, I've emphasized the importance of aligning with Green IT and Green Software Development. But what does this really mean in the context of GIS tasks?

Reduce Computational Complexity: Energy-efficient algorithms simplify computational tasks, reducing both time and space complexity. This results in fewer resource requirements and lower energy consumption.

Optimize Memory Use: Efficient data structures minimize memory usage. By reducing the memory footprint and improving access efficiency, these structures cut down on energy needed for memory operations. SGIS exemplifies this with its minimal storage usage. For instance, SGIS Desktop v1.0 shows an allocated heap size of 146 MB with 12 MB free, allowing effective resource management. In comparison, a basic browser like Google Chrome consumes significantly more storage.

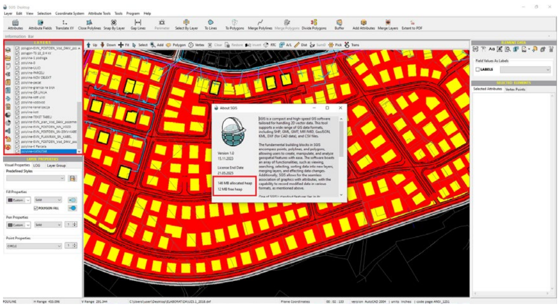

Figure 7. When using SGIS Desktop v1.0, with multiple layers of data opened, the system displays an allocated heap size of 146 MB, with 12 MB of free heap available. This information helps users monitor memory usage and manage resources effectively within the software.

Minimize Data Redundancy: Reducing redundancy and optimizing storage solutions lowers the required storage and associated energy usage.
Leverage Renewable Energy: Utilizing renewable energy sources for powering systems and data centers processing GIS data wherever possible.
Sustainable Software Design: Designing energy-efficient software minimizes the need for frequent updates or upgrades and ensures compatibility with existing hardware, extending its lifespan.

9. CONCLUSION

9.1 WHAT IS THE ROLE OF ENERGY EFFICIENT ALGORITHMS IN GIS?

Energy-efficient algorithms play a vital role in GIS, especially in supporting sustainable energy initiatives like the European Commission's "20–20–20" targets through initiatives such as the Sustainable Energy Action Plan (SEAP). These plans emphasize efficient energy management and quality control, where GIS provides essential data on building energy performance and consumption.

In urban contexts, GIS, coupled with technologies such as BIM, LIDAR, and Remote Sensing, aids in implementing and monitoring energy policies at regional levels. This integration supports policy-making and enhances urban planning and resource management.

However, behind these technological advancements lies ongoing development. Through this research, we emphasize the importance of refining algorithms and practices to promote green software development. This approach drives innovation in IT while contributing to a sustainable future.
Examples in GIS, alongside LIDAR technology, demonstrate significant potential to achieve environmental goals and enhance efficiency.

The efficiency provided by algorithms in problem-solving is a key factor that greatly enhances productivity across various domains. The right algorithm can simplify a complex problem, requiring minimal resources and time, which is highly valuable today.

Throughout my research, I have emphasized that algorithms boost efficiency by optimizing resource use. Computationally, this means reducing the memory or processing power needed to solve a problem. However, their importance extends beyond this. The right algorithm can significantly cut the time needed to find a solution, and we all know how critical time can be in determining success or failure.

While I have highlighted the importance of energy savings in this digital era, we must also consider the human effort and time that can be used more efficiently. In GIS technology and similar industries that handle vast amounts of data, effective algorithms that automate routine and repetitive tasks while promoting sustainability are invaluable. This allows human workers to focus on more complex and creative aspects of their work.
Moreover, developing algorithms that promote Green IT fosters creativity. Since there are often multiple ways to solve a problem, creative developers are encouraged to develop solutions independently rather than relying on external libraries. This creative problem-solving skill is particularly important in software development. By encouraging this approach, we promote innovative solutions that can lead to breakthroughs in both technology and user experience.

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For more information on SGIS, please visit www.simplegissoft.com.

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