Technical Aspects of Converting Analogical Cadastral System to Digital System – A Case Study in Israel

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SUMMARY

In the year 2006, the Survey of Israel (SOI) published a tender for converting sixty cadastral blocks, bounded to the Israeli seashores, to digital cadastre.

The mission was defined clearly; for each parcel in each block the coordinates of the boundary points should be computed in the updated national Israel grid, according to the Israeli surveyors' regulations instructions. In addition, a new and novel methodology for fulfilling the mission for better results was asked.

The paper presents several issues regarding the mission of converting existing cadastral blocks to digital cadastre concept, some of which: defining the cadastral process recommended by the surveyors' regulations, defining the new methodology concepts; their advantages and disadvantages, exposing the mathematical procedures as well as the geodetic ones for achieving calculated accuracies, homogeneous results and finally trying to optimize the accuracy level of the result.

The results of converting 15 cadastral blocks bounded the Haifa seashore to digital cadastre is presented at the end of the paper in order to examine the methods as well as evaluate the future digital cadastral system accuracy level in Israel.

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1. INTRODUCTION

At the end of the year 2005, the Survey of Israel (SOI) published a tender for special cadastral project aimed to convert sixty cadastral blocks, bounded to the Israeli seashores, to digital cadastre.

The mission was defined clearly; for each parcel in each block the coordinates of the boundary points should be computed in the new IG05 national Israel grid (Steinberg and Even-Tzur, 2005), according to the Israeli surveyors' regulations instructions. In addition, a new and novel methodology for fulfilling the mission for better results was asked. The primary request of the SOI was to add an additional research characteristic for the project. Hence, participated surveyors companies were asked to accompany with cadastral science expert as a supervisor.

This paper summarizes the Zeibak and Sabbagh Company L.T.D main work which has been done for fulfilling the tasks of the project. The project staff has been trained to investigate every step in the whole procedure for optimizing the results. Optimizing results includes achieving computed high level accuracy results, enlarging the reliability of them as well as shortening the time of the whole transformation of the existed analogical cadastre system to Legal Digital Cadastre (LDC) one.

2. STEPS OF FULFILLING MISSION

For computing the final national grid coordinates of every boundary point for establishing the cadastral parcels of the project, technical specifications of the project tender counted several steps:

1. Looking for authentic old control points in the old Kasini projection grid and linking them to the IG05 national grid.
2. Establishing new control points and linking them to the IG05 national control grid.
3. Collecting all the cadastral foundation data needed for building the cadastral blocks from the SOI archive. The step is finished with testing the completeness of the data.
4. Looking for authentic cadastral boundaries monuments (such as boundaries wedges and old control points which were used for measuring the existing block) in the blocks area and linking them to the new IG05 control grid.
5. Computing the coordinates in the old Kasini soldner control grid of the entire cadastral parcel boundaries' points of the block. This step is based primarily on the cadastral foundation data collected in step number (2). This step is finished in validating the computation results as a quality assurance process. The main validation criteria is concentrated on the boundaries fronts which are recorded in the field sheets of the cadastral blocks. Field sheets maps document the fronts measurements between

boundaries with each other and between boundaries and existing control grids in the block area.

6. Transformation process of the Kasini Soldner grid coordinates to the new IG05 coordinates according to the Israeli 1998 regulations instructions (http://www.mapi.gov.il/page.php?gallery=1&inum=8&id=reg_inst/man_reg/file08/)
7. Building the new based coordinates block by set of IG05 coordinates with area computations.

These steps are similar to those recommended by the surveyors' regulations instructions of Israel, version 1998.
Finally every contractor from those who won the tender (and there are four of them), have been able to change the arrangement of the above instructions.

Our goal is to supply a possible well-defined solution for providing homogeneous coordinates values of the boundaries' points in the IGD05 control grid with maximum accuracy. Achieving homogeneous values means that; if any licensed surveyor uses the supplied solution he will provide the same exact coordinates.

2.1 Specific Issues, Possible and Selected Approaches

The project staff has to make several decisions for several questions before starting the mission:

The first question that the project staff tries to answer is: Has the SOI let one surveyor company to perform the entire mission for the whole block individually? Or it would choose to divide the mission to sub-missions? The main advantages for dividing the mission are:

- Trying to achieve higher accuracies since every step would be completely defined. In addition to the fact that the quality assurance process might be intensive.
- Trying to minimize the time which is needed to transform all the cadastral system to LDC one. In the same point of view, there are sub-missions, like looking for authentic cadastral points, as time goes by, more authentic cadastral monuments might disappear. This might be critical for reinstating the authentic cadastral boundaries.

Thus the staff has decided to adopt the *division principle of the entire mission*.

The second question related to the mathematical method for describing the geometrical shape of the parcel. Choosing the optimal method is affected by the authentic cadastral foundation data. There are several possible options data:

- Field books which describe documented cadastral measurements executed by the chain method (or the orthogonal method) (see figure 1).
- Field sheets maps which describe measured fronts, different measurements between boundaries and authentic control points, distances between boundaries and objects' points like buildings corners, describing geometrical constrains such as straight line consisted from a number of boundaries' points etc…

- Mutation plans that intend to change the partition of the basic cadastral layer. The mutations plans could be based on the old Kasini Soldner control grid before the year of 1998 or on the New Israel Grid (NIG) (Stenberg). In such plans there is a computation book attached that describes the coordinates of the mutation points.
- Papers block maps that describe the final partition of the inner parcels of the block.
- Any combination of the above options, and sometimes there is no data except the block map itself.

