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A new approach for automating land partitioning using binary search and Delaunay triangulation

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ABSTRACT

One of the most important, yet time-consuming steps of the land consolidation process, which is related to pooling fragmented lands together, is the production of land partitioning plans. After the land redistribution process is finished, the land partitioning process begins. In that process, the locations of parcels within the blocks are determined. Due to the non-uniform geometric shapes of the blocks, the areas of the parcels cannot be divided directly. The production of an ideal land partitioning plan is not suitable automatically unless a quick, accurate process to divide the lands is secured. In this study, production of a pre-land partitioning plan is realized using both the binary search method and the Delaunay triangulation method, taking into consideration shape, size, value and road access criteria. The result of the experimental study shows that the proposed approach for dividing the parcels makes the process take place more quickly. Thus, a solid base for creating an automatic land partitioning plan—one that is closest to an ideal plan—will be provided with this study.

1. Introduction

Economically and socially, agriculture is one of the most important trade sectors for many countries. Despite an increase in the human population in many regions, the total area of farmlands in some of those regions has remained relatively stable. In other regions, however, farmlands have decreased in total area. This presents a challenge—to discover a more efficient use of available farmland. In many nations, existing farmlands have become fragmented, disorganized, or inconvenient for agricultural production. This situation will get worse unless urban transformation projects and integrated plans tackle the problem (FAO, 2003). Land consolidation (LC) is the most useful land management approach for solving land fragmentation. Furthermore, it has been applied successfully in many countries around the world (Demetriou et al., 2012). Also, LC is an excellent tool to implement rural development projects. It improves agricultural structures, implements nature and environmental projects, and incorporates national and local infrastructure projects in the same land consolidation project (Pasakarnis and Maliene, 2008). Land reallocation, the most important process in land consolidation, is split into two sub-processes: land redistribution and land partitioning (Demetriou et al., 2012), both of which are complex, time-consuming, and trying parts of the LC (Uyan et al., 2015; Rosman, 2012) process. In the redistribution stage, parcels and their blocks are determined according to given rules and limitations. As Demetriou et al. explain, "The output from the land redistribution process is input to the land partitioning (or re-parceling, parcellation) process." (Demetriou et al., 2013). Parcellation is the stage in which parcels and their place within the blocks are determined after distribution. According to Demetriou et al. (2013), land partitioning is a basic process of land consolidation that involves the subdivision of land into smaller sub-spaces (i.e., land parcels) to produce a final land reallocation plan. The goal of this process is to obtain a land partitioning plan with regularly-shaped parcels which all have access to at least one road.

The way land partitioning is done affects the whole process. A disorganized land partitioning process can cause an LC project which seems to be on the road to success to instead yield unfavorable results. There are strict criteria and rules for land partitioning which the designer and his or her team must follow. Although the purpose of LC is the same, the rules (or laws) that determine the criteria differ by nation (Vitikainen, 2004). Parcel location, road access, and the parcel's degree are determined at the stage of land partitioning. New parcels are placed into non-uniform geometric-shaped blocks one by one according to the area of the parcel and land partitioning criteria. Before the placement, the axis (x or y)

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of the partition should be determined according to the blocks' inclination. In addition, the land in each block may not have the same degree or quality. For this reason, when a land is divided inside the block, a degree map should be used to calculate the real land value.

Today, the land partitioning process is done manually by a designer with the help of computer software. This means the process is in the hands of the designer's knowledge and skill. Furthermore, the process continues for weeks, depending on the designer's expertise and the size of the project. The manual land partitioning of the blocks will take up a considerable amount of time—possibly weeks or months—depending on the size of the project, the size of the farm, and the number of designers in the project. Because of the duration of this period and the degree of expertise that the designer has, the design and selection criteria will most likely vary depending on the day of the week—or even on the hour of the day—on which the tasks are performed (Rosman, 2012). Due to the fact that the land partitioning process is a complex, ill-defined problem which contains a large set of oft-conflicting demands, conventional programming techniques are not sufficient for this problem (Buis and Vingerhoeds, 1996). Also, the blocks in LC projects do not have uniform geometric shapes. This creates problems in the division of parcel areas within these blocks. The non-uniform shapes of the blocks inhibit the use of mathematical modelling through integration and differentiation.

