Automated parcel boundary design systems in land consolidation

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Key words: Land consolidation, design support system, land readjustment

SUMMARY

One aspect of the design of a new parcellation in land consolidation projects is the formation of new parcel boundaries. Creating a parcellation design can be a time-consuming process and this makes exploration of alternative designs intractable. Automation of the process is difficult but not impossible. The paper describes two approaches. The first is appropriate in areas with few topographical limitations and where agricultural considerations are paramount. This approach is being implemented in the land reallocation application R-app. The second approach takes a number of extra constraints into account and has been implemented in Transfer, the reallocation application of the Dutch Cadastre, Land Registry and Mapping Agency. Both systems are described.

The systems are based on the determination of a value allocation plan as the first step of the design process. In both systems the formation of the parcel boundaries is a series of interdependent steps and user interactions, which differ because of the different sets of constraints.

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1. INTRODUCTION

Land consolidation projects can have many goals in diverse sectors, but with agriculture as the main type of land use. Other sectors involved may be village development, infrastructure, nature preservation, nature development and outdoor recreation. The driving force behind land consolidation is the improvement of land use through land reallocation. Other project types are possible (such as land banking) but the main advantages of reallocation are the integral approach to the project area and the possibility to spread the advantages to all community members.

In the Netherlands for years there has been a considerable effort to execute integral land consolidation for many decades. Policies and legislation have been updated to reflect developments in spatial planning and in rural areas (Van Rij, 2005). One of the tasks that the Dutch Cadastre, Land Registry and Mapping Agency (Kadaster) has in these projects is the design of the reallocation plan. For the general IT-support for the registration of ownership and land use several systems were developed, among them ***LIN*** (Systeem Land Inrichting) and currently ***SHW*** (Systeem Herverkaveling WILG). Two systems are being used for the actual design of the reallocation: Transfer for the value allocation plan and MapInfo for the design of the parcel boundaries. This last step is now being replaced by GeoMedia which is the basis for SHW.

The design of the parcel boundaries is a labor intensive manual process, which has some obvious drawbacks, both in project costs and from the theory of design.

This paper will concentrate on the new development of automatically generating the parcel boundaries with the goal of providing a fully automated preliminary "sketch" quickly and repeatedly and of producing a user-assisted final design more efficiently.

Two variants of this approach are described in this paper, the first is implemented in the application ***R-app***, the second is implemented as an extension of the ***Transfer*** application. R-app is an internationally oriented spin-off of Transfer.

2. GENERAL APPROACH

2.1 Terminology

For the description of the process the following terms will be used:

Land use – right of the owner to a parcel or group of parcels in the existing or newly designed situation. The total area of the parcels of an owner is the **claim area** in the project (the total value is the **claim value**). If the legal system allows for the possibility that land is allocated to the actual land user (tenant), then the area and value is included in the claim of the land user (tenant). The owner still retains ownership of the allocated land, but it is allocated in combination with other parcels of the actual land user.

Land user – owner of land in the project area or the tenant or other legal person (party) entitled to the allocation of parcels.

