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An automated land subdivision tool for urban and regional planning: concepts, implementation and testing

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Keywords

automated, land, subdivision, tool, for, urban, regional, planning, concepts, implementation, testing

Disciplines

Life Sciences | Physical Sciences and Mathematics | Social and Behavioral Sciences

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**An automated land subdivision tool for urban and regional planning: concepts,
implementation and testing**

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Abstract

Simulation of the land subdivision process is useful in many applied and research areas. Planners use such tools to understand potential impacts of planning regulations prior to their implementation. While the credibility of both landuse change and urban growth models would be enhanced by integrating capabilities to simulate land subdivision, such research is lacking in the published literature. Of the few subdivision tools that exist, most are either not fully automated or are unable to generate realistic subdivision layouts. This limits their applicability, particularly for high resolution landuse change models. In this paper, we present a fully-automated land subdivision tool that uses vector data and is capable of generating layouts with both lot and street arrangements for land parcels of any shape. When the new streets are generally parallel to each other and lots are of approximately the same size, the simulation's output very closely resembles observed subdivision patterns in our southeastern Australia study area. From this, we identify opportunities to improve the subdivision tool for a next version. Future research will also explore how this subdivision tool could be used in conjunction with a landuse change model for urban and regional planning.

Keywords: land subdivision, automated tool, ArcObjects, urban and regional planning

Software availability

Name of software: Land Subdivision Simulator

Developer: Rohan Wickramasuriya

Software required: ArcGIS 9 (ArcView license)

Program language: ArcObjects and VBA

Availability and cost: Freely available by contacting authors

1. INTRODUCTION

Land subdivision is a standard practice in land surveying that aims to partition a tract of land into smaller sized 'lots' (Easa, 2008). It is normally conducted using expert knowledge and skills, rigorous field work, both spatial and non-spatial data, and through incorporating a range of zoning and development rules (Chen and Jiang, 2000; Wakchaure, 2001).

Simulation of the land subdivision process is useful in many applied and research areas. For example, exploring the effects of various subdivision layouts on a given parcel is an integral component of 'build out' analysis, which is performed by planners who seek to understand potential impacts of planning regulations prior to their implementation (Wakchaure, 2001).

Similarly, land subdivision plays a vital role in urban growth (Stevens and Dragicevic, 2007, Vanegas et al., 2009; Morgan and O'Sullivan, 2009) and landuse change modelling (Alexandridis and Pijanowski, 2007). Stevens and Dragicevic (2007) in their study of urban growth modelling emphasize the importance of incorporating automatic land subdivision capability in theirs and similar models to maximize their effectiveness. In summary, models and tools capable of simulating the land subdivision process are in demand by planners and researchers alike.

Any simulation model should meet certain criteria to be considered well designed and practical. For example, Jakeman et al. (2006) argue that a model developed to influence decision-making should be tested against criteria such as 'fitness for purpose' and transparency. In this vein, Parker et al. (2002), suggest that a model's ability to approximate reality is an important evaluation criterion - as a model's behaviour approaches reality, its fitness for purpose increases. For example, Rietveld et al. (2010) and Piuleac et al. (2010) evaluated the performance of their models by comparing predicted values with observed or known values, and claimed that the models have achieved the design goals as the predicted

values approximated the observed values well. Further criteria for evaluating a simulation model include the level of automation and the computational complexity (Kohn et al., 2009). Keeping the tool computationally simple is vital. It is easy for a complex tool to exceed current computational power when the tool needs to simulate subdivision of a large area.

Following from these issues, there are several sub-criteria against which the tool should be evaluated in order to assess the extent to which it meets the fitness for purpose criterion. These are: (1) Can the tool generate both lots and streets? (2) Are all lots given access to the street network? (3) Can parcel boundaries and shapes be realistically portrayed? (4) Can the tool generate cul-de-sacs and multiple direction streets? (5) Is the tool able to make the optimum use of space by intelligently choosing an appropriate subdivision layout for a given parcel? Adding the level of automation and the computation efficiency to this list yields seven criteria against which to assess a given model. Meeting all of these criteria is not necessarily our aim at this stage. The development of a tool is an incremental process – any given version of a particular tool will inevitably involve some compromises. We argue that the tool presented here represents an improvement on previous tools and we assess it and existing tools against the aforementioned criteria in subsequent sections.

Information on attempts to simulate land subdivision is limited. Few studies have modelled land subdivision either as an integrated module in a landuse model, or as a stand alone application. One notable exception is, Alexandridis and Pijanowski (2007), who used a parcelization algorithm in an agent-based landscape model. Further, Ko et al. (2006) developed a model called 'FLOSS' to simulate ownership fragmentation. Recently, Morgan and O'Sullivan (2009) derived a binary space partitioning algorithm to generate cadastral spatial patterns of cities. However, all of these land subdivision automations are developed

for raster-based landscape models, and are performed at relatively coarse resolutions. Street generation, which should accompany a realistic land subdivision simulation, is missing in all three studies. On the whole, subdivision layouts generated by these raster-based tools do not sufficiently resemble the observed subdivision layouts produced by traditional methods. A major reason for this inferiority of raster-based approaches is the inability of regular tessellation of cells of the same size and shape to simulate irregular and heterogeneous real-world phenomena (Moreno et al., 2008). Hence, raster-based tools can not realistically portray parcel boundaries and shapes. The computational simplicity of the raster versus vector-based approaches explains why land subdivision more commonly uses the former. We are aware of only two studies that do use a vector based approach and incorporate street generation. Wakchaure (2001) used a semi-automated tool to generate realistic subdivision layouts. This tool is capable of generating large-scale subdivision layouts (with both lot and street arrangement). However, its semi-automated nature is itself a limitation, particularly when the tool is to be used as an integral component in a simulation model. Vanegas et al. (2009) developed a fully automated parcel subdivision module which is capable of generating both lot and street arrangements. Their module uses recursive binary division on an initial parcel until lots of desired size are achieved. However, the model is computationally complex, and does not aim to optimize the use of space in a given parcel when lots and streets are generated.

