Precise Coordinate LIS for Improving Planning and Land Registration Processes in the Modern Real Estate Markets

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Key words: Analytical Cadastre, LIS, Real Estate Markets

SUMMARY

As in many other countries, the existing statutory division of land - the cadastre – in Israel is based on filed surveying which were recorded during decades in field books and were used to determine the boundaries of the block and parcels. Cadastral measurement is a continuous process, due to changes in land ownership, union and division of parcels, and the constant necessity to redefine and update the ownership boundaries. Most information is currently kept on paper (field books, field sheets), which does not permit its computerized management. Inherent contradictions and inaccuracies in the existing material cause difficulties in its use and delays in tracking and measuring the changes, and in updating the cadastral map. The result of urban and regional planning which is carried out based on the non-precise graphical cadastre are non-precise plans which cause difficulties in preparing the mutation plans and thus very long processes of registration the ownerships of the land re-parcelation. The solution for the problems of the current cadastre which has a "graphic nature" is to establish an analytical cadastre in which the location of each entity is unequivocally determined precisely by the state plane coordinate system. The data of the analytical cadastre will thus constitute a spatial information system defining the statutory land division. Modern real estate markets will be significantly affected by a precise cadastral LIS. Within these influences can be mentioned: preventing the transaction costs that correspond to disputes and lawsuits between landowners, stakeholders, and other potential conflicting interests; allowing a reliable land valuation; decreasing the uncertainty that accompanies real estate transactions; and, accelerating the execution of real estate transactions.

Currently, the Survey of Israel (SOI - the governmental geodetic, topographic and cadastral mapping agency) is starting a project to improve the quality of the existing analogue graphical cadastral maps and convert them to a digital format that will establish a precise geospatial database (a precise LIS). The GIS technology will provide the basic tools for storing, managing and analysis of the digital cadastral information, thus establishing the basis for improving the planning and land registration processes

The paper describes a pilot project that was carried out in order to examine and evaluate new methods for generating a spatially accurate, legally supportive and operationally efficient cadastral database of the urban cadastral reality. Furthermore, the relationship between precise cadastral coordinates and the registration and planning processes is analyzed, and forecasted influences on modern real estate markets are examined.

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1. INTRODUCTION

In Israel, as in many other countries, there exists a statutory division of land - the cadastre. Generally speaking, the cadastre is a method of registration that contains information on the land parcels, such as their boundaries, areas, ownership, etc. Cadastral mapping commenced in Israel in 1926, based on the Torrens method - Registration of Titles (Dale, 1976; Dowson, Sheppard, 1952), the most advanced and innovative system at the time. This system defines a unit of land and its area based on official surveying and mapping carried out by the state and linked to the national coordinate network. Measurement results are recorded in field books and used to determine the boundaries of the block and the parcels, as well as other features (buildings, fences, electric poles, etc.) on a field plan sheet. Maps of the blocks are prepared based on the field sheet, consisting of all parcels in the block (according to their numbers) and all included features. These maps contain neither the measured data nor any dimensions whatsoever of the parcel boundaries. The current cadastre in Israel can therefore be defined as a measurement base cadastre of a graphical nature.

Most measurements for cadastral mapping were performed by using the chain surveying method. This method necessitates prior marking and measurement of control points in the field (a traverse network), and linking them to the national control network (the trig points). The first blocks in Israel were based on a control network of very low accuracy. Until the 1980s, the calculation of these traverses was based on separate adjustment of each traverse and not on a rigorous adjustment as a uniform network. The adjustment method used is the Bowditch method (first handling the angular misclosure, then following with the linear misclosures) (Berthon, 1972). Most of the blocks were plotted manually based on chain surveying measurement, without calculating coordinates. Measurement and drawing control was performed by measuring direct distances (fronts and diagonals) in the field, and comparing these with the same distances obtained in the plotted map.

Quality of the cadastral maps improved with the development of modern measuring instruments and introduction in cadastral measurements of the polar method (theodolite and electrooptical distances measuring). Concurrently the new block maps were being drawn by plotters based on calculated coordinates. Another improvement in quality and accuracy of cadastral maps took place in the course of the 1980s and 1990s following the increased accuracy of the Israeli control network. During the 1990s with the instruction of the GPS system (and later the RTK GPS) in cadastral measurement, additional improvement has been achieved.