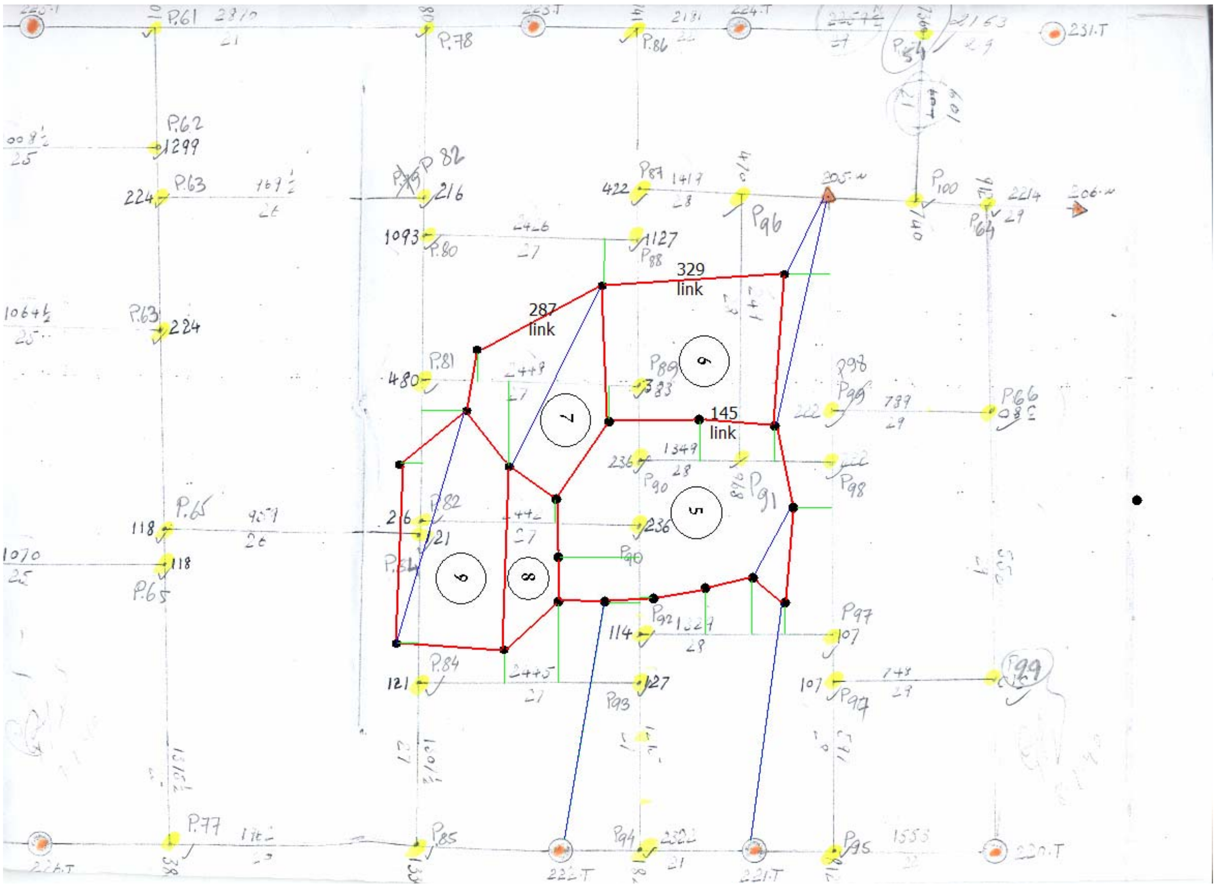

Figure 1: Illustrates the field book measurement chain method and the possible measurements that could be documented in the field sheet.

The 15 blocks are built from: field books, field sheets, block maps as well as mutation maps in the old Kasini-Soldner Israeli control grid and in some cases in the NIG. In this case, the surveyors' regulation asks surveyors to compute the boundaries coordinates in the old control grid and after that performing a transformation process based on specific instructions. At the end surveyors have to check if the distances' differences computed between the final coordinates and those which are documented in the filed sheets are meeting the regulations criteria. The same quality assurance is done for geometrical constrains and the registered area. If there are differences that exceed the limits permitted by the surveyor regulations, surveyors have to deal with manual adjustment process for closing the gaps. This manual procedure usually leads to inhomogeneity in the final coordinates whereas two or more surveyors have

tried to compute the same data. Additionally, manual adjustment does not lead to optimal result with the higher accuracy level.
Finally, the major problems with the computation process that might lead to low level of accuracy are:

- Basing the calculation on the Old Kasini Soldner grid would decrease the inner accuracy of the parcel definitions geometrical data. Inner accuracy is the accuracy of such a cadastral point in relative to its neighbors. This is a result of the low and the inhomogeneous accuracy characterized the Old Israel grid…
- Existence of fatal error in the cadastral foundation data.
- Every block may be composed from different cadastral foundation data sources with different levels of accuracy.

As a result, four major decisions have been made:

1. Adopting the least square computations for adjusting the coordinates to fit all the measurements of the field book with the field sheets constraints and other measurements.
2. Trying to avoid using the Old grid when computing the field books. This decision
3. When there are different foundation data sources for the same cadastral block, the staff should deal the block as one puzzle creation trying to describe it as accurate as it could be in its "local" grid. After assembling the entire puzzle, the staff had to link it to the world using physical monuments' measurements at the IG05.
4. Trying to look for maximum number of cadastral authentic monuments in the field in order to reinstate the original measurements errors and inaccuracies.

The third question that the staff had to deal with related to the transformation process to the updated IG05 grid, is not presented in the paper because of its high complexity which justifies writing an individual paper.

2.2 The Mathematical Challenges

Adopting the four decisions exposed several mathematical challenges:

- The first and the third decision which are: using the least square computation and working with local grid, forced the project staff to look for specific geodetic software in the World Wide Web that enables different kinds of measurements adjustments: orthogonal measurements of the chain methods, distance measurements, angles measurements as well as keeping on different geometrical constraints. Geometrical constraints could be a straight line composed from boundaries' points, paralleled lines and etc…
- The second and the fourth decision which obligate the project staff to avoid the Old grid of Israel led them to look for minimum authentic point in the field and linked them to the IG05. These points should be used for basing the computation of the least squares adjustment and computing the final coordinates in the IG05 directly without using transformation methods. The small number of the authentic points that were found in every registered block was not sufficient for solving the defect of the block measurement network (Wolf and Ghilani, 1997).