Value allocation plan – a list of items with areas and values and the land user to which they are to be allocated. This is the first step in creating a design of the allocation. In fact in the Netherlands the reallocation is now based primarily on area, but the resulting difference in value per land user should be below a certain criterion. In order not to complicate the text, this paper will only use the area to describe to process.
Blockpart – is a part of the project area surrounded by roads, ditches, irrigation channel etc. which form natural boundaries to the blockpart. Further division may be necessary if soil types or local conditions are different (e.g. if in proximity to the village there is an area a small scale vegetable gardens).
The value allocation plan should ideally be balanced in all blockparts, i.e. the allocated area should match the available area of the blockpart. Exact balancing is often difficult to achieve and can have disadvantages too. If in a blockpart the demand for allocation is unequal to the available area, there is a residual area; if demand is larger this residual is positive. In theory the sum of all residuals must be zero, but in practice this is rarely the case.
Prefixed allocations – are allocations to public bodies for infrastructural and other measures in the project area. The prefixed allocations originate from a decision by the provincial council. These allocations have a fixed location and shape and in the design process they take priority over other allocations, including **fixed allocations** of owners such as home parcels. Of course there is much to be said about the nature of these prefixed allocations, both legal and procedural, but this is outside of the scope of this paper. Because prefixed allocations take up area in the blockparts and may cause other land users to be (partly) shifted to other blockparts, they are included in the value allocation plan.
Pool of unallocated items – is list of items for each blockpart in the value allocation plan for which a parcel has to be formed. Items in the list still can be joined or split or moved to another blockpart, depending on the progress in the parcel boundary design. Items in the list may have a designated location or have a shape (e.g. home parcels and prefixed allocations).
Home parcel – for every land user that has farm buildings inside the project area, there is a parcel on which the buildings stand. The farmer usually lives there as well. This parcel may be neighbored by other parcels of the same land user or these parcels may be reached easily across a ditch owned by others. All of these parcels together are considered to be the home parcel. In general, farms want the size of the home parcel to be as large as possible. This is especially true in dairy farming, less so in crop farming.

2.2 Summary of the design process

The technical process of designing an allocation plan consists of the following steps:

- Collection of data of the existing situation (ownership, tenancy, soil quality etc.),
- Drafting of lists, maps of owners and parcels for public inspection and preference hearing,
- Collection of preferences of land users (in a research project this can be simulated using models),
- Elaboration of the value allocation plan,
- Design of the parcellation by fixing parcels locations and formation of boundaries,
- Drafting of lists of entitled parties, parcel maps etc. for public inspection and preparation of legal documents.

We concentrate here on the actual tasks in the design of the parcellation plan on the basis of the value allocation plan. This process can be summarized by the following steps:

1. Check starting conditions,
2. Select a blockpart, (1a) stop if all blockparts are completed,
3. Select an item from the pool of unallocated items of the blockpart,
4. Select a suitable location for the item,
5. Form a boundary,
6. Check the pool for unallocated items until (6a) the pool is empty or (6b) the blockpart is completely filled.

In this way in each of the blockparts the new parcels can be allocated. Complications in this process are the constraints that topographical and other conditions in the blockparts provide which can lead to adaptations of the value allocation plan and, in consequence, influence the order in which the blockparts are processed. A human designer could switch from one blockpart to the next before completing the blockpart.

2.3 Design theory

From design theory, as it was extensively explored by Buis (1998), it can be deduced that the order in which items are to be processed depends on the number of constraints that apply in a particular situation.

For a human designer this will be largely based on experience. For instance, blockparts close to a village may have more constraints on the design than other blockparts and therefore have priority. If a farm building is located in a blockpart, then the parcel on which it stands has absolute priority (it is an "immovable", a location constraint). Parcels should have access to road and/or irrigation etc. (a functional constraint).

Location of access, location of boundaries and size are properties which do not have discrete values and can be varied or moved continuously between certain limits (or in the case of dividing lines the can even be rotated). As a consequence one cannot actually enumerate *all* alternatives, however, given a certain approach by a human designer (e.g. making several alternative maps, see Fig. 1) or a certain implementation in software, it is possible to enumerate a set of alternatives. Properties of these alternatives must lead to an ordering of the alternatives, of which the best can be realized in the design for the blockpart.

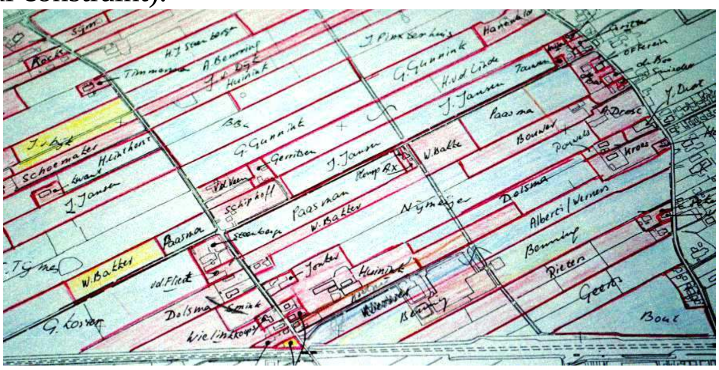


Fig. 1. A manually elaborated parcellation plan at an office of Kadaster (Ph. by F. Rosman, 1993).