Cadastral measurement is a continuous process, due to changes in land ownership, union and division of parcels, and the constant necessity to redefine and update the ownership boundaries. Accurate, accessible and updated cadastral information constitutes the basis for planning and implementation of a variety of real estate related operations in many areas. In the present form of the graphic cadastre, the existing cadastral information does not fulfill

these needs. Most information is currently kept on paper (field books, field sheets), which does not permit its computerized management. Inherent contradictions and inaccuracies in the existing material cause difficulties in its use and delays in tracking and measuring the changes, and in updating the cadastral map. It is important to note that according to the current surveying regulations in Israel, restoring of boundaries must be performed according to the original measurements from the field books and not according to calculated coordinates, with the final decision regarding the location of the boundary to be made on the basis of adjustment between the measurements and the actual situation in the field.
The solution for the problems of the current graphic cadastre is to establish an analytical cadastre in which the location of each entity is unequivocally determined by the state plane coordinate system. The data of the analytical cadastre will thus constitute a spatial information system defining the statutory land division. GIS systems provide the basic tools for storing, managing and analysis of digital spatial information, thus establishing the basis for the cadastral information system (as an LIS system).

2. ISSUES WITHIN THE ISRAELI CADASTRE

Israel has today four different Registry Methods.

- 95% of Israel's land is registered according to Torrens method - "Registration of Titles" (or "the new method") (Dale, 1976).
- Registration according to "Registration of Deeds" method. A method that was implemented by the Ottoman government in Israel from 1858 until 1928 ("the old method") (Gavish, Kark, 1993).
- Registration according to the "Registration of Deeds" method accompanied by precise surveying.
- Condominium Apartments Registration.

The "old method" allows registration of an individual piece of land. Individual pieces of land were registered according to the book number and the page number of the relevant city. The advantage of this method is due to the fact that any individual's ownership rights can be registered immediately, without the requirement to postpone it until registering a complete block. The main disadvantage of this method is that the State has no responsibility to handle a comprehensive cadastral inspection (in contradiction to the "new method"). This is also the reason why registration according to the “old method” constitutes "prima facie evidence." This means that when registering a property section, one can appeal the previously defined boundaries of the area in the registration. Similarly, if a neighbor scrutinizes the previous registration of his section, and concludes that the registration of his property borders was incorrect, he can ask the Registrar to correct the registered section's borders.
The Torrens method (the “new method”) permits several landowners to register together, requiring an inspection of each of the landowners' sections. Each landowner marks the borders of his section. The border marks were surveyed according to the surveying methods and available equipments since the 1920s (mainly chain surveying method). In practice, this would be the ideal method if all the turning points could be precisely coordinated. However, as mentioned previously, past work methods caused discrepancies and a lack of homogeneity between the line polygons. Furthermore, adding new points to the previous points during a survey of the border only increased these discrepancies. The measuring techniques as well as

computation and adjustment procedures since the 1920s, caused to a situation where a marked polygon point would have to some extent different coordinates if being computed based on different polygons in the near vicinity (sometimes diverged up to 40 centimeters).
Based on these facts, it is almost impossible to establish new borders or restore old boundaries according to the numerical values of the coordinates of these points (values which appeared in the calculation files). According to the Israeli cadastral regulations, establishing new borders should be based on the authentic points in the field or, alternatively, restore the borders on the basis of original features (such as houses, walls etc.) which appeared in earlier surveys.
Accelerated real estate development in Israel resulted in authentic points disappearing, and it has become increasingly difficult to reestablish new border points. This situation made it inevitable to find a different method to calculate and manage a border database and cadastral data. The different method requires changing over to analytical cadastre based on coordinates in which all of a cadastral border points would be determined by a collection of controlled, adjusted and homogeneous coordinates.