Hence, our primary objective in this study was to develop a fully automated vector-based land subdivision tool to generate complete subdivision layouts, showing both lot and street arrangements for a given parcel of any shape and its existing street arrangements, all while remaining relatively simple computationally. Such a tool should be capable of selecting a subdivision layout that generates the highest number of lots and the lowest number of streets

for any given parcel. Subdividing an irregularly-shaped land parcel is more challenging than subdividing a regularly-shaped parcel. Thus, the other objective was to identify areas where further development of the tool is warranted, particularly to improve its ability to generate a variety of realistic subdivision layouts that can handle many situations involved in subdividing irregular-shaped land parcels.

2. METHODS

As used here, the term ‘parcel’ describes a land area that is managed as a single, relatively large unit and which is the target of the subdivision process. The term ‘lot’ refers to a relatively small, single subdivided unit of land resulting from the subdivision of a much larger parcel.

The subdivision tool described in this paper handles parcels that are either rectangular/square or irregular in shape. This subdivision tool is an extension of a tool we previously developed to handle situations where all parent parcels for subdivision are either rectangular or square in shape (Wickramasuriya et al., 2010). Here, we not only extend the subdivision tool, but also validate the tool’s performance against observed data. Before going into the details of extension and validation, we first briefly revisit the concepts and methods used in the original tool.

2.1 Revisiting the methodology for automating a rectangular parcel subdivision

In addition to the constraint of rectangular shaped parent parcel, we assume that all lots generated by subdividing a target parcel also remain rectangular or square in shape. Lot length and lot width are key parameters of the automation, and are user inputs into the tool. The tool aims at achieving the maximum number of lots for each target parcel while creating

the least possible number of new streets. The implemented procedure also ensures that all the lots in the subdivision layout have access to at least one street.

The subdivision tool basically evaluates a parent parcel to be subdivided against four candidate subdivision layouts as shown in Figure 1. In Figure 1, P_w is the parcel width, P_l is the parcel length, L_w is the lot width, L_l is the lot length, and s is the street width.

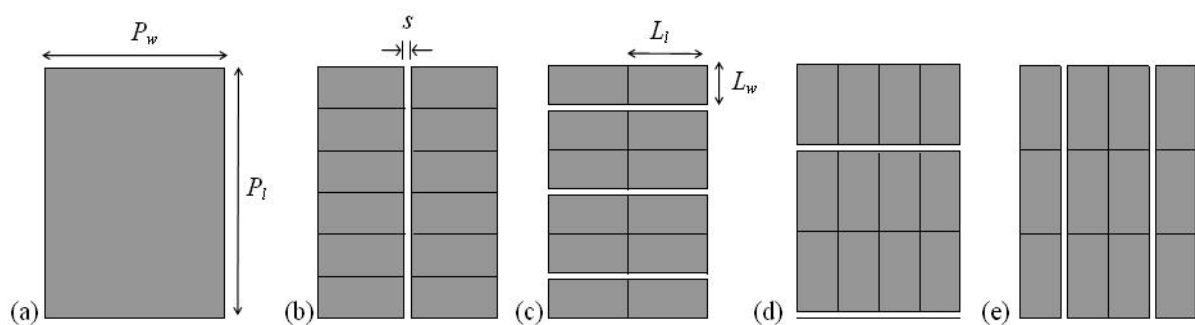


Figure 1. (a) Parent parcel, (b) Subdivision layout: blocks of lots and new streets are parallel to parcel length, (c) blocks of lots are parallel to parcel width, but new streets are parallel to parcel width, (d) blocks of lots and new streets are parallel to parcel width, (e) blocks of lots are parallel to parcel length and new streets are parallel to parcel length.

Note that in a subdivision layout, a stack of lots is termed a ‘block of lots’. For example, the layout shown in Figure 1(b) is comprised of two blocks of lots and six rows of lots. Hence, the maximum number of lots generated in a subdivision layout is the product of ‘blocks of lots’ and ‘rows of lots’.

The tool chooses the subdivision layout that generates the highest number of lots with which to proceed. When it is impossible to select a layout based on the criterion ‘number of lots’ (i.e. two or more layouts generating the same number of lots), preference is given to the layout that generates the minimum number of new streets.

Calculating the maximum possible number of lots and the associated number of new streets for a given subdivision layout is an iterative process. This iterative process is briefly outlined in the next subsection using the subdivision layout shown in Figure 1(b) as an example. A more comprehensive description of this process can be found in Wickramasuriya et al. (2010).

Calculating the number of blocks of lots, rows of lots and new streets

Step 1: Given the parcel width (P_w) and lot length (L_l), the number of blocks of lots (b) that could be generated is calculated as;

$$P_w / L_l = b + R \quad (1)$$

where b is the quotient and R is the *remainder*/ L_l .

Depending on the number of existing streets adjacent to the parent parcel and the number of blocks of lots returned from equation 1, there may be a need to generate new streets to provide access to all lots in the subdivision layout.

Step 2: The number of new streets required can be easily calculated using equations 2, 3 or 4. If the number of blocks of lots (b) is odd, and the number of existing streets adjacent to parcel length (e_l) is zero, the minimum number of new streets required (n_l) is given by;

$$n_l = m + 1 \quad (2)$$

where m is the quotient of integer division $b/2$.

If b is odd and e_l is either 1 or 2;

$$n_l = m \tag{3}$$

Figure 2 shows examples for each of the above situation using a case of three blocks. In Figure 2, the hatched symbol represents existing streets and the white stripes between blocks of lots represent new streets.

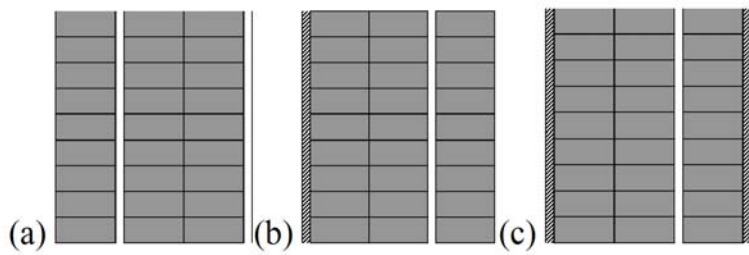


Figure 2. New street requirement for an odd number of ‘blocks of lots’ (a) for zero existing streets, (b) for one existing street, (c) for two existing streets, along the parcel length.