In order to learn more about the mathematical formulas for using the least squares computation method of the cadastral measurements one should read the paper of Klebanov and Doytsher which was written and published in 2008 (Klebanov and Doytsher, 2008). They detailed the formulas with an appropriate simulation for using them. The next chapter has a description of particular application which was developed especially for that purpose.
The main issue which has to be highlighted with using the least square computation for adjusting the original orthogonal measurements of the chain methods with the sheet fields' measurements, (which are mostly distances) is dealing with the question of how to set or determine their weighting matrix. In order to set the weighting matrix in the least square computations the covariance matrix Σ_{L^b} of the measurements must be known (see formula num. 1).

$$
\begin{aligned}
& V = AX - L \\
& L = L^b - L^o \\
& A \textit{ is the design matrix} \\
& X \textit{ is the unknown variables matrix (which are the final coordinates)} \\
& L^b \textit{ is the measurements matrix} \\
& L^o \textit{ is the measurements matrix calculated from the} \\
& \quad \textit{mathematical design formulas using the initial} \\
(1) \quad & \quad \textit{values of the variables } L^o = f\left(X^o\right). \\
& \textit{When} \\
& A = \frac{\partial f}{\partial X}; \\
& N = A^t P A \\
& U = A^t P L \\
& P = \Sigma_{L^b}^{-1} \\
& X = N^{-1} U
\end{aligned}
$$

Two approaches were examined:

1. The first approach is delivered from the law point of view according to Craig and Wahl interpretation in their paper "Cadastral Survey Accuracy Standards" In Surveying and Land Information Science Journal:
   "*Regarding the Law point of view toward the authentic Cadastral Measurement accuracy:*
   ...This law declared that the original survey and its monuments are as if they "were without error" in the eyes of the law. This codification of a common law concept forgave a myriad of sins but also allowed the surveys to be completed expeditiously..." (2003).

2. At the same assumption spirit of Craig and Wahl (2003) interpretations, the project staff returned back to the surveyors' regulations which were valid at the same time of registering the block main field book in order to check out what the Israeli law permitted!? These Israeli regulations permitted the existence of inaccuracy in the cadastral measurements of 8 cm for each distance which is less than 50 meter, and relative error of 0.0016 for every distance more than 50 meter (see formula num. 2).

$$\begin{aligned} &\sigma = 8\ cm && for \quad Dist \ \leq\ 50\ [m] \\ &\sigma = 0.0016 \times Dist && for \quad Dist \ <\ 50\ [m] \end{aligned} \qquad (2)$$

Before executing the least square surveyors should eliminate any fatal errors in the measurements. The main criteria which were used for recognizing fatal errors are:

(a) Comparing the distances computed from calculating coordinates in the "local grid" of the block, which is usually the same as its field book grid, with the same distance that is documented in the field sheet of the same block. The criterion which was used for the permitted disclosure between the two above distances is described by formula num. 2

(b) Comparing the block main map digitized coordinates with the approximate coordinates ,which was used as the initial solution of the final adjusted coordinates in the least squares computation process. For executing such a comparing process, the project staff have executed a specific affine transformation from the sheet maps to the "local grid" of the block in which the digital coordinates of the block were computed. Two systems were created; the first system is the transformed block map one and the second is the cadastral foundation measurements data system. Distance difference computed from the same coordinates in the two systems, which exceeded a limit of 1 mm in the scale of the block map highlighted a possibility of fatal error in the original data. The consideration that the human conspirator of separation average equal to 0.2 mm. Thus when surveyors drew the block map and when digitizing process was made a 0.2 mm mistake might be fallen twice. It means that according to expansion error rules every distance that exceed three times the $\sqrt{2 \times 0.2^2}$, should be treated as fatal error of the result (about 0.85 mm). Because the ancient methods of establishing the maps were not ideal and also included additional errors caused from manual hand writing, the value of 1 mm seems to be logical for this purpose.

The second criterion was also used for the quality assurance process of the final results.

3. APPLICATION DEVELOPMENT FOR EXECUTION THE MISSION

For calculating the foundation cadastral data by using the least square method a special MATLAB application has been developed, it is called "Clever Cadastre". The Clever Cadastre application was used for computing all the 15 blocks of the Haifa seashore blocks of the tender. This application has been supported by several features and functions like: normal computation functions for calculating the cadastral field books' measurements according to the regulations instructions, fatal errors detection models, least squares computations with different possibilities of using the fix points of the measurement net (it enables user to choose specific control points used as known points for adjusting the net), free net adjustment, different transformation methods used for transforming grid coordinates to others, integration between coordinates digitizing measurements and field book and sheets' measurements field measurements and finally the Clever Cadastre application is able to define and generate cadastral parcels geometry of the title registered block according to the regulations instructions' criteria. Figure (2) presents the main windows user interface of the application:

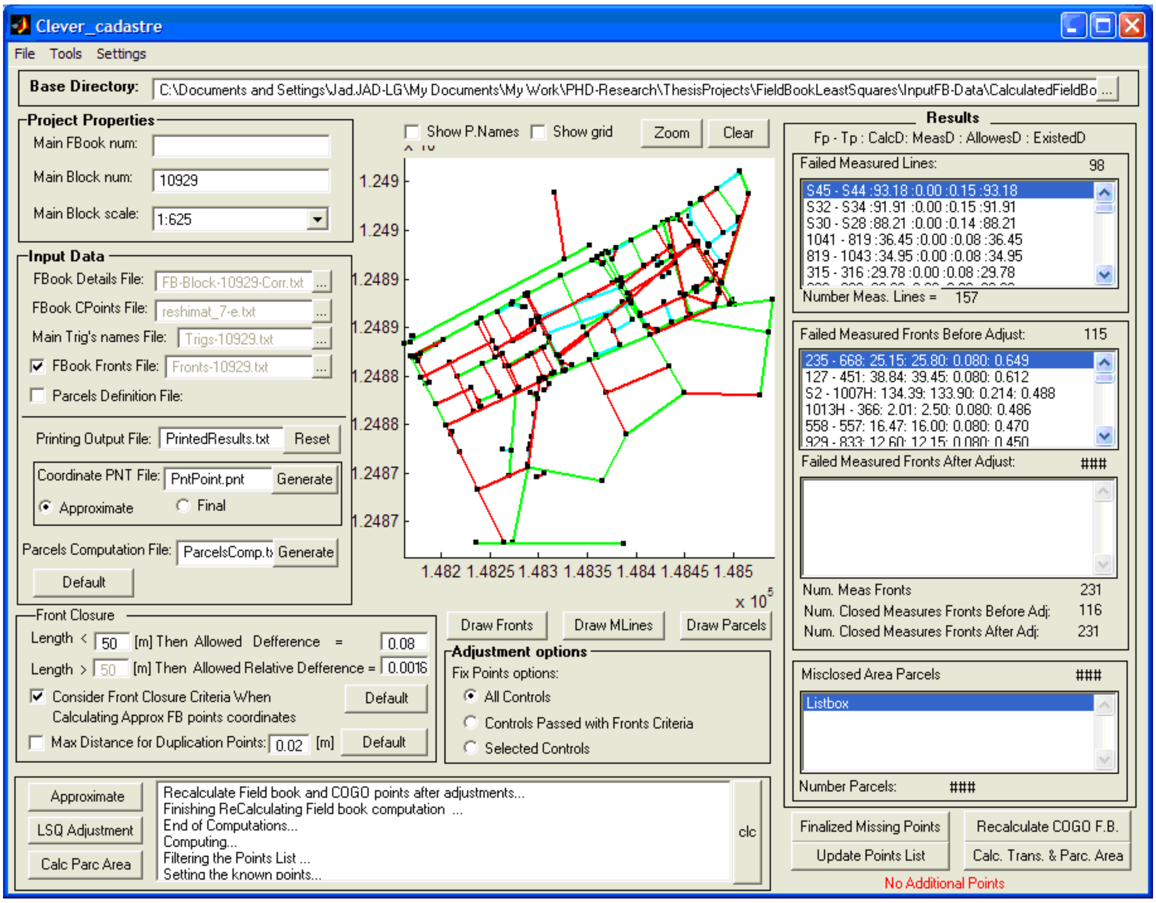

Figure 2: The main window of the Matlab computer application written for adjusting the chain method measurements with fronts distance measurements that are documented in the field map attached to almost every block map. Block 10929 results of the least squares computations used for adjusting all its cadastral foundation data are shown.

4. TRUE DATA STUDY CASE

As an example for advantage of using the least square computation method for adjusting the cadastral foundation data, block number 10929 which is one of the 15 blocks of the entire tender project would be shown:

Block 10929 is an urban block could be shown in figure 3 with ortho-photo image in his background. It is consisted from 44 cadastral parcels with buildings inside them. The block field books are more than 10. They contain all the boundaries and buildings' measurements. A field sheet also exists and it contains most of the boundaries' fronts' measurements. More than1100 points of boundaries and objects are involved in one art creation which is called cadastral block.
It could be shown, at the right hand side of the Clever Cadastre application main window, that when running the computation of the cadastral foundation data of block 10929 according to the regulations' instructions, after eliminating fatal error measurements, only 116 front distances measurements were passed the surveyors' regulations criterion described in formula number (2).
In such similar situation, surveyor would be asked to close these disclosures by manual adjustment process. Thus, it is time consuming with no success promised. Even if the surveyor would succeed, the results' values and their accuracies are neither homogenous nor optimal.

Figure 3: Block number 10929 on ortho-photo background of the block area in Haifa.

After integrating the fronts' measurements with the orthogonal measurements data computation using the least squares adjustment method all the 231 fronts have been passed.

Fronts which haven't pass the criteria before the least square adjustment process, are shown in red lines inside the Clever Cadastre application software main windows in figure (2). Those which have passed are drawn in green color. While after running the least squares by the

Clever Cadastre method, every passed front from those which haven't passed before is shown in blue line (see figure 4). It could be clearly noticed that there are no red lines inside the drawing of the block measurements network shown in figure 3.

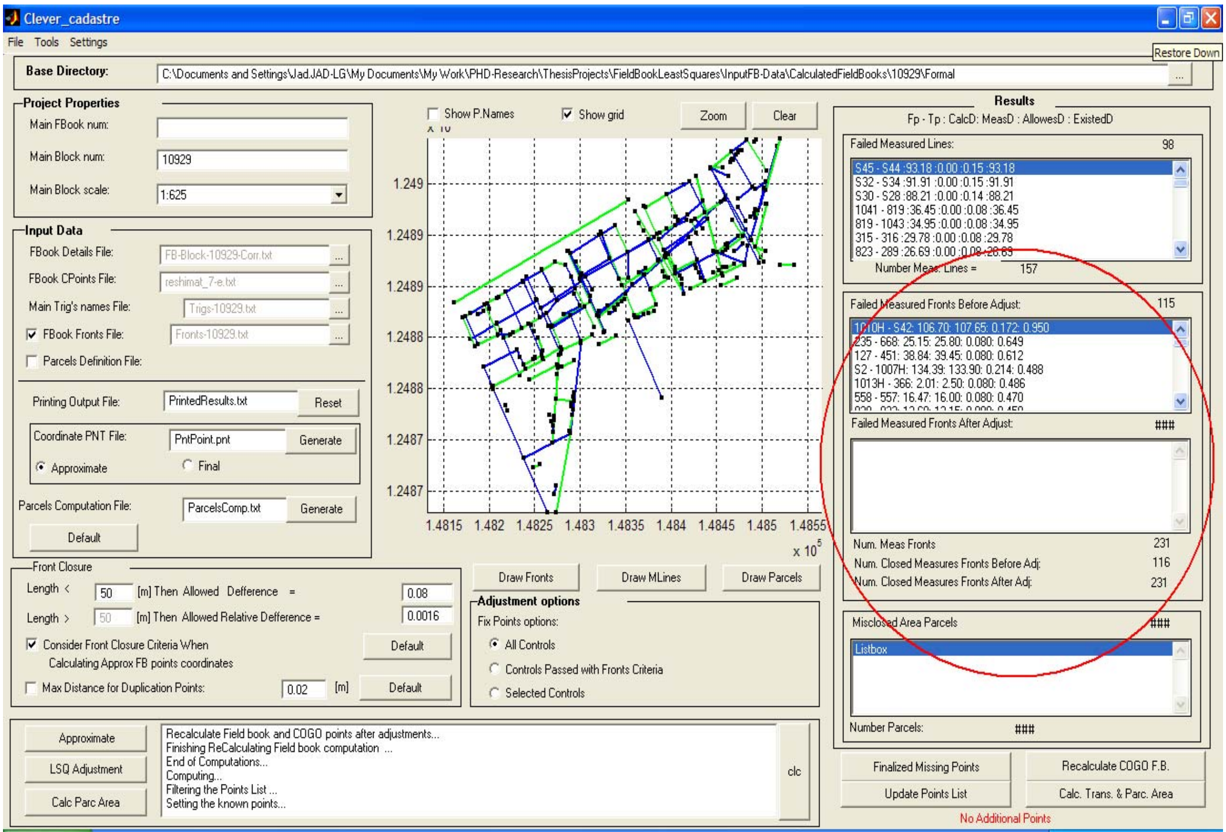

Figure 4: The application window display, as it is executed after the least square adjustment process. The red circle highlights the fronts' measurements that do not pass the criteria before and after the least square adjustment process.