3. ANALYTICAL CADASTRE

Obtaining the digital mapping data is the bottleneck in the process of establishing the analytical cadastre. Several basic sources exist for obtaining such data: field measurements of land boundaries; digitizing existing maps; and processing the existing surveying data.
Resurveying all land boundaries could constitute a radical solution for the problem. It would be necessary to restore the boundaries according to the existing information in the field books and sheets, and measure these in relation to a new control network. Restoring the boundaries as-is constitutes a tremendous effort, whose estimated cost is extremely high. The cost of measuring the restored boundaries further on in the process is estimated to be similarly very high.
A possible alternative for restoring the boundaries could be the surveying of the existing boundaries. This solution would in practice to cancel the current statutory validity of the land boundaries and would in fact institute a new real estate order, with all that this implies. This solution is impractical in countries with a legal real estate order as in Israel, and moreover, there is no doubt that it has no economic justification.
Another solution would use the original measurements and would be based on recalculating the field books. Calculating the books as a stand alone process for establishing an analytical cadastre is unsuitable due to several reasons. Within these reasons one may mention: Weakness of the original control network on which the measurements were based; Need to adjust the calculation results to the fronts that appear in the field sheets; In many cases the statutory changes in the field were marked and drawn in the field sheets but were not recorded in the field book; and, Due to the situation in Israel, not all the field books that cover 80 years of Israeli cadastral surveying are available.

Converting graphic data on existing maps to digital data would of course be the least expensive and the fastest way of obtaining such data. There are about 15,000 cadastral block maps in Israel, prepared in different periods, employing different methods of measurement, calculation and drawing, as well as on different scales. Simply digitizing the existing maps will not contribute to obtaining a database which would be adequate for the analytical cadastre, both from the accuracy aspect and from the judicial validity aspect. This fact is due to the heterogeneity in the quality of the maps, and due to the accuracy limitations inherent in the digitization process itself.

As a result of the need to improve the quality of the data digitized from the cadastral maps, in the recent years the issue of integrating external information with digital data derived from maps has been studied. Two types of external information can be distinguished: "cadastral" information and "geometrical" information. Cadastral information is the registered area of a parcel, the length of a front, right of way, etc. Due to the legal aspects of this information, and in order to ensure the judicial validity of data derived from maps, it is necessary to adjust it to the cadastral information. As distinct from the cadastral information which is explicitly displayed on the cadastral maps or the field sheets, the geometry is contained in the maps and first needs to be identified. These are geometric conditions which define the shape of the entities described in the map (closed polygons, straight lines, circular arcs, parabolic curves, etc.), as well as the existing spatial relationships between the various entities (parallelity of lines, perpendicularity of lines, etc.).

Reconstruction of geometric and cadastral conditions is generally performed on each map using adjustment techniques. Some of the points on the map must concurrently fulfill several conditions (the intersection points of lines, for example). Considering this fact as well as the large number of equations (as a function of the number of conditions), the practice is to solve them by stages (when only one condition is adjusted) and by iterations (a consistent solution of all equations describing the conditions).

4. PREVIOUS RESERACH

Developing a precise and accurate analytical cadastre is an ongoing issue in Israel, as in many other countries, for the last 10-15 years. Previous research has been focusing on particular aspects of establishing an analytical cadastre in urban or in rural neighborhoods.

Fradkin and Doytsher (2002) have developed a new method for generating an analytical cadastral database of the urban cadastral reality. The definition and compilation of an accurate cadastral database was based on new GPS control points and traverse networks for providing the framework; the old field books for defining the links between the various original ground features; and a geometrical and cadastral adjustment process as a conceptual basis.

A substantial difference exists between calculating the coordinates of the boundary points from field books and between restoring them in the field by traditional methods. The restoring process is local by its nature, relying only on findings in the near vicinity (the neighboring parcels) of the restored boundary and the original measurements. Application of a new process which analytically imitates the traditional process is relying on the precise location of several existing features in the field, features that are linked to the old measurements. The only way to obtain the location of these features is to identify them in the field and to measure them in relation to a new control network that is free of the constraints, inaccuracies and errors inherent in old control networks. Their method was based on the principles of:

- Combining the old measurements with a limited number of new measurements, in order to enable the calculation of boundary points according to the new control network;
- Reliance on using features that are well defined in the field, which do not require to be restored and can be identified with certainty;
- Based on features which are linked to the cadastral boundary points.