When b is an even number and e_l is either zero or 1, n_l can be calculated using equation 3. If b is even and e_l is 2;

$$n_l = m - 1 \tag{4}$$

Step 3: Next, the tool checks if the remaining width (T_r) after calving out the blocks of lots is enough to accommodate new streets. T_r is given by;

$$T_r = R \times L_l \quad (5)$$

Given the street width (s), total width required to accommodate all new streets (T_s) can be calculated as;

$$T_s = n_l \times s \quad (6)$$

If $T_s \leq T_r$, the calculation stops at this point. If not, one block is dropped to find space for new streets. Dropping one block necessitates recalculation of the number of new streets for the revised number of blocks ($b-1$). This means that steps 2 and 3 are repeated until the final number of blocks (b^*) and new streets (n_l^*) are reached.

Step 4: Once the final number of streets (n_l^*) is known, the total width required to accommodate n_l^* is calculated using equation 6. Therefore, the remaining width (W_r) that can actually be used to accommodate final number of blocks is given by;

$$W_r = P_w - (s \times n_l^*) \quad (7)$$

Final lot length (L_l^*) therefore becomes;

$$L_l^* = W_r / b^* \quad (8)$$

Hence, final lot length is either equal to or slightly higher than the user specified lot length.

Figure 3 summarises the iterative process employed in deciding the final number of blocks of lots and new streets.

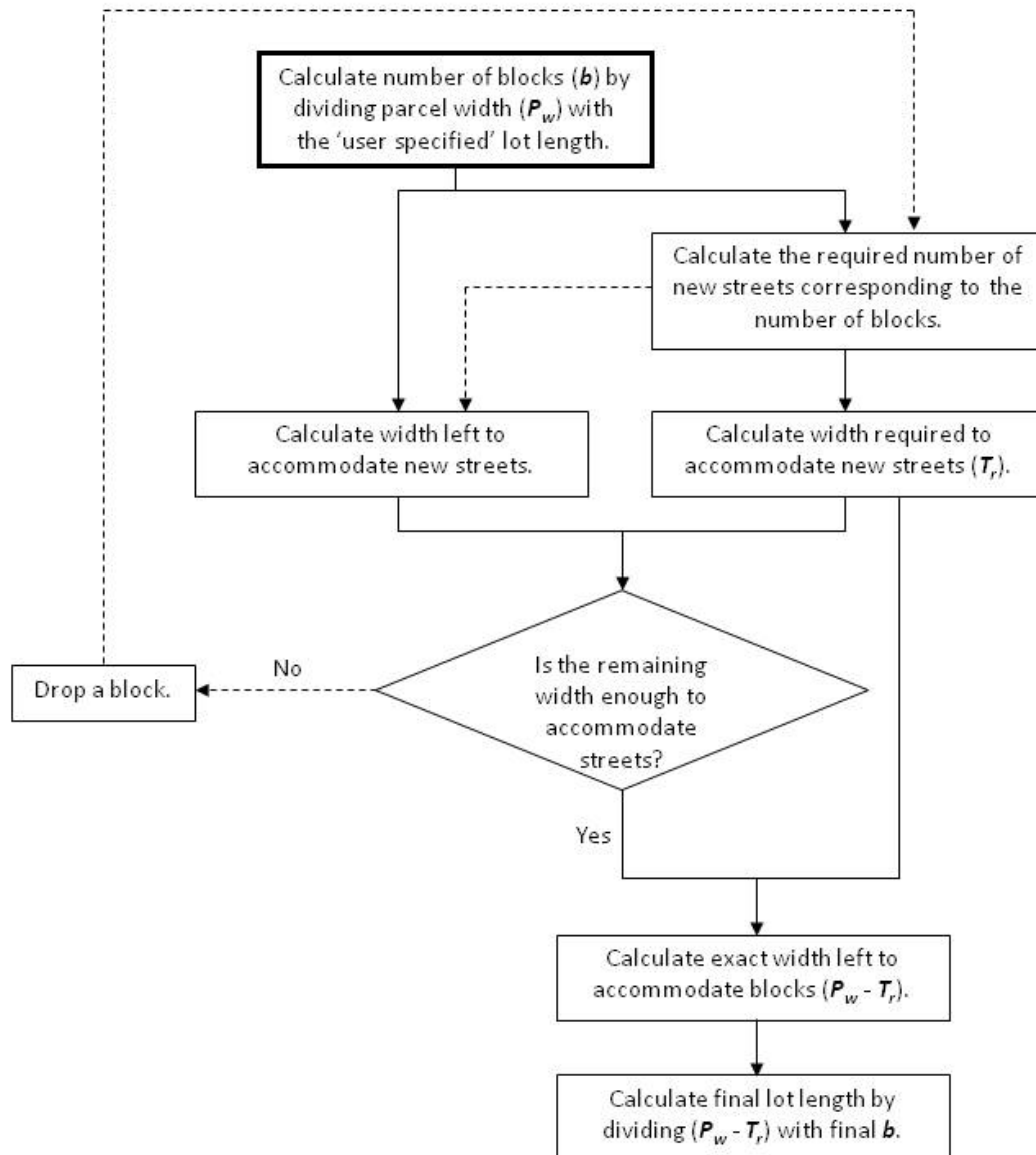


Figure 3. The iterative process for deciding final number of blocks of lots and new streets.

In addition to the streets calculated above that run parallel to parcel length, there should be at least one street running adjacent to the parcel width that acts as a *connecting* street. Unless there is an already existing street to fulfil this requirement, a new street must be generated in the subdivision layout. This calculation is carried out along with the calculation of rows of

lots. Rows of lots are computed by dividing parcel length (P_l) with the lot width (L_w). The procedure adopted to reach the final number of rows of lots is similar to the procedure outlined in Figure 3, except that the process iterates at most twice. This is the case because the tool creates only one connecting street (given that there are no existing streets to act as connecting streets), and it assumes that the lot width is always higher than the street width.