4.1 Experience

Trying to eliminate the influence of the Old Kasini Soldner Israeli grid, the field project staff has tried to look for maximum authentic cadastral points, especially control points. Solving the field book measurements integrated with those measurements of the field sheets, based on IG05 would need sufficient authentic control points existed in the field.

There is no block, from the 15 blocks, which has included sufficient authentic points enabled solving the cadastral foundation books in the IG05 directly. In addition, the number of the authentic points that could be used for basing the transformation process from the block grid to the IG05 is also not sufficient for adequate quality assurance process in cadastral point of view.

The number of the authentic points that were found is between 0 to 5 points an average, when only the 10929 block has more than 20 authentic points between old control points and boundaries' monuments. Boundaries' monument could be a small carved cross or metal corner wedge (see figure 5).

Figure 5: An authentic cadastral carved cross boundary mark.

More than two thirds of the project area is rural. When there are no human development activities were done to them. Despite that fact only few authentic monuments were found.

Thus, because of the authentic cadastral monuments importance for the cadastre digital system in the future (since they are the only way to link the cadastral foundation data to the IG05 grid):

The project staff **advises the SOI** to start publishing special project tenders especially for looking for old authentic cadastral monuments which could bring huge benefits for establishing the future digital cadastral system to be as accurate as the original measurements which were executed when registering the cadastral blocks, and not less than it. It is important to highlight the fact that taking the final decision for announcing about a monument as an authentic point is not an ordinary and easy decision. Experienced surveyors and those who are expert in this kind of cadastral work will contribute for better decision in such cases. These experienced surveyors seem to be old. Thus, they are used not to go out to the fields for measuring. Solving this issue, the project staff has used the digital cameras to document every authentic monument as well as several validation criteria for validating the authentic degree of the monuments for final decision whereas it would be authentic or not. Validation criteria are used to be geometrical calculations like fronts distance measurements that contain the suspicious authentic monument.

Another problematic issue that was emphasized during the project staff work which is related to the topology rules of the block boundaries with those blocks which surround them. Because of using the least squares method for computing the local geometry of the block taking into consideration only the measurements which belong to the block itself, gaps were generated between the block and the bounded ones.
For solving this issue, the project staff integrated some cadastral measurements from the surrounded blocks foundation data which contributed to minimizing the topological gap. This

is not a full solved issue, it might need a special paper, and thus it will not be discussed widely in this paper.

4.2 Results

For standing on the accuracy level of the initial version of the future digital cadastre data base of Israel, the 15 blocks were computed and the standard error deviation histogram of every block boundaries' coordinates were generated. In figure 6, it could be shown the results clearly: the standard deviations errors' values averages seem to be between 10 and 70 cm.

Manu efforts were invested to find out some relationships between the results and the property of every block. For example; the date of the measurements was checked and did not give any obvious relationship. Even the scale of the block; the two blocks 10929, with 1:625 scale and block 10818, with 1:1250 scale, they almost have the same accuracies.
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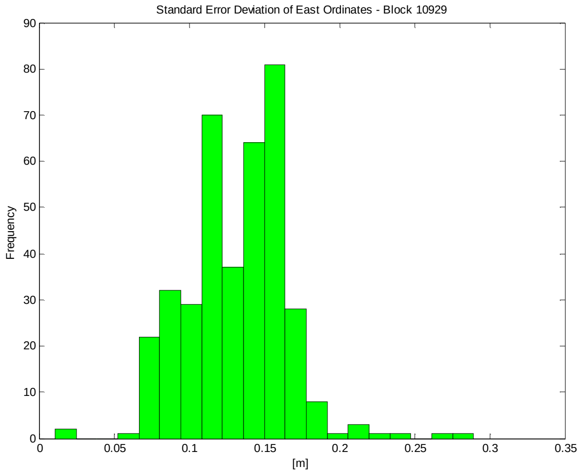