Buildings were chosen to create the “link” the updated measurements and the new network with and the historical measurements and the previous network. The decision was made due to the certain identification of the buildings in the field (there is no need to restore their location, only to identify them and ascertain that their shape has not changed during the years); and, the relative ease of measuring the building corners. Based on the simple geometric link between the building corners and the parcel boundary, a new measurement of the two corners of the building with the addition of the previous measurements easily permits the calculation of the parcel corner coordinates.

The buildings (as secondary features which are not connected to the land boundaries) were not measured directly from the measurement lines, but were linked to the parcel boundaries. The level and accuracy of the building measurements is poor in comparison with the level and accuracy of measurement of the boundary points. As a result, differences were obtained between the coordinates of the same boundary points common to two adjacent parcels which were calculated separately according to the measurements of two neighboring buildings. Since each of the two nearby buildings permits use of independent measurements for restoring the boundary point between them, it was possible to calculate common boundary points for the various parcels using adjustment procedures. Further strengthening of the shape and location of the boundaries was achieved by applying geometric and cadastral conditions. A pilot project showed that the accuracy estimates for the adjusted coordinates (RMS) is better than 0.10 meter.

Gavish and Doytsher (2002) have suggested a method for establishing an analytical cadastre in rural/suburban areas. In these areas, where the original measured land features no longer exist, the current land reality is usually different, thus causing severe difficulties when trying to restore the cadastral boundaries. Mere use of new aerial photographs, describing the current land reality, and applying modern photogrammetric methods cannot avoid the tedious manual restoration of the cadastral boundaries. In order to bypass the main problem of not being able to find the previous measured features, it was proposed to use aerial photographs from previous periods and thus, being able to re-measure the “vanished” features. The method suggested a “virtual journey in time” by using two sets of aerial photographs - one set that was taken recently and another set that was taken several years earlier when the original land features still existed and could be measured from the photographs. Thus, comparison of the two mapping realities, the current and the previous, was achieved. Four “mapping environments” can be defined:

- The current reality (in terms of field surveying, new control points etc.);
- New photogrammetric models (enabling to measure the current reality without field surveying);
- Previous photogrammetric models (enabling to measure the land reality at the time when the cadastral maps were prepared); and,
- The previous reality (as it is defined by the cadastral maps)

A sequential linkage between these four “mapping environments” enabled to define an analytical restoration process for the cadastral boundaries, without the necessity of manual field restoring efforts. The applicability of the photogrammetric process to solving future cadastral problems was examined, thus defining another technique for establishing an analytical cadastre with sufficient statutorial reliability.

They showed the feasibility of using this technique for improving the graphic cadastral data in order to establish the analytical cadastre in an area where the original cadastral field books, field sheets and cadastral map were measured in the 1930s. The final results showed that the accuracy of the coordinates of the cadastral parcel corners was in the range of 0.10 up to 0.30 meters.

5. TRANSFORMATIONS

Transformations are the mathematical tools to be used for converting analogue cadastral maps to digital cadastral data. Transformations in the cadastral context can be subdivided into two main issues. First, as there are many types of mathematical transformations, which type of transformation should be applied for each specific case; and, second, what should be the extent of applying these transformations. Mathematical transformations can be subdivided into two main groups: global transformations, and local transformations.

The global transformations are realized by mathematical models with various degrees of freedom, ranging from a rigid-body transformation with three degrees of freedom up to an Affine transformation with six degrees of freedom, or a projective transformation with eight degrees of freedom (Fagan and Soehngen, 1987). Although polynomial based transformations with higher degrees of freedom may also be considered for this purpose, in practice they are not recommended due to their potentially erratic behavior. Within the local transformations the common methods are the rubber sheeting mechanism, and methods based on finite elements (Doytsher, 2000; Doytsher and Gelbman, 1995).

In all these transformations, if redundant points are identified the transformation parameters may be estimated using the Least Squares adjustment technique, during which weights may be assigned to each measurement (Greenfeld, 1997). For non uniform homologous point distribution a modified least squares scheme is required in order to eliminate the effect of leverage points (Kampmann, 1996). Various geometrical and/or cadastral constraints may also be incorporated in order to maintain the consistency of the existing data and possibly upgrade it (Fradkin and Doytsher, 2002).