The subdivision tool calculates the final number of blocks of lots, new streets and rows of lots under each subdivision layout illustrated in Figure 1. It then selects the layout that matches the previously established selection criteria, and performs the actual subdivision.

2.2 Extended methodology to handle subdivision of an irregularly-shaped parcel

In the majority of practical situations, land parcels that need to be subdivided exhibit various irregular shapes that deviate from the ‘perfect’ rectangular or square shape. This calls for methods that can handle the subdivision of irregularly-shaped parcels. However, reported research on automating subdivision of irregular parcels is limited. We attempt to fill this gap by extending the subdivision automation procedure discussed in preceding sections.

Our approach is to generate a Minimum Bounding Rectangle (MBR) for the irregularly-shaped parcel, subdivide the MBR using the same algorithm explained in Section 2.1, and then clip the subdivided MBR using the parent parcel as a mask. Every polygon’s minimum x and y extent is given by its spatial envelope. The size of the envelope for the same polygon can vary depending on its orientation in space. Once faced with an irregularly-shaped parcel, our algorithm calculates the area of the envelope of that parcel, and stores the value in memory. Thereafter, the parcel is rotated by a small rotation angle ($\Delta\theta$) around its centroid, and the area of the new envelope is calculated. This new area value is compared to the area

stored in memory. If the new area is smaller than the area calculated in the previous step, area stored in memory is replaced by the new value. This process is repeated until the envelope with the minimum area is found, and that envelope is considered the MBR for that parcel (see Figure 4). The rotation angle that gives the smallest envelope is kept in memory for later use.

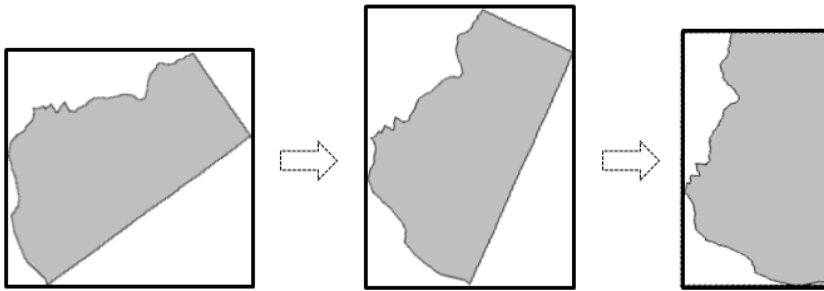


Figure 4. Generating the minimum bounding rectangle for an irregularly-shaped parcel

The least area envelope, or minimum bounding rectangle (MBR), is then converted into a polygon feature, which is aligned in horizontal-vertical planes. The MBR is partitioned using the algorithm explained in Section 2.1. This results in lots and new streets that are not oriented in the initial direction of the parent parcel. These are rotated back to the initial orientation of the parent parcel using the previously stored rotation angle. Lots and streets are then clipped using the parent parcel as a mask. Figure 5 shows the flow of steps involved when subdividing an irregularly-shaped parcel.

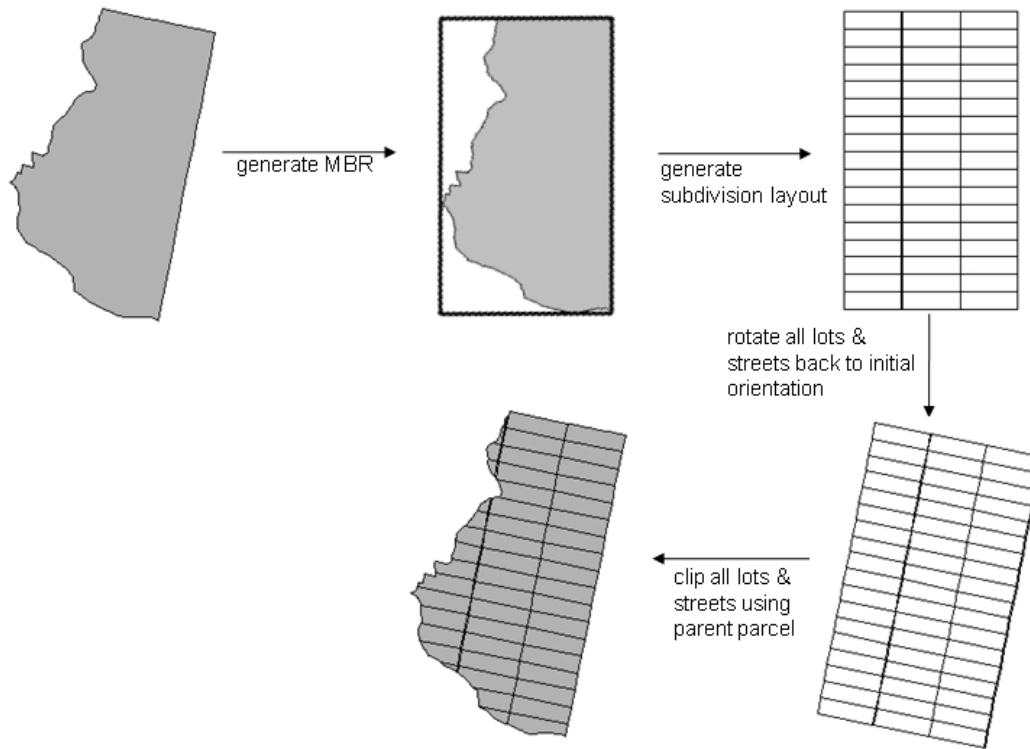


Figure 5. A method to subdivide an irregular shaped parcel.

This method can be used to subdivide a parcel of any shape. However, the resulting lots always remain rectangular unless some parts of the lots are clipped out by the original parent parcel as per the last step.