Selecting the best option is often difficult, especially if the option has to be finished first before a score can be calculated. And this is the case in geometric design: to assess to suitability of a parcel boundary design, the boundary has to be constructed and from a performance perspective this is not practical. Therefore a predictive score must be used. In a situation with many constraints on the design, one cannot afford to overlook a successful ordering based on such predictive scores. This is the reason to use a branching strategy: systematically explore all options to find a) one solution and b) continue to find the best solution.

If parcels with less constraints are positioned in the blockpart *before* parcels with more constraints, the process of designing an adequate parcellation will be frustrated (and the designer too). For instance if smaller parcels are positioned earlier than a large parcel, it may become impossible to fit in the large parcel, or if a parcel has particular restrictions on road access (access to a road of good quality), this must be dealt with before parcels with no access requirement (for nature elements this is less important).
The general rule therefore is that items with fewer options must have priority over items with a larger number of options. This holds on the level of blockpart selection, of item selection within a blockpart and of location selection of items in a blockpart. In an automated system it can be difficult to make the restrictions explicit and to quantify their relevance to produce an ordering. The human designer has these problems too but also has the problem of having to keep track of all relevant restrictions.

It may well be that during the process it becomes apparent that for certain items there are *no* options. The constraints are conflicting and a solution can only be found by changing the constraints. In this case the first step is to change the value allocation plan to accommodate for the new insight. This may be done by transferring entire items between blockpart, or changing value and area of certain items and compensating the change in other items of the same land user.
Other ways to relax the constraints may be difficult, since the topographical conditions are more difficult to influence. Solving conflicts in constraints very much depends on the situation. In an automated system this will still mean that some form of user intervention is required, or in case of a preliminary sketch, some arbitrary decisions by the system must be made.

The manual processing of the blockparts and items will take up a considerable amount of time -possibly weeks or months- depending on the project size, farm size, and number of designers in a project. Since this is work by humans, and because of the duration of this period, design and selection criteria will most likely vary depending on the day of the week or even of the hour of the day on which the tasks are performed.

With tens of blockpart in a project and tens to hundreds of items to allocate in each blockpart, it is clear that the design process can benefit from using specialized software to support the tasks of the designer.
The benefits can be twofold: a) speed up the process to reduce project costs and b) to improve the quality of the parcellation design by using consistent criteria for selecting items and locations and c) to improve the quality by the possibility of generating alternative parcellation designs based on variations of the criteria and constraints.
Human intervention is still required, since the resolution of constraint conflicts should be left to the human designer.

2.4 History

The idea to automate the design not only the value allocation plan, but also the design of the parcel boundaries is certainly not a new one. Van der Veen explored the concept of in integrated system in including the manual drawing of parcel boundaries in 1979, although with the hardware available at that time the implementation of the described system would hardly have been feasible (Van der Veen, 1979). In the Netherlands implementations of specialized computer aided software were also attempted, e.g. in the 80's a system at the Instituut voor Cultuurtechniek en Waterhuishouding, Wageningen, at the Kadaster in the 90's the before mentioned LIN system. After this, a customized GIS was used by Kadaster to support creating a sketch plan. In 1996 at Delft University of Technology Buis created a prototype expert system to do automated design during her PhD research, although the expert-system approach, the performance and unavailability of some needed data at that time prevented developing this approach into a practical user-friendly application. The ongoing development of Transfer (Rosman, 1998 and Louwsma, 2010) made it possible to extend the application for design support for the value allocation plan into automated parcel boundary design. R-app is a more generalized spin-off of Transfer, also developed by Delinea.