In order to account for the resulting random distortions, a rubber-sheeting process can be employed. During this process the distortions are spread linearly among the control points - points which the transformation is based of.

It should be noted that the underlying assumption in the rubber sheeting process is that both data sets (the analogue and the digital sets) are identical in terms of their accuracy characteristics. This assumption serves as the basis to averaging of coordinates and to the linear diffusion of the distortions. Yet, in many cases this assumption is not fully justified: averaging is not straightforward as it is not clear whether both data sets share the same accuracy characteristics, while weight assignment can not be carried out without explicit knowledge on the accuracy relations between the data sets. The same difficulty applies in the case of the linear distribution of distortions: this process can be justified only by the assumption that the change in the distortions is linear throughout the data set.
From a mathematical perspective, Affine or Conformal transformations can be defined as:

$$\begin{aligned} x_i &= a_1 + a_2 * X_i + a_3 * Y_i \\ y_i &= a_4 - a_3 * X_i + a_2 * Y_i \end{aligned} \qquad (1)$$

Where [x,y] and [X,Y] are the two coordinates systems, and the conformal transformation is achieved by applying the following condition:

$$a_2 * a_2 + a_3 * a_3 = 1 \qquad (2)$$

Based on the Israeli grid systems, one may define

$$\begin{aligned} \Delta X_i &= a_1 + a_2 * (X_i - X_0) + a_3 * (Y_i - Y_0) \\ \Delta Y_i &= b_1 + b_2 * (X_i - X_0) + b_3 * (Y_i - Y_0) \end{aligned} \qquad (3)$$

Where $\Delta X_i = x_i - X_i - 500000$ and $\Delta Y_i = y_i - Y_i - 50000$, and the mathematical solution is:

$$\begin{aligned} C * A - \Delta\{X\} &= V\{X\} \\ C * B - \Delta\{Y\} &= V\{Y\} \end{aligned} \qquad (4)$$

where

$$C = \begin{vmatrix} 1 & X_1 - X_0 & Y_1 - Y_0 \\ 1 & X_2 - X_0 & Y_2 - Y_0 \\ 1 & X_3 - X_0 & Y_3 - Y_0 \\ \vdots & \vdots & \vdots \\ 1 & X_N - X_0 & Y_N - Y_0 \end{vmatrix} \qquad \Delta\{X\} = \begin{vmatrix} \Delta X_1 \\ \Delta X_2 \\ \Delta X_3 \\ \vdots \\ \Delta X_N \end{vmatrix} \qquad \Delta\{Y\} = \begin{vmatrix} \Delta Y_1 \\ \Delta Y_2 \\ \Delta Y_3 \\ \vdots \\ \Delta Y_N \end{vmatrix} \qquad (5)$$

$$A = \begin{vmatrix} a_1 \\ a_2 \\ a_3 \end{vmatrix} \qquad B = \begin{vmatrix} b_1 \\ b_2 \\ b_3 \end{vmatrix}$$

and

$$\begin{aligned} A &= (C^T P\ C)^{-1}\ C^T P\ \Delta\{X\} \\ B &= (C^T P\ C)^{-1}\ C^T P\ \Delta\{Y\} \end{aligned} \qquad (6)$$

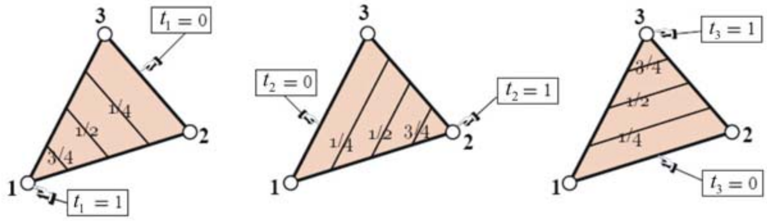
As to the rubber sheeting solutions, there are several mathematical models that enable applying this mechanism. One of the more common methods is to construct a triangulation (triangular network) in the region under consideration where the triangulation is based on the control points (a set of the homologous point pairs common to the two analogue and digital datasets). The triangulation is built by applying Constrained-Delauny-Triangulation (CDT) (Okabe et al., 1992). Linear rubber sheeting in each one of the triangles may be applied by using the Triangular Coordinates mechanism. The geometry of a triangle is specified by the location of its three corner nodes on the $\{x, y\}$ plane. The nodes are labeled 1,2,3 while traversing the sides in counterclockwise fashion.