2.3 Implementation

Both rectangular and irregular subdivision automations are implemented as macros in ArcGIS software using ArcObjects and VBA programming. The main user input to the tool is a polygon shapefile which includes both parcel and street polygon features. The attribute table of the shapefile should contain two additional attributes; 'Label' and 'Shape_Area'. 'Label' should only contain two attribute values; 'parcel' and 'street'. 'Shape_Area' contains actual area of each polygon. At the run time, user is requested to enter values for minimum lot width, lot length and street width.

The tool checks if the first parcel passed in for subdivision is rectangular, and if not it generates a MBR for the parcel. It then rotates the parcel or the MBR parallel to horizontal/vertical planes. Afterwards, the tool evaluates the rectangular parcel or the MBR for all four subdivision layouts (as shown in Figure 1), and selects the best layout. It then generates lots and new streets according to the selected layout to match automatically calculated parameters (based on user specified constraints such as minimum lot width, lot length and street width). These parameters are the final number of ‘blocks of lots’, new streets, ‘rows of lots’ and connecting streets. If the subdivision is carried out for an irregularly-shaped parcel, new lots and streets are clipped using original parent parcel as a mask. Subsequently, the original parcel is replaced with the newly generated lots and streets. Then the tool begins to subdivide the next parcel if requested.

2.4 Validation of the subdivision tool

Model evaluation and testing represent one of the most important steps in any environmental model development cycle (Jakeman et al., 2006). We recognize the importance of model validation in terms of how best our tool can generate realistic subdivision patterns.

Careful observations of real land subdivisions in urban/suburban/rural areas reveal the existence of two different subdivision layouts related to irregularly-shaped parcel subdivision. For the first of these, subdivided lots predominantly orient in one direction with all new streets (if existing) mostly running parallel to each other. Lots within this layout are predominantly rectangular in shape. We refer to this subdivision as ‘*type A*’ from here onwards. Figure 6 shows three such examples from a residential area called Albion Park in New South Wales of Australia. The other layout (‘*type B*’ subdivision) is comprised of either

rectangular or irregular-shaped lots that are oriented in many directions, as well as new streets running in several directions. Some streets in *type B* layout do not completely traverse the parcel, unlike in *type A* layouts. Figure 7 shows two examples for this subdivision type from the same residential area.

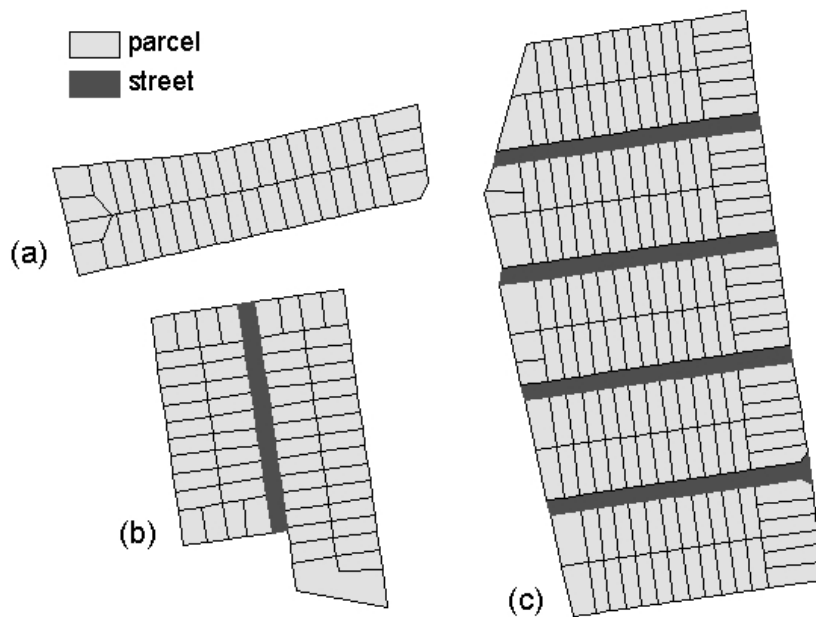


Figure 6. Observed subdivision layouts in Albion Park, New South Wales where lots are nearly rectangular and oriented mostly in one direction with: (a) zero new streets, (b) one new street, (c) many new streets.

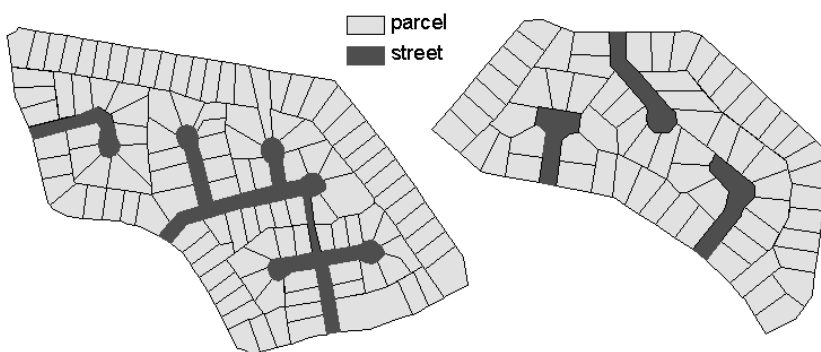


Figure 7. Two examples for observed subdivision layouts where lots are either rectangular or irregular, and are oriented in several directions

We anticipated that the subdivision tool would not be able to produce layouts that closely resemble *type B* subdivision, because the tool is not capable of generating either streets running in several directions, or streets that do not completely traverse a parcel. Yet, we were interested to know how the subdivision layouts generated by the tool for *type B* subdivision scheme deviate from the observed layouts. Therefore, the ability of the subdivision tool to generate layouts for both types was tested. Fourteen parent parcels of various sizes that have been subdivided according to the *type A* scheme, and seven parent parcels of various sizes which have followed the *type B* subdivision scheme were selected. Relative scarcity accounts for the lower number of parent parcels used in the test for *type B* scheme. The subdivision tool was then used to generate subdivision layouts for each of the parent parcel. Lot width and lot length of the most frequently *observed* lot from each subdivision layout were fed as input parameters to the subdivision tool. Observed subdivision layout and the subdivision layout generated by the tool (also referred to as model-generated layouts) for each parent parcel were compared visually as well as statistically.