Figure 6.1.a: North ordinate STDR value of Block 10929

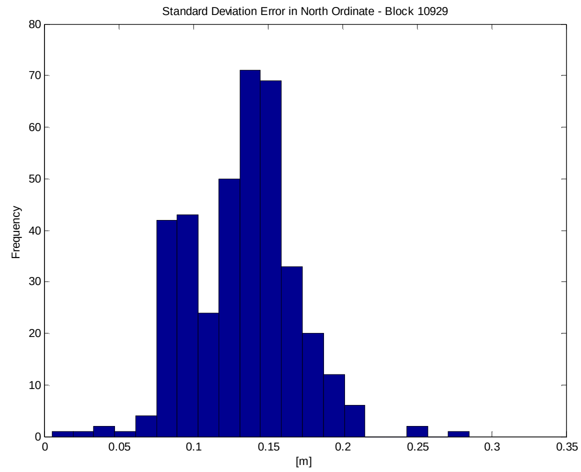

Figure 6.1.b: East ordinate STDR value of Block 10929

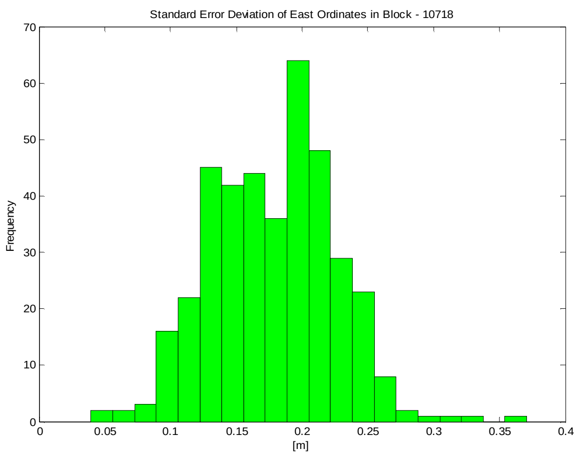

Figure 6.2.a: North ordinate STDR value of Block 10818

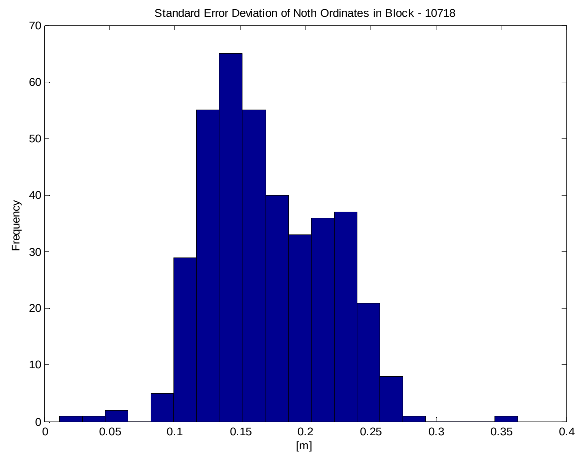

Figure 6.2.b: East ordinate STDR value of Block 10818

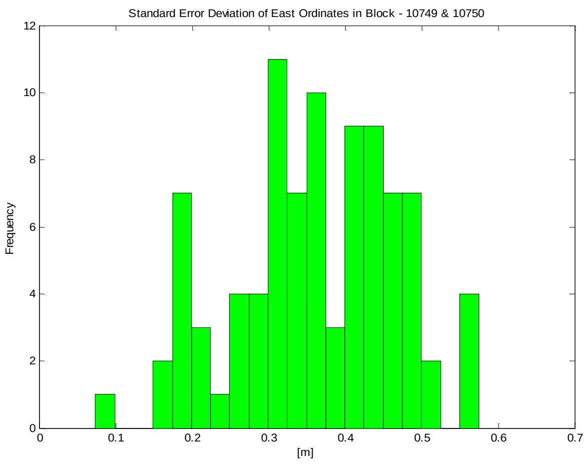

Figure 6.3.a: North ordinate STDR value of Block 10749 &10750

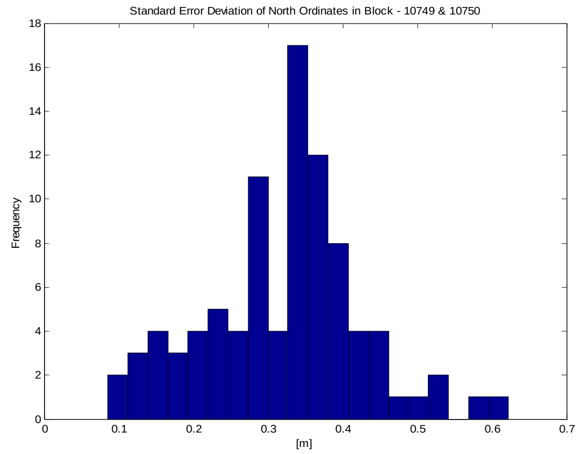

Figure 6.3.b: East ordinate STDR value of Block 10749 &10750

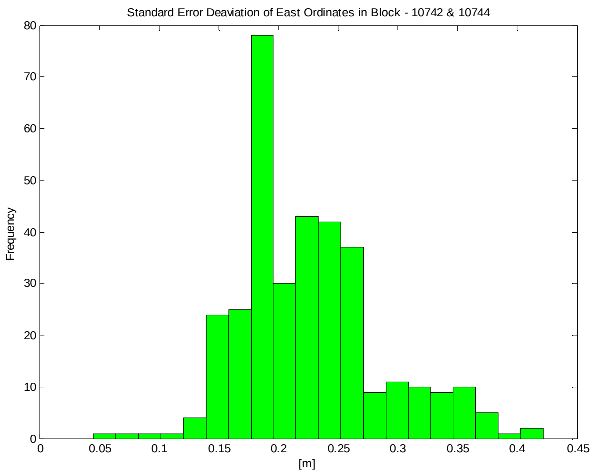

Figure 6.4.a: North ordinate STDR value of Block 10744 & 10742

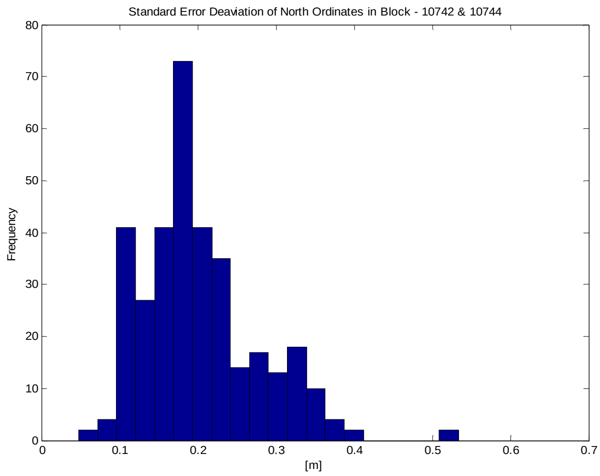

Figure 6.4.b: East ordinate STDR value of Block 10744 & 10742

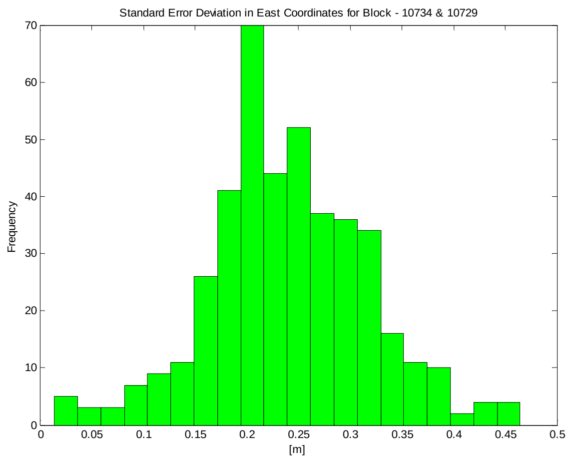

Figure 6.5.a: North ordinate STDR value of Block 10734 & 10729

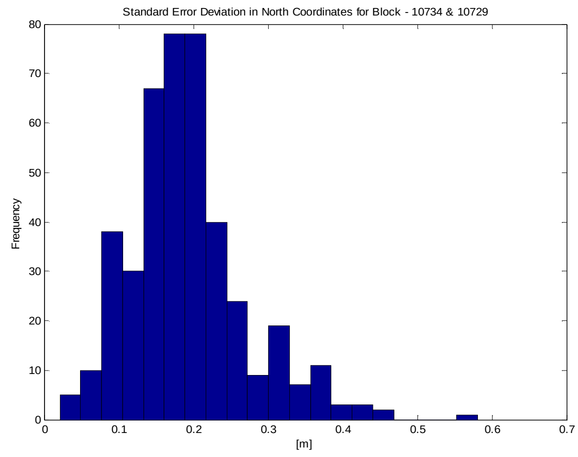

Figure 6.5.b: East ordinate STDR value of Block 10734 & 10729

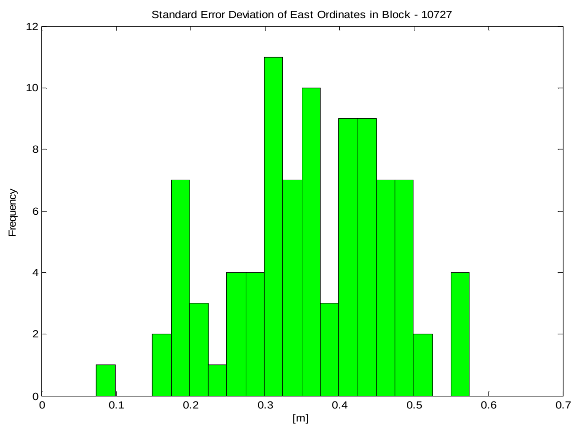

Figure 6.6.a: North ordinate STDR value of Block 10727

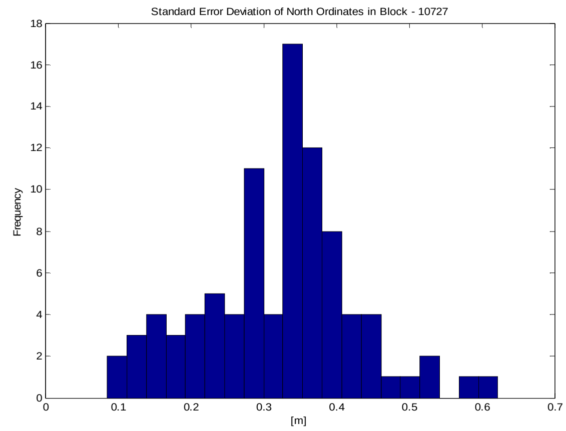