$$\begin{bmatrix} 1 \\ x \\ y \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ x_1 & x_2 & x_3 \\ y_1 & y_2 & y_3 \end{bmatrix} \cdot \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} \quad (7)$$

Where the solution of t_1 t_2 t_3 is according to (where A is the area of the triangle)

$$\begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} = \frac{1}{2A} \begin{bmatrix} (x_2 y_3 - x_3 y_2) & (y_2 - y_3) & (x_3 - x_2) \\ (x_3 y_1 - x_1 y_3) & (y_3 - y_1) & (x_1 - x_3) \\ (x_1 y_2 - x_2 y_1) & (y_1 - y_2) & (x_2 - x_1) \end{bmatrix} \cdot \begin{bmatrix} 1 \\ x \\ y \end{bmatrix} \quad (8)$$

The Triangular coordinates system is depicted in the following figure



The transformation of each one of the cadastral points can be computed according to

$$f(t_1, t_2, t_3) = f_1 t_1 + f_2 t_2 + f_3 t_3 = \begin{bmatrix} f_1 & f_2 & f_3 \end{bmatrix} \cdot \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} = \begin{bmatrix} t_1 & t_2 & t_3 \end{bmatrix} \cdot \begin{bmatrix} f_1 \\ f_2 \\ f_3 \end{bmatrix} \quad (9)$$

and the final coordinates are computed (according to equation 3) as

$$\begin{aligned} x_i &= X_i + 500000 + f_1 * \Delta X_1 + f_2 * \Delta X_2 + f_3 * \Delta X_3 \\ y_i &= Y_i + 50000 + f_1 * \Delta Y_1 + f_2 * \Delta Y_2 + f_3 * \Delta Y_3 \end{aligned} \quad (10)$$

A continuous transition between the adjacent triangles as well as between adjacent cadastral blocks can be achieved by applying the Quaternion mechanism (Shoemake, 1985), where by using a unit Quaternion for orientation parameterization as

$$|\mathbf{q}| = \sqrt{w^2 + x^2 + y^2 + z^2} = 1 \quad (11)$$

Then, translating the Euler rotation matrix into Quaternion space:

$$R = \begin{bmatrix} 1-2y^2-2z^2 & 2xy-2wz & 2xz+2wy \\ 2xy+2wz & 1-2x^2-2z^2 & 2yz-2wx \\ 2xz-2wy & 2yz+2wx & 1-2x^2-2y^2 \end{bmatrix} \tag{12}$$

By using a spherical linear interpolation (SLERP) in unit-quaternion space, as suggested by Shoemake (1985), we ensure a continuous transition between adjacent cadastral units/maps (more details can be found at [Shoemake, 1985]).

6. PILOT PROJECT

A pilot project initiated by the Survey of Israel is composed of 60 cadastral blocks that are located along the Mediterranean seashore in 4 different zones. The authors were involved in the pilot project of one of these zones - in the center of Israel covering an area of ~ 5.5 km in the south-north direction and less than 1 km in the east-west direction. The area is covered by 15 cadastral blocks and about 200 mutation plans. The maps (cadastral blocks and mutation plans) were measured during a period of several decades in different measuring technologies, kept as analogue documents (field books and field sheets), and were based on three different grid systems - local, old (Cassini-Soldner) and New (Israeli Transverse Mercator) systems.
In order to achieve the challenging specifications of the project in terms of accuracy and reliability, is has agreed upon that a very careful field study should be carried out. During this study the authentic data have been searched for, identified and measured in the 2005 GPS based Israel Grid. The average number of polygon points, border points and original details per each one of the cadastral blocks were at the range of 60-70 control points. In addition, and in order to get a reliable mathematical definition of the precision of the various cadastral maps and mutation plans, starting from the initial stage of the Land Registration through the different mutation plans measured during the years based on various grids, we decided to calculate all field books as well as surveying the current borders of the cadastral blocks. Each one of the field books was calculated according to the original grid system in which it has been measured. Furthermore, the current cadastral subdivision (which is the result of many cumulative re-parcelation processes) has been also calculated.
As a first stage, the current cadastral subdivision has been transformed to new 2005 Israeli Grid based on all authentic and identified control points (several dozens per cadastral block) by applying standard transformation models. The numerical results of applying these mathematical transformations were disappointing and unacceptable in terms of achieved accuracy. The residuals of the control points after the transformation were in the range of many decimeters (up to and above than 1 meter).
A careful analysis of these results exposed the main reason for this phenomenon which is due to the fact that the current cadastral subdivision is composed of data accumulated after re-parcelation processes (unifications and divisions), occurred over time (based on many mutation plans that were measured separately and were based on different grid systems). Fortunately, it was found that single patches of the cadastral environment that were measured as one cadastral surveying project (usually being a part of a single mutation plan) are relatively accurate.