3. RESULTS AND DISCUSSION

3.1 Validation

The ability of the subdivision tool to generate observed subdivision layouts was assessed using visual and statistical tests. We first discuss the tool's performance for type A subdivision, and then for type B subdivision.

3.1.1 Type A subdivision

The tool is able to produce very similar subdivision layouts in all cases for which *type A* subdivisions were carried out. Three examples of the tool's performance for varying parent parcel sizes are shown in Figure 8. In all cases, the number of streets and number of blocks of lots generated by the tool are exactly the same as those of observed layouts. Moreover, the orientation of all streets and majority of lots are also the same for observed and model-generated layouts. Locations of new streets also clearly match with the observed layouts.

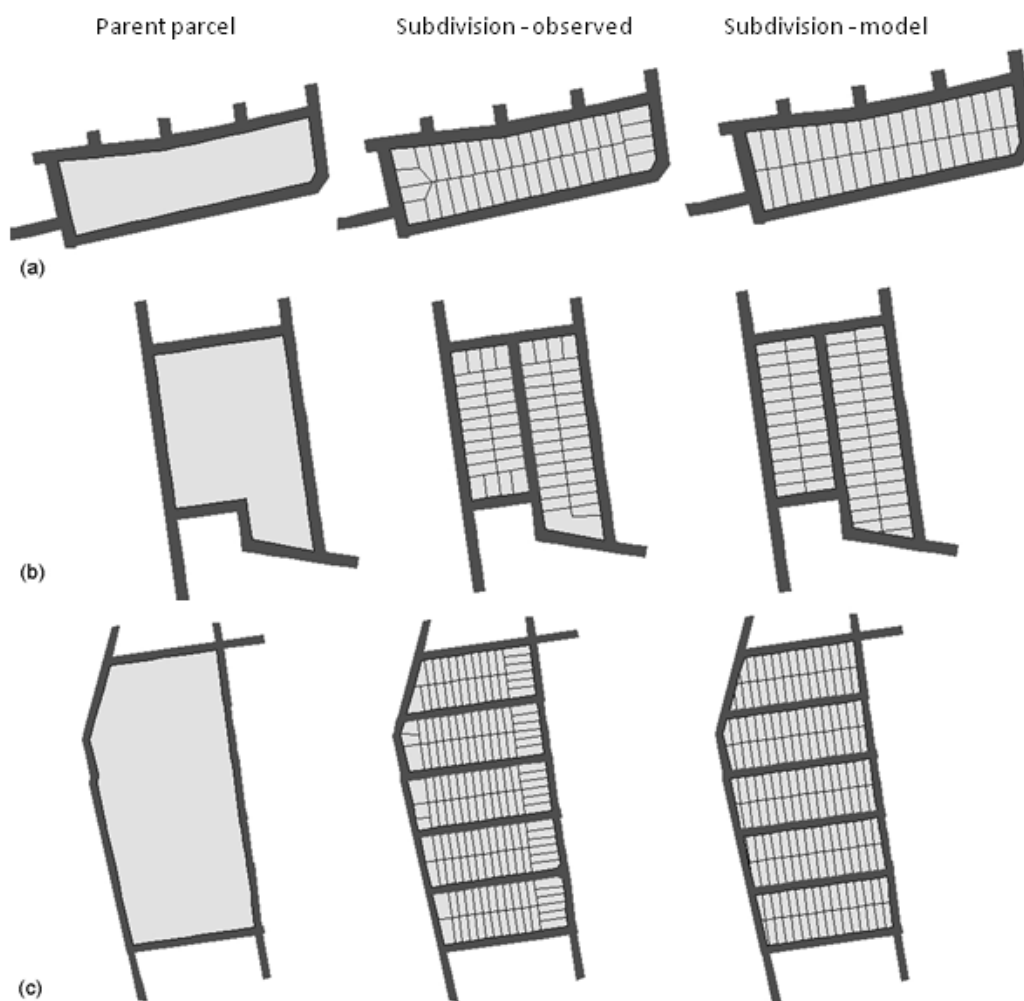


Figure 8. Comparison of observed and model-generated subdivision layouts for regular subdivisions with: (a) no new streets created, (b) one new street created, (c) many new streets created.

For example, the observed subdivision layout in Figure 8(a) has two blocks of lots and zero new streets, while the model-generated layout also contains two blocks of lots and zero new streets. Figure 8(c) is a more complex subdivision layout where the tool has succeeded in generating four new streets and ten blocks of lots to match the observed layout.

Lots generated by the subdivision tool match those of observed layouts most of the time, except towards either ends of blocks of lots. Observed lots in these areas tend to change orientation and sometimes size and shape. Lots generated by the tool always keep to the rectangular shape, unless some parts are clipped out by the parent parcel boundary during the last step of the automation. This step actually results in lots that are smaller than the rest of the lots. One solution to this problem is to merge those smaller lots into adjacent ones until there is no lot available with an area less than the minimum lot size. Automating this task is challenging as there are many different ways one could merge smaller lots into adjacent ones. However, a solution to this problem is planned for further development of the subdivision tool. An incentive to strive for implementing such a solution is an expected improvement in lot size and shape achieved for those lots along the border.

An accuracy assessment of the tool shows that it generates exactly the same number of new streets that are oriented in exactly the same direction as observed in all fifteen subdivision layouts tested. Furthermore, all new streets in the model-generated subdivision layouts overlap with all corresponding streets in the observed layouts along the full street length. The average percentage of street area overlap of 91.4% between model-generated and observed layouts further verifies a high location accuracy of new streets generated by the tool.