Figure 6.6.b: East ordinate STDR value of Block 10727

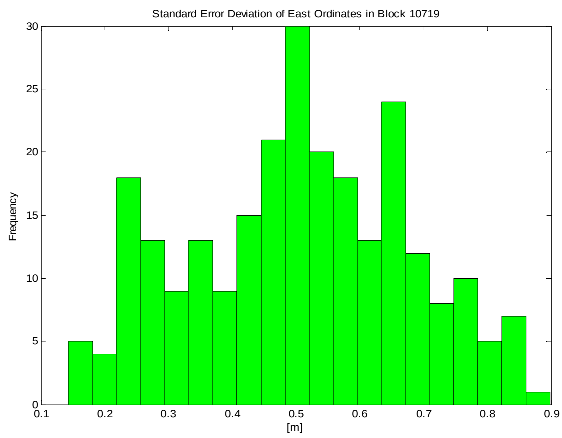

Figure 6.7.a: North ordinate STDR value of Block 10719

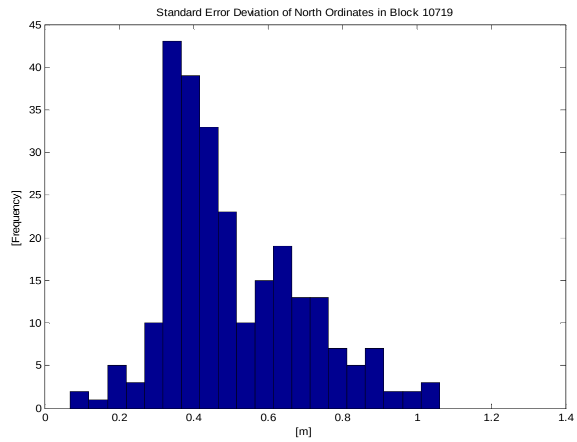

Figure 6.7.b: East ordinate STDR value of Block 10719

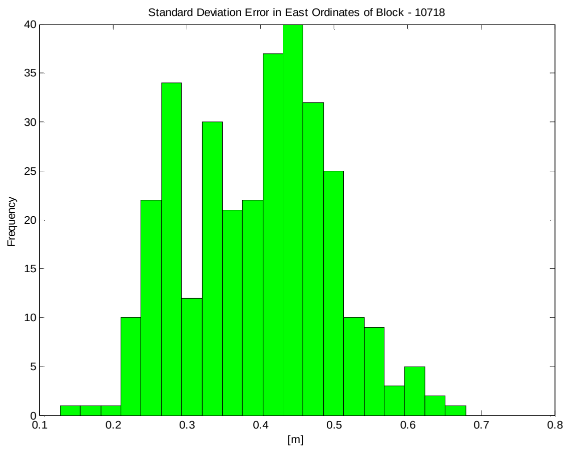

Figure 6.8.a: North ordinate STDR value of Block 10718

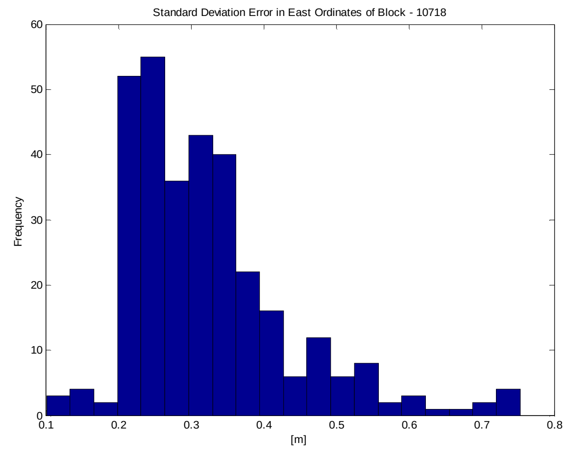

Figure 6.8.b: East ordinate STDR value of Block 10718

Figure 6: Histograms of standard error deviation (STDR) in North and East coordinates components of the 15 block boundaries' points basing on the least square adjustment process of the documented block measurements of the chain method (in the field book) and the fronts distances in the field maps.

The only two conclusions that could be concluded are:

- *The scale of the block indicates the lowest accuracy that its cadastral foundation measurements should be*
- Since blocks 10818 and 10929 are the only blocks that are located in urban areas, it could say that in urban area surveyors used to execute better measurements than in rural area.