On the other hand, local discrepancies between adjacent mutation plans and/or adjacent cadastral maps have been found. A thorough analysis of these results pointed out to the difficulty of converting the whole cadastral map on a global basis, in other words the difficulty to applying one mathematical transformation to data coming from different sources (different cadastral projects and different mutation plans). Consequently, the conclusion was that global mathematical transformations are not the answer for the problem. Instead, a "cadastral mechanism" of transformations has been adopted. Accordingly, the cadastral information has been subdivided into its original "patches" where each patch was a single surveying project, e.g. a mutation plan, or an initial cadastral map (before applying all re-parcelation processes). Each one of these patches has been transformed to the 2005 (new) Israel Grid based on the authentic control points within the patch while using the simplest transformation mechanism (a 3 parametric conformal transformation without scale change).
We were pleasantly surprised by the excellent results that we received by applying this "cadastral" transformation mechanism. In total, we received excellent results with deviations of few centimeters between adjacent mutation plans within the same cadastral block. The deviations between adjacent cadastral blocks were usually in the range of 1-2 decimeters, and only in a few unusual cases, the deviations were larger - up to 3-4 decimeters. It appears as these large deviations were due to the fact that the original survey was of poor quality or had gross unidentified errors.

7. CADASTRE AND REAL ESTATE MARKETS

Establishing an analytical cadastre constituting a spatial information system defining the statutory land division will have major effects not only on the urban and regional planning discipline, but on the real estate markets. Modern real estate markets will be significantly affected by a precise analytical cadastre (a cadastral LIS). Within these influences should be mentioned the following aspects:

- Saves multiple measurement of the same land area over different points in time and for different uses;
- Economizes the per measurement cost (no need to repeatedly conduct the entire tedious measurement process);
- Prevents the transaction costs that correspond to disputes and lawsuits between landowners, stakeholders, and other potential conflicting interests;
- Incorporates a fairness effect: the objective measurement mechanism prevents from the more powerful party to exercise its power in case of dispute;
- Allows for a reliable land valuation;
- Decreases the uncertainty that accompanies real estate transactions, thereby reduces the involved transaction costs and further allows for more efficient decision making;
- Accelerates the execution of real estate transactions (including private transaction, re-parcelation, land use conversion, alterations in planning programs, etc.);
- The benefits that are directly generated for the real estate transaction may, of course, produce indirect economic benefits for the entire set of activities that are related to the transaction.

8. CONCLUSIONS AND SUMMARY

The article described the efforts to establish an analytical cadastre in Israel. The current Israeli cadastre with its graphical nature and the inherent difficulties to use it as is for restoring the cadastral boundaries were presented. Options as to establishing an analytical cadastre were discussed. A pilot project that was intended for transforming graphical cadastral maps into precise analytical cadastre in the form of digital datasets was described. The pilot project showed that by measuring new and accurate GPS control points together with restoring well identified previous (old) control points, together with a very careful mathematical computation and transformation procedure, the relatively inaccurate cadastral maps can be converted into a precise analytical database. The main conclusions can be summarized as:

- The transformation laws cannot be foreseen in advance.
- If the basic calculations of the field books are accurate in terms of proper front lengths and parcel areas, there is no need to increase the number of the authentic points to implement an adequate successful transformation.
- In blocks that have many mutation plans, each mutation plan must be examined by its self when the transformation data diverges from the registration plans.
- Until achieving a comprehensive and continuous analytical cadastre based on coordinates, we still have to utilize past border points for carrying out cadastral projects in the present.