To test the accuracy of generated lots compared to the observed, four indices: 1) number of lots, 2) mean lot size, 3) Standard Deviation of Lot Sizes (SDLS), and 4) Mean Shape Index (MSI), were calculated for both observed and model-generated layouts for all fifteen instances. MSI is a measure of shape complexity found in Fragstats (McGarigal and Marks, 1995). For our purpose, we treat MSI as the sum of each lot's perimeter divided by the square root of lot area (in hectares) for all lots, adjusted for circular standard (for polygons) , and divided by the number of lots. The correlation coefficient and its significance for two indices (number of lots and mean lot size) between observed and model-generated layouts were examined. Furthermore, a t-test was performed considering observed and model-generated layouts as two independent treatments and fifteen layouts as replicates. The hypothesis tested was;

H₀: Population mean for each index is the same between observed and model-generated layouts.

H₁: Population means are different.

Table 1 shows results of two statistical tests for two selected indices, while Table 2 lists summary statistics for two other indices.

Table 1. Correlation coefficient and t-Test statistics for two selected indices (type A)

	Correlation coefficient	<i>p</i> value of t-Test
Number of lots	0.99*	0.8762
Mean lot size	0.92*	0.4616

* significant at 0.01 alpha level

Table 2. Summary statistics for two selected indices (type A)

	Average value	
	Observed	Model
LSSD	0.0084	0.0082
MSI	1.46	1.29

It is possible that strong correlation coefficients are not always significant. A strong correlation coefficient could merely be a result of chance when the sample size is small. Therefore, it is important to test the significance of the correlation in this case. Correlation coefficients for number of lots and mean lot size between observed and model-generated subdivision layouts are strongly positive, as well as significant at 0.01 alpha level. Furthermore, results of the t-test do not provide evidence to reject the null hypothesis. The average values for LSSD and MSI indices are also comparable between the model and observed layouts. In short, the tool is capable of producing subdivision layouts that closely match the observed subdivision layouts for *type A* subdivisions.

3.1.2 Type B subdivision

A second subdivision type is characterized by new streets and lots of various sizes oriented in several directions within a subdivision layout. As expected, the subdivision tool described in this paper is only able to partially capture the characteristics of observed subdivision layouts of this type. Figure 9 shows the observed and model-generated subdivision layouts for a parcel that follows type B subdivision.

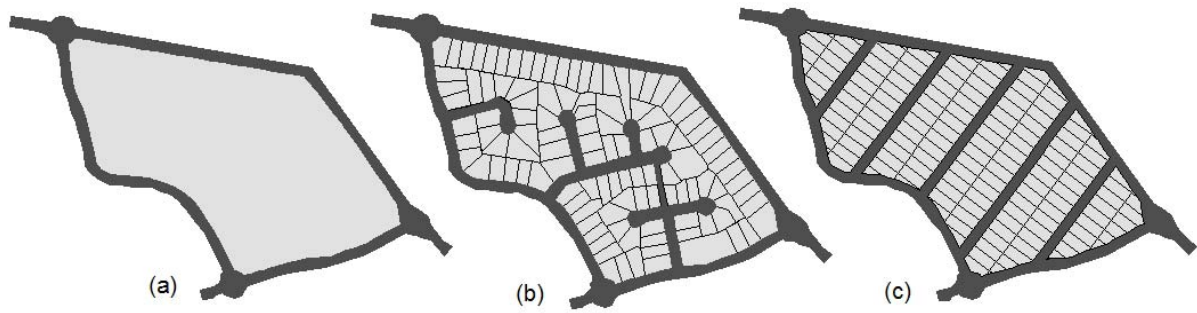


Figure 9. Comparison of observed and model-generated subdivision layouts for irregular subdivisions, (a) parent parcel before subdivision, (b) observed subdivision layout, (c) subdivision layout generated by the algorithm.

The number of blocks of lots, number of streets, length of streets, and most of the time the orientation of streets do not match between model-generated and observed layouts. The correlation coefficient for the number of streets between model-generated and observed layouts was also found not to be significant statistically. The average percentage overlap of new streets between the model and observed layouts is only 22.4% compared to 91.4% for type A subdivision. This suggests that the positional overlap of streets between the model and observed layouts is inadequate, which also is confirmed by Figure 9. Table 3 and Table 4 show the results of statistical analysis for the same indices discussed in Section 3.1.1 under a type A subdivision. Note that the null and alternate hypotheses are also the same as those describe in Section 3.1.1.

Table 3. Correlation coefficient and t-Test statistics for two selected indices (type B)

	Correlation coefficient	<i>p</i> value of t-Test
Number of lots	0.98*	0.483
Mean lot size	0.58	0.001

* *significant at 0.01 alpha level*

Table 4. Summary statistics for two selected indices (type B)

	Average value	
	Observed	Model
LSSD	0.027	0.017
MSI	506.28	1.25

Interestingly, the number of lots still matches between the model and observed subdivision layouts, suggesting that the fundamental assumption behind the tool's development, which is 'maximizing number of lots generated', is valid irrespective of the subdivision type. The strong and significant correlation coefficient for the index 'number of lots' also supports this argument. However, the t-test for mean lot size provides evidence to reject the null hypothesis, implying that the model and observed layouts are significantly different in terms of lot sizes. Also, the correlation between model and observed layouts in terms of mean lot size is not significant.

The difference of average LSSD values between observed and model-generated layouts are notably higher for the type B subdivision (0.01) compared to that for the type A subdivision (0.0002). As the size variation of observed lot sizes increases, the tool's ability to reproduce

the same variation decreases. Observed lots have also shown a large variation in shape as evident by a much higher MSI which the model has failed to achieve. This is obvious as the subdivision tool is generating same size (apart from the lots that are on the boundary) and same shaped (rectangular) lots.

3.2 A comparison between the new subdivision tool and other similar tools

In the last decade, researchers have begun to realise the importance of, and attempt to automate, land subdivision (Wakchaure, 2001; Ko et al., 2006; Alexandridis and Pijanowski, 2007; Moreno et al., 2008; Vanegas et al., 2009; Morgan and O'Sullivan, 2009). However, a traditional land subdivision is carried out by an experienced surveyor based on field surveys, considerable forms of spatial and non-spatial data, and various zoning and development rules (Chen and Jiang, 2000; Wakchaure, 2001), which makes it quite challenging to automate. Recent work, including this study, does not yet fully replicate the traditional approach. However, valuable progress towards doing so is being made.