In the following chapters the implementations in the applications Transfer and R-app are discussed. Both systems support the determination of a value allocation plan as the first step of the design process. In both systems the formation of the parcel boundaries is a series of interdependent steps and user interactions, which differ because of the different sets of constraints.

3. IMPLEMENTATION IN *R-APP*

3.1 Project properties and design constraints

The approach as described in 2.2 is the basis for the implementation of automated parcel boundary formation in the software application ***R-app*** (v2.0), to be released in the fall of 2012. This is intended for use in projects areas with few spatial constraints in the blockparts. In many countries the villages are located away from the fertile arable land within the boundaries of a village. In this way less arable area is occupied by non-agricultural forms of land use. As a consequence the parcellation and infrastructure (roads, irrigation) can be organized more efficiently than would be the case with immovables present on the agricultural parcels.

R-app is a design support system with a range of data and relationships, including parcels, parties (owners and other parties), parcel-owner relations, as well as tenancy and mortgage relationships. (Transfer only holds the subset of land use information relevant to the actual design.)

The projects in R-app typically have blockparts consisting only of arable land of one type (soil, crop, pasture, etc.) which can be divided for the new parcellation.

This does not mean that there are no constraints emanating from the existing parcellation. For instance perennial crops (fruit trees, olive trees) may require a parcel to be reallocated in the same location, possibly to be extended by parcels from the same land user elsewhere in the project area. This is taken to be the exception in such projects.

R-app allows for different a set of blockparts for the existing situation and for the allocation, which can be relevant if the land consolidation project involves implementation of a new irrigation or road network. The claims of the land users can be inventoried on the existing blockparts, the preferences for reallocation can be registered on the basis of the new blockparts. There is no separate layer for the boundaries of the prefixed and fixed allocations. They are part of the value allocation plan.

The project database may contain only the owners and land users of the *arable* land; it is not necessary to include the parcels containing the infrastructure if the location and size of these parcels are not part of the design process. As a result, there will be a space between blockparts boundaries where the surrounding infrastructure is located.

3.1.1 Check starting conditions

R-app has an integrated issue-tracking system, which assists the designer to keep the data consistent and correct. All issues need to be solved before the designer can proceed with the design.

All prefixed and fixed allocation items should be marked as such. In each blockpart the prefixed items will be allocated first, the fixed items as much as possible unless they are in conflict with the prefixed items.

The location of the farm (building) is directly relevant to selecting a location of the new parcels on the basis of road distance. All land users must have a relevant location for their farm building. Since all land users are expected to have this location outside any of the blockparts, the system cannot the check the relevance automatically.

For each blockpart, a primary design axis is needed. The design axis is a line indicating the direction for subdividing the blockpart. The designer can e.g. indicate one of the sections of the blockpart boundary as primary design axis. By default parcel boundaries are oriented perpendicular to the primary axis. If preferred, the designer can cause skewed parcels to be designed by indicating a secondary design axis that is not perpendicular to the primary axis.

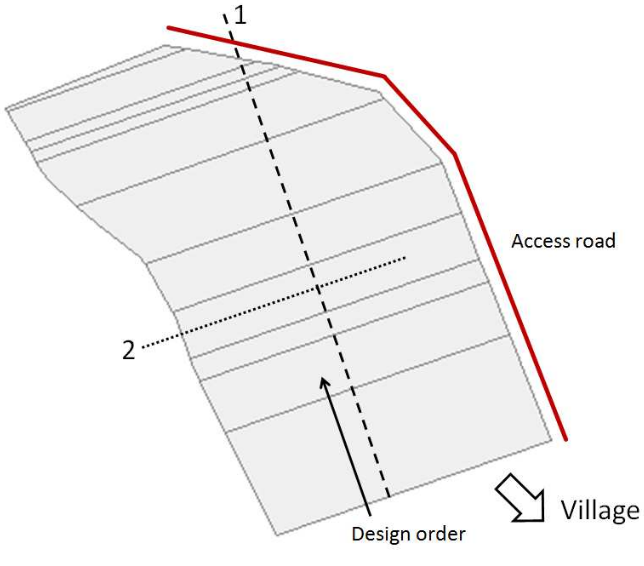


Fig. 2 Principal elements of the design approach in R-app. (1: primary design axis, 2: secondary design axis). The

design order is dependent on the distance to the village (location of the land user) along the road network.