ACKNOWLEDGMENTS

The pilot project described in the paper was planned and budgeted by the Survey of Israel under project 3256. The authors wish to thank the Survey of Israel and its Director General, Dr. Haim Srebro, for their initiative and support.

REFERENCES

Dale, P.F. (1976), "Cadastral Surveys within the Commonwealth", pp. 36-55, London, HMSO.

Dowson, E., Sheppard, V.L.O., (1952), "Land Registration", HMSO

Doytsher Y., (2000), "A Rubber Sheeting Algorithm for Non-Rectangular Maps", Computers & Geosciences, 26 (2000), pp. 1001-1010.

Doytsher Y., Gelbman E., (1995), "Rubber Sheeting Algorithm for Cadastral Maps", Journal of Surveying Engineering - ASCE, Vol. 121(4), pp. 155-162.

Fagan G.L., Soehngen, H.F., (1987), "Improvement of GBF/DIME File Coordinates in a Geobased Information System by Various Transformation Methods and Rubbersheeting Based Triangulation", Proceedings of Auto-Carto 8, pp. 481-491.

Fradkin K., Doytsher Y., (2002), "Urban Digital Cadastre: Analytical Reconstruction of Cadastral Boundaries", Computers, Environment and Urban Systems, Vol. 26(5), pp. 447-463

Gavish Y., Doytsher Y., (2002), "Analytical Cadastre in Israel: Restoring Land Boundaries Based On Photogrammetric Tools", 22nd International Congress of Surveyors, Washington DC, USA

Gavish D., Kark R., (1993), "The Cadastral Mapping of Palestine", 1858-1928, The Geographical Journal, 159(1), pp. 70-80

Greenfeld J., (1997), "Least Squares Weighted Coordinate Transformation Formulas and their Application", Journal of Surveying Engineering - ASCE, Vol. 123(4), pp. 147-161.

Kampmann G., (1996), "New Adjustment Techniques for the Determination of Transformation Parameters for Cadastral and Engineering Purposes", Geomatica, Vol. 50 (1), pp. 27-34.

Okabe A., Boots B., Sugihara K., Chiu S.N. (2000), "Spatial Tessellations – Concepts and Applications of Voronoi Diagrams", 2nd edition, John Wiley & Sons, 671 p. ISBN 0-471-98635-6.

Shoemake K., (1985), "Animating Rotation with Quaternion Curves", Proceedings of the 12th Annual Conference on Computer Graphics and Interactive Techniques, pp. 245-254, ISSN:0097-8930.

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Joseph Kraus graduated from Surveying College in 1962. He worked for 6 years in the Survey of Israel where he gained experience in cadastre. In 1966, he received his Licensed Surveyor license. In 1969, he opened his own surveying company. His company offers a full range of planning services with an emphasis on preparing background planning for City Planning plans. He has carried out extensive surveying for background planning in precise engineering works and primarily engages in the field of cadastral surveying. His office employs 20 engineers and technicians. The office is equipped with the modern equipment and software, and has taken part in geodetic plans. The office has carried out large-scale photogrammetric surveying. Mr. Kraus is a member of the Licensed Surveyor Association since 1966, served consecutively as a committee member since 1978 and is the president of the Association since 1999.

Uri Shoshani graduated from the Technion - Israel Institute of Technology in Civil Engineering and Geodesy in 1958. He has been lecturing since 1969 Cadastral Surveying and Cadastral Laws as an Adjunct Senior Teaching Fellow at the Mapping and Geo-Information Engineering Division of the Technion, as well as in Tel-Aviv University. He was the Deputy Director General of the Survey of Israel during the 1970s and the Director of the Planning and Construction Authority at the Ministry of Building and Housing during the 1980/1990s. He served as the President of the Israeli Licensed Surveyors Association during the years 1988 to 1999.

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