Although there are studies which focus on speeding up the redistribution stage of LC, there are not many studies about the land partitioning stage. A mathematical model (Ayranci, 2007), fuzzy logic (Cay and Iscan, 2011), decision-support machines (Uyan et al., 2013), and genetic algorithms (Uyan et al., 2015) have been used to automate the redistribution stage. Rosman (Rosman, 2012) presented two different approaches which include interdependent steps and user interactions used to determine parcel boundaries. While Rosman was doing land partitioning plans with the system he designed, he placed parcels from allocation plans according to existing criteria such as distance, fixed facilities, and existing parcels. Demetriou et al. stated that there are only two studies in the literature regarding the automation of the land partitioning process (Demetriou et al., 2013). The first one, by Buis and Vingerhoeds, suggests a knowledge-based system and a GIS-based semi-automatic design that helps the user (Buis and Vingerhoeds, 1996). The system is not completely automatic and only supports the designer's decisions. In the second one, land partitioning is achieved using area enlargement and simulated annealing techniques by Tourino et al. (2003). Firstly, the parcel lands inside the block are enlarged according to the circumstances of the organization's owners, and then the shapes of these places are refined with the simulated annealing technique. Demetriou et al. though, state that the results Tourino et al. produced in his study are adequate for the average level, but are different than a land partitioning plan that is produced by a designer and which is more dependent on block shapes and the sizes of the original parcels (Demetriou et al., 2013).

Demetriou et al. (2013) realized land partitioning for two blocks using the features of shape, size and land value by using single- and multi-objective approaches with genetic algorithms. Demetriou et al. emphasize that the results are promising, yet admits that they need more progress with regard to the accuracy of results and calculation time. Demetriou et al., using two blocks as a case study, was able to realize optimization in terms of the shape in 4.8 h for block I, which contained six parcels and had an approximate total size of 3 ha; and in 12 h for block II, which contained 10 parcels with an approximate total size of 5 ha (Demetriou et al., 2013). Although Tourino et al. did not state a calculation time, he needed 10,000 stages for a block with 5 parcels. Although the stated duration of the calculation time meets normal expectations, considering the difficulty and complexity of the land partitioning process, this duration will increase when a project has, for example, 20–30 blocks. Furthermore, though these results are promising, they are not sufficient for a land partitioning plan which will be realized by a designer. As seen, new approaches for decreasing the calculation time and providing land partitioning plans which meet the local criteria are needed.

In this study, a new approach is suggested. This approach aims to reduce the calculation time so that a more convenient and more accurate land partitioning plan is done that comes closer to the ideal. Providing a preliminary land partitioning plan is done automatically by a computer with the help of both the binary search (BS) and the Delaunay triangulation (DT) methods, which consider the parcel's shape, its size, its access to a road, and the value of the land within it. These methods are used to determine which part of the non-uniform geometric shaped block needs to be divided from which point. A time analysis is done. Using a pilot application, a land partitioning plan is extracted in minutes in the study area according to criteria such as shape, size, land value, and road access. Thus, a base for an ideal land partitioning plan which meets all the criteria can be prepared.

The rest of the paper is divided as follows: In Section 2, the land partitioning problem itself, as well as the binary search algorithm and the Delaunay triangulation methods are presented. The proposed approach is implemented in a land partitioning problem in Section 3. In Section 4, the experimental results of the proposed approach are presented. Finally, the conclusion of the paper suggests some proposals for the future of this approach.

2. Material and method

2.1. The land partitioning problem

The parcels whose blocks are determined in the redistribution process form the land partitioning problem, which is related to the parcels' placement in each block. Fundamental parameters like parcel shape, parcel size, parcel value, and road access are taken into account to simplify the problem of land partitioning and subsequent calculations that are subject to many parameters and restrictions (Demetriou et al., 2013).

Firstly, the axis of the parcels within each block should be decided and divided while the designer performs the land partitioning of each block. This operation is easily determined by the designer according to the block's inclination towards the vertical side. After determining the axis and after the distribution phase is completed, the designer enters individual field values for the parcels based on the values of the division designated for that block during the redistribution process. While the division is performed, the parcels are expected to be in the form of a rectangle and closer to the original (cadastral) parcels and the original quality. Also, access to water channels and roads for each parcel is given priority. This subdivision generally starts from the bottom of the block and requires the designer to redo the entire process if he or she makes a mistake. This, of course, extends the duration of the process.

The quality of the soil may not be the same. A degree map is done in order to determine the land quality. In this degree map, the land is assigned a degree between 0 and 1, according to the soil quality. The soil quality will affect the size of the parcels proportionately. For instance, if one wants to carry a 1000 m^2 parcel with a rating of 1 to an area with a rating of 0.8, one will have to give more than 1000 m^2. Because of decreasing degree of parcel, one will have to increase size of parcel. In other words, to avoid the owner from suffering damage, the parcel size will increase as the degree of parcel decreases. Detailed explanation for this subject