3.1.2 Select a blockpart

The order in which the blockparts are selected is on the distance to the village. If land users from different villages are present, a weighted average is used, resulting in a lower priority.

3.1.3 Select an item from the pool of unallocated items of the blockpart

Prefixed and fixed items are allocated first. Fixed items may need to be expanded according to the value allocation plan; this takes priority. Preparation by the system of the data for the parcellation in a blockpart includes the ordering of the unallocated items along the primary design axis (or axes). This is done on the bases of distance to the farm building. The items are processed in order of priority.

3.1.4 Select a suitable location for the item

The order of the parcels is defined along the primary design axis, but the exact location can only be determined if items with higher priority have been processed into parcels.

3.1.5 Form a boundary

Most boundaries will be formed as strips of land across the blockpart parallel to the secondary design axis. This will ensure access from the narrow part of the parcel for all land users (access to road and irrigation channel).

3.1.6 Check the pool for unallocated items

The system continues with the next item to step 3.1.3. If the value allocation plan is balanced, all items should fit, but this may prove to be impossible during the design process. If items are "left over", these are moved to suitable neighboring blockparts (which have not yet been designed). It the list is empty and the blockpart is not yet completely filled, the blockpart is not closed. The area that is left over may be necessary later to accommodate allocation items that did not fit in other blockparts. If the blockpart is completely filled, the design is closed.

If the design of the blockpart is closed, the result is presented to the designer to be examined. Although the total design may take considerable time (30 minutes to 1 hour) this is still considerably less than the manual approach.
Examination of the design may lead to changes in the input data or to the design process settings. After that it is possible to run the design again from the start.

4. IMPLEMENTATION IN *TRANSFER*

4.1 Project properties and design constraints

The approach to designing a parcellation plan based on a value allocation plan as described in 2.2 has recently been implemented in the Netherlands in the software application ***Transfer*** (v5.0) for use in the Dutch Kadaster. This implementation is based on the Dutch situation which for the present subject of automated design can be characterized as follows:

– Project areas have been subject to land consolidation projects in the past. Current projects again aim to optimize the parcellation of agricultural land use but are now usually started for an external goal, for instance to allocate land on a certain location for non-agricultural land use (highway, village by-pass, new nature, outdoor recreation etc.) and to meliorate the negative influence on the agricultural land use caused by the external measure, such as effectively cutting off a land user from one of his parcels by inserting a highway.

- Project areas have a relatively good parcellation because of the prior land consolidation projects, but the spatial structure of farms has deteriorated mainly because of land acquisition by the farmers.
- The project database contains all of the parcels in a project area, including the parcels on which infrastructures are located. The blockparts therefore also contain these parcels and they are given special status (fixed or prefixed items). Typically there is no space between borders of neighboring blockparts.
- Farm buildings are generally located on the land in the blockpart, outside of the villages. In general in the past already a large number of farms, including all buildings, were located outside of the villages. Through the economy of scale that has increased the size of individual farms (and decimated their number), combined with environmental concerns, it is now almost impossible to operate a farm from buildings within a village. From an allocation perspective this means that many blockparts have a large proportion of the land in "fixed" parcels containing buildings.
- Landscape preservation is an ecological, cultural and cost reduction goal in the projects and this means that existing topographical boundaries which have hedges, ditches, tree rows etc. must be preserved by using them as parcel boundaries in the new parcellation. Not using such elements as boundaries between different owners can be seen as potential environmental damage (Bullard, 2007).

This means that the design process is highly constrained because much of the existing situation will have to be reallocated in the same place and the remaining free space in the blockparts has to be allocated respecting topographical boundaries as much as possible as well as conforming to criteria such as accessibility from the road network (eliminating access across other parcels) and improvement of parcel shape.