The subdivision tool presented in this study is implemented using vector data model, whereas the subdivision tools developed by Ko et al. (2006), Alexandridis and Pijanowski (2007), Morgan and O'Sullivan (2009) use a raster data model. Moreover, these tools simulate subdivision at a coarse spatial resolution and ignore the street generation that should accompany a realistic land subdivision. Moreno et al. (2008) developed a tool that allows geometric transformation of objects using a mix of vector and raster based operations. Although this tool can simulate a polygon losing its area to the neighbouring polygon that exerts an influence on it, the output of the tool is not a realistic subdivision layout comprised of lots and streets.

Similar to our subdivision tool, the tools developed by Wakchaure (2001) and Vanegas et al. (2009) are vector based, and produce large scale, realistic subdivision layouts comprised of lots and streets. However, Wakchaure's (2001) subdivision tool is only semi-automated, requiring significant user intervention to generate subdivision layouts. This is a limitation when the subdivision forms part of a landuse change model or an urban growth model that subdivides land parcels during run time without any user intervention. The land subdivision mechanism presented by Vanegas et al. (2009) is fully-automated. However, the subdivision tool discussed in this paper can generate realistic 'blocks' and 'rows' of lots one would find in a residential development plan because it considers the initial spatial configuration of the target parcel in relation to neighbouring parcels and streets, and then generates the maximum possible number of lots and minimum possible number of streets in one step. Further, perhaps the most striking difference between the subdivision automation of Vanegas et al. (2009) and our subdivision tool is that the former employs a recursive binary division on a parcel until a minimum lot size is achieved, whereas our tool intelligently decides the appropriate subdivision layout for a given parcel that maximizes the use of space while sticking to the user specified minimum lot size and to the rule of providing access to all lots with minimum number of new streets. Furthermore, our subdivision tool is simple in design, involving few datasets and rules, while still achieving high standards of predictive capacity for type A subdivision.

As mentioned earlier, computational efficiency is important for tools of this type to ensure they are feasible to run for actual case studies. Stating an average time to complete one subdivision iteration is somewhat misleading for a tool of this nature (Stevens and Dragicevic, 2007) as it depends on various factors such as total area, number of parent parcels and lot dimensions. As a general guideline, our tool takes less than ten seconds to

subdivide an area of 6km*8km that contains nine large parcels into 92 lots of 550m*750m, and less than twenty five seconds to subdivide the same area into 293 lots of 300m*450m.

In summary, our subdivision tool satisfies six out of seven criteria established in the introduction. It is computationally simple, yet fully automated. It generates both lots and streets in a subdivision layout, and makes sure that all lots have access to the street network. It can realistically portray parcel boundaries and shapes because it uses a vector based approach. This subdivision tool is also capable of selecting a subdivision layout for any given parcel in such a way that the space is best utilized. Currently, the tool can not generate cul-de-sacs and streets that are oriented in many directions. These features will be introduced in future versions of the subdivision tool.

4. CONCLUSION

The land subdivision tool presented in this paper generates subdivision layouts for a given parcel and maximizes the number of lots while minimizing the number of new streets generated under the constraints of minimum lot width, lot length and street width. The tool also ensures that all lots in the layout have access to at least one street, despite the minimum number of streets it generates. The extended tool is capable of subdividing parcels of any shape. Subdivision layouts produced by the tool resemble the observed layouts very closely, when a parent parcel is subdivided to produce more or less parallel new streets, and when lots are oriented mostly in one direction (type A subdivision). As the observed layouts contain lots and new streets of various sizes oriented in many directions (type B subdivision), the layouts generated by the tool clearly deviate from observed. However, the majority of the observed subdivisions in our study area follow the type A scheme. Moreover, type A

subdivision is also common in many urban, suburban and rural areas of Australia, areas of the United States where rectangular land survey systems is adopted (Brown, 2003 ; Donnelly and Evans, 2008), and virtually in any properly planned city in the world. Thus, the subdivision tool presented here has a broad, global-level applicability even at this initial development stage.

The accuracy of model-generated layouts for irregular parcels can be improved in several ways. For example, sliver polygons (under-sized lots) created during the subdivision of an irregular parcel can be joined to adjacent, proper-sized lots. Alternatively, adjacent sliver polygons can be joined together to ensure a minimum lot size. Further, it would be helpful to allowing the most exterior lots to change their orientation if needed. A limitation of the current version of the tool is the fixed lot size used within a subdivision layout per parcel – addressing this would be helpful as well. While the aforementioned improvements to the model could enhance the accuracy of subdivision layouts generated for both *type A* and *type B* schemes, allowing the tool to generate streets that do not completely traverse a parcel (i.e. cul-de-sacs) could augment its ability to generate more close matches for *type B* subdivision layouts in particular. Though all of the improvements noted above are technically challenging, we plan to incorporate them into future versions of the subdivision automation tool. Finally, though we do not address it here, the frontage of lots generated by the subdivision tool compared to that of the observed lots could be an important assessment criterion, particularly in places like North America. Therefore, potential users of this tool are advised to test how the tool behaves in relation to lot frontage, prior to using it in areas where lot frontage is equally important as the lot size.

Subdivision layouts generated by the tool discussed in this paper are not intended to replace layouts produced by a surveyor based on field measurements. This tool should instead be used for initial exploratory work prior to actual field survey. Aside from direct land subdivision tasks, many other application areas may benefit from the subdivision tool presented. For example, landuse change models could use this tool to simulate subdivision of land parcels, where modelling land subdivision phenomenon is an integral component of the overall model. Environmental planners and policy makers could use this subdivision tool to analyse habitat fragmentation due to land development, gaining an estimate and a means to visualize how habitats are fragmented and lost due to differing subdivision schemes. This would assist governing bodies to set appropriate zoning regulations to minimize the negative effects of land subdivision on biodiversity.

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