5. CONCLUSION

The above results in figure 6 were also checked after the transformation process to the IG05 coordinates grid was generated. The differences between the final points coordinates calculated from the entire process and between the measured ones in IG05 for some monuments provide the same accuracy results. The common property which gathered the two good accuracies result blocks, 10929 and 10818, was their existence almost in urban areas. In urban area blocks, surveyors usually execute optimal measurements keeping on physical monuments to be measured as accurate as possible. Thus, in most of the developed blocks area, the accuracies shall be between 15 and 30 cm. In rural areas they may not be as good as these values. Thus, in rural area, other methods could be used for computing the final coordinates without spending too much time for executing a complex method like the one describe in this paper.
It is important to remind, as a comparable step, that Fradkin and Doytsher, in 1998, mentioned that the optimal accuracy of the Israeli cadastre might be around the 10 cm level…

Additionally, despite the desire for eliminating the Old Kasini Soldner grid influence, the project staff has not managed to do that. It is because of the shortness of the authentic control points that disabled computing the least squares adjustments basing on new measured IG05 authentic control. Thus, the transformation process should be necessary in most of the cases, since the SOI shall start looking for authentic monument as soon as possible by publishing stand alone projects for this purpose.

Finally, the project staff offers to execute the whole mission with different steps, suggested by the tender document (see section 2), which are described in figure 7. When the step in blue color is suggested to be done by the SOI itself, the yellows could be done by private surveyors, but those which are bounded with gray squares should be done by experienced surveyors or experts.

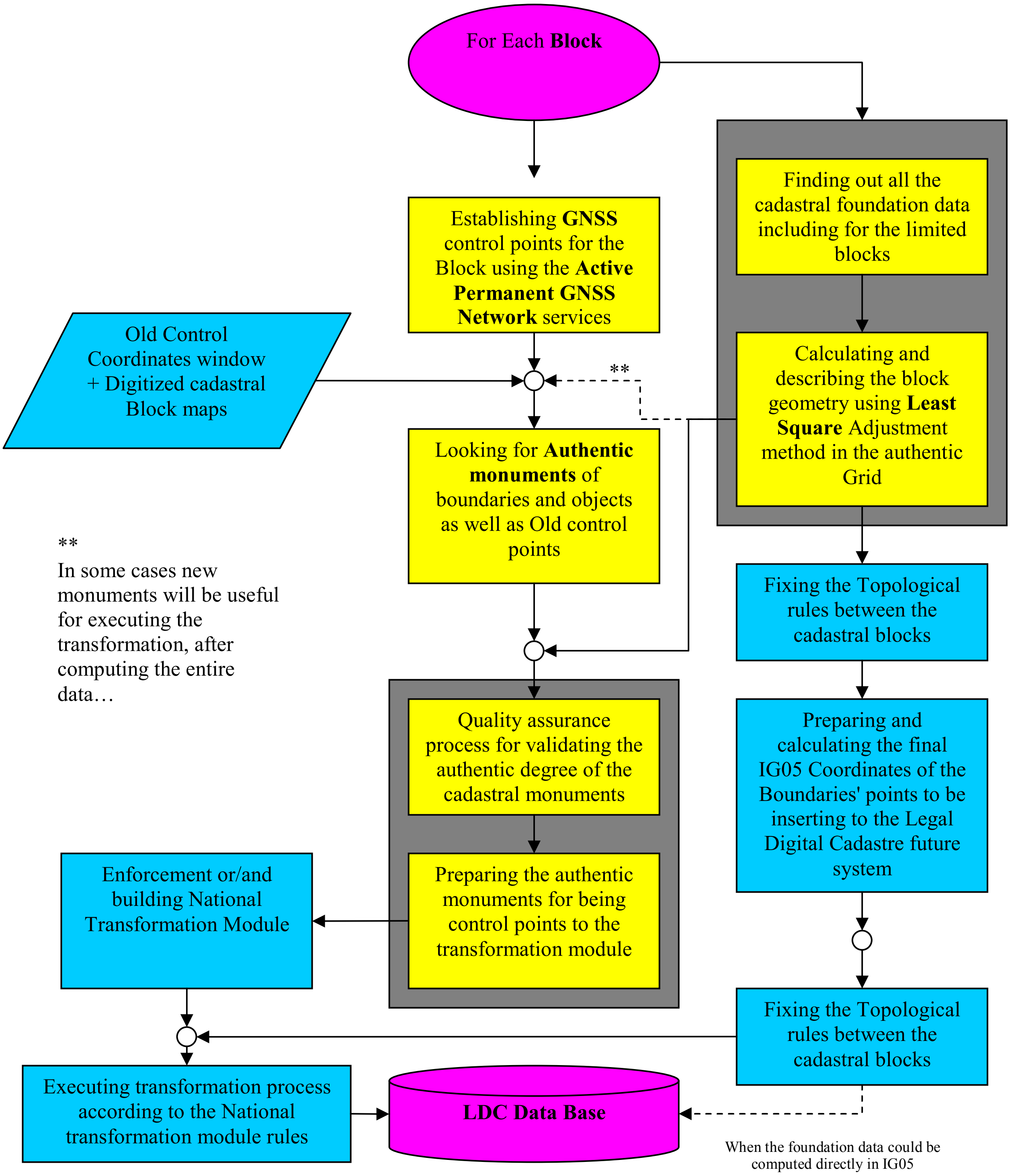

Figure 7: A flowchart describing the project staff steps advise for fulfilling the whole mission of transforming the Israeli cadastre to digital cadastre system

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Jad Jarroush was born in Nazareth in 1977; he received his B.Sc. in Geodetic Engineering in 2000 with honors. In 2002 he received the B.Sc. in Civil Engineering with honors too and the M.Sc. certificate in Geodetic Engineering as well. All are at the Technion. He is currently a graduated student at the faculty of Civil and Environmental Engineering, division of Transportation and Geo-Information Engineering as a Candidate for Ph.D. degree in Mapping and Geo-Information Engineering. Before few months he has passed the final exam of the PhD. He is also the head of research and software development of Zeibak and Sabbagh L.T.D Company in Nazareth and the same of Zaid Orniv L.T.D Company in Ramat-Gan. His main fields of interest include: Cadastre, 3D Cadastre, Dynamic Cadastre, Legal Digital Cadastre, GPS RTK, VRS GPS, VRS RTK GPS and 3D infrastructure presentation models.

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