Preparation of data takes more effort, because the higher number of constraints must be available in data, both geometrically as well as coded in properties. In the project two layers are prepared:

- **Layer of prefixed allocations –** is a layer of polygons representing allocations to public bodies required for the formation of new or widening of existing infrastructure, including measures for public walkways and cycling paths (needed to improve road safety and for outdoor recreation);
- **Layer of design parts –** is based on the parcels of the existing situation, this layer is intersected with polygons from the prefixed allocation which are necessary as building blocks for the design process. The result must be checked on access of the design parts to the road network. Not all parts will have access, but this means that they can only be used as extension of parcels which do have access from the road network.

4.1.1 Check starting conditions

Before the process can start, the designer has to check the database on several points. Transfer assists this check by providing a list of issues and visual feedback by placing exclamations marks in lists and maps.
During the design of the parcel boundaries, the application can transfer unallocated items to alternative placements in other blockparts (if those blockparts have not yet been completed). The alternative placements are primarily deduced from the owner's or land users' preferences. However, especially when a positive residual is too large, if the residual cannot be reduced given the alternative placements of the unallocated items in the blockpart, this constitutes a blockage for continuing the parcellation design. The designer must first solve the situation by splitting unallocated items and moving sufficient parts to other blockparts.
The location of the land users' home parcel is indicated in the fixed or unallocated items.

4.1.2 Select a blockpart

The blockparts are ordered by counting the remaining number of items to be allocated. In case of equal numbers they are ordered by the size of the remaining area.
Since residuals areas from one blockpart may be transferred to another during the design, the order of blockparts may change during the process.

For each blockpart that is activated, the systems sets up a data structure in which layers with topology are constructed with design parts and fixed allocations. The fixed allocations are derived from items in the value allocation plan. Home parcels that retain their shape (unchanged reallocation) are also copied to the design layers.
The system then searched for suitable allocation items for each of the remaining *design parts*. Priority is given 1) to a neighboring item if it is a home parcel that needs to be enlarged 2) to a land user that has parcels in the existing situation 3) to another land user based on distance.

4.1.3 Select an item from the pool of unallocated items

If present, the system selects items from the unallocated items that have a farm building (home parcel) on it and, since they have a fixed location, constructs an (initial) parcel boundary. This parcel is enlarged if necessary, according to the value allocation plan. Next, to select items from the 3 categories in 4.1.2, a score is calculated based on area, existing situation and road distance to the home parcel.

4.1.4 Select a suitable location

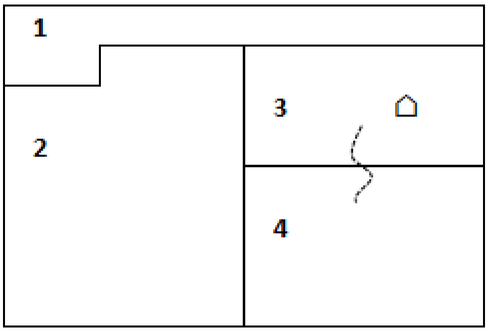
From the unallocated design parts a starting location for the item is selected based on accessibility of the design part from the road network, neighborhood of the home parcel or distance to the home parcel, the existing situation and the status of "competitors": other items in the same blockpart to be allocated to other land users.

4.1.5 Form a boundary

Most boundaries are formed by joining design parts together. In some cases it is necessary to split the design part into two or more parts. For a design part which is adjacent to a road, this is done perpendicular to the road. In this way the remaining design part will still be accessible from the road and is still a candidate field parcel for another land user. If the design part is not adjacent to the road, it will be split in such a way that the new parcel has a good shape.

4.1.6 Check the pool for unallocated items
If there still is an unallocated area in the blockpart then the next item is selected from the list of unallocated items and the process continues. In case the list is empty and the blockpart is not yet completely allocated (negative residual) then the process continues with the next blockpart and the blockpart is not closed. The extra area may be necessary later to transfer items from blockparts with positive residual.
In case the blockpart has a positive residual, the system checks the other blockparts to transfer items (or part of items) to those blockparts.
If the blockpart is completely allocated then the design of the blockpart is closed and the result is presented to the designer.

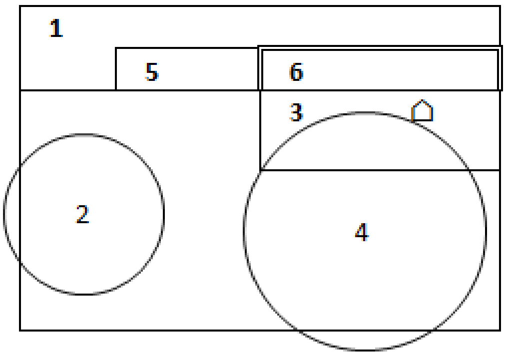
4.2 Schematic example
A small schematic example is used here to illustrate the process:



(Fig. 3a) **A. Existing situation**

Parcel	Land user	Area in ha	Usage	Type
1	1	4.8	road	fixed
2	2	13.2	field	
3	3	6.0	home	fixed
4	3	8.0	home	fixed

Land user 3 has additional area elsewhere, total area of the claim: 20.0 ha.
According to the value allocation plan all land of land user 3 is allocated in this blockpart, also some land of Land user 5 and 3 prefixed allocations:

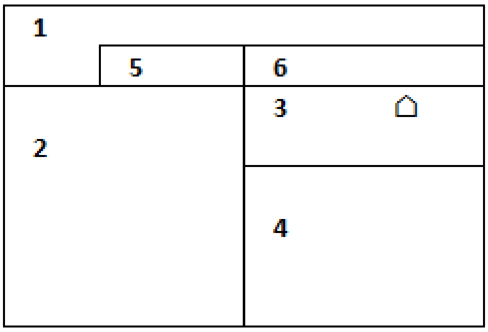


(Fig. 3b) **B. Value allocation plan**

Item	Land user	Area	Usage	Type
1	1	4.8	road	prefixed
2	5	2.0	field	
3	3	6.0	home	fixed
4	3	14.0	home	fixed
5	1	1.2	road	prefixed
6	1	2.0	road	prefixed

The allocation of Land user 5 has no location and no shape. Item 4 must be allocated adjoining the fixed home parcel. Items 3 and 6 overlap, but item 3 is prefixed and so it has priority. The value allocation plan is not concerned with the spatial overlap, the numbers add up and the blockpart is balanced.

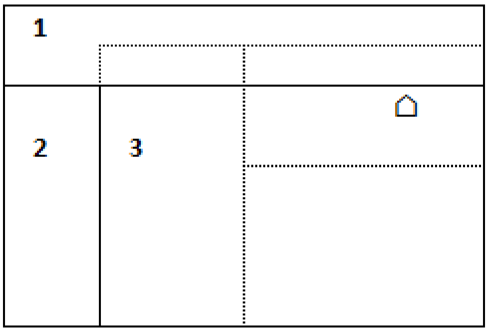
At the start of the parcellation design, the data is as follows.



(Fig. 3c) **c. Design parts**

Design parts	Type	Area
1	prefixed	4.8
2		12.0
3	fixed	4.0
4		8.0
5	prefixed	1.2
6	prefixed	2.0

Parts 1, 5 and 6 are placed at the start. Starting point for the allocation of the home parcel of land user 3 is the clipped parcel 3 (design part 3) which needs to be enlarged. Design part 4 is used next, because it is not near a road, it neighbors part 3 and part 3 needs to be enlarged. The remaining area is for the field parcel of Land user 5.



(Fig 3d) **d. Allocation (sketch)**

Parcel	Land user	Area	Usage
1	1	8.0	road
2	5	4.8	field
3	3	20.0	home

Note that the extension of design parts 3+4 by adding a part of design part 2 by a division perpendicular to the road, in such a way that the remaining part is a parcel with access to the road (design part 1).

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BIOGRAPHICAL NOTES

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