Rebuilding the Cadastral Map of the Netherlands: the Overall Concept

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Key words: cadastral map, communication, geometric quality, artificial intelligence

SUMMARY

Kadaster provides legal certainty about every piece of land in the Netherlands. Cadastral parcels are recorded in land surveying fieldwork reports and processed in the nationwide Cadastral Map. Because of the different working methods over time and the production scale, the current map has a so-called graphic quality. As a consequence of this graphic quality (standard deviation of boundaries are 20 cm for urban areas and 40 cm for rural areas), the current map is not suitable for determining the exact parcel location in the terrain. With increasing digitization and open data policy, multiple sources of information (including the Cadastral Map) are becoming increasingly accessible to a wide range of users. This situation leads to bottlenecks and incomprehension.

That is the reason why Kadaster has started a research program to develop a map where the location of borders is so accurate, that the map is more in line with future developments. For this purpose, almost all (historical) field sketches have to be processed. An enormous challenge that requires far reaching automation. The research program has investigated whether it is possible to automatically extract the original measurements from the fieldwork reports and to combine this information and re-determine the location of the boundaries. With the help of several companies in the field of Artificial Intelligence, it has been possible to build an accurate cadastral map with known geometrical quality: the Reconstruction Map.

In addition to the technical challenge, it was also investigated whether the more accurate map meets the future needs. With the arrival of the new map, a changing way of communicating is foreseen. When the built-up (partial) Reconstruction Map is ready and the involved parties agree, it will be introduced and presented as the Cadastral Map Next and will replace the current Cadastral Map.

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1. INTRODUCTION

1.1 Current Cadastral Map

Kadaster provides legal certainty about the ownership status of each piece of land in the Netherlands, the cadastral parcels of land. Since the beginning of Kadaster in 1832 (when parcels of land have been created) new boundaries are measured accurately by surveyors. These measurements are recorded in surveyor fieldwork reports that form the basis for the boundaries in the map and are also used to reveal boundaries in the land upon request. The measurements are also processed to scale in the Cadastral Map (1:1000/1:2000).

The Cadastral Map provides a visualization of the (relative) location and shape of all cadastral parcels of land in the Netherlands. Such an image of 100% land coverage that is seamless throughout is relatively unique. However, the graphic quality of the boundaries in the cadastral map, renders this map unsuitable for accurate measurements in the map. Moreover, the correlation of boundaries with information from other sources (such as topographical maps) is less clear or accurate and therefore a potential source of misunderstanding. Misunderstandings are also created through the increasingly better connection of digital maps and the ability to easily combine them and to zoom in.

In the current information-driven society, this situation leads more frequently to bottlenecks and sometimes misunderstanding. The fact that the Cadastral Map has for years been open data and can be viewed and combined by a broad user base contributes to this. The user is missing insight into the meaning and history of the current Cadastral Map. The map is essentially meant to be an index (with parcels of land as entry point) to the Cadastral Registration, for which the current graphic quality is sufficient. However, users currently do not realize this (any longer) and expect greater accuracy and applicability of the information displayed. In addition to misunderstanding about location of boundaries, the inaccuracy of the surface area of parcels in the Cadastral Map is an increasingly greater problem due to the difference with the official surface area of the parcel in the registration.

1.2 In our dreams: an accurate cadastral map

From its responsibility, Kadaster strives to improve the aforementioned situation and dreams of an ideal: a map where the location of boundaries is so accurate that a much broader scope of application is created and the map performs better in the digital society. A situation where the combination of data sources and for example, the relationship with 3D objects and digitization strengthens this and produces no (more) bottlenecks. With that, the value of the information greatly increases.

First explorations in 2015 indicated that in order to be able to make this dream come true, practically all of the (historical) fieldwork reports have to be used and processed. A huge challenge that demands time and costs for significant automation, because complete manual construction of the map is not cost effective. The alternative of remeasuring all of the boundaries is even more expensive, legally undesirable and therefore not an option. The plans for a research programme were presented during the 2017 FIG Working Week in Helsinki, Finland [10].

This research programme was launched within Kadaster in 2017, in collaboration with specialist Artificial Intelligence parties, in order to determine in which manner the information from the historical fieldworks could be processed in an automated way to form the Reconstruction Map. This is the working title for the more accurate cadastral map with known geometrical quality and higher accuracy. It has been examined whether it is possible to automatically extract the original measurements from the fieldwork reports with new innovative (data) technology such as machine learning and to combine and validate this information into an accurate map. The interim research results are promising and many parts already show that an automated solution is highly possible.

1.3 Societal need

In addition to the technical challenge, it has also been examined whether the accurate map meets the needs in a changing and highly information-oriented society. Kadaster's goal aligns with the broader trend of digitization, data-driven processes and related quality improvement (Figure 1). But it remains, based on Kadaster's statutory duty regarding the corresponding registrations and associated legal certainty now and in the future. With the possible advent of the new map, a different way of communicating is provided. When the established Reconstruction Map has been completed for an area and relevant parties are in agreement, it will be phased in and presented as Cadastral Map Next to replace the cadastral map: the transition process.

An underlying driver for Kadaster to fulfil its goal at this time is the fact that knowledge about the previously applied methods and techniques will be lost as a result of the outflow of personnel (through retirement) and the disappearance of physical characteristics in the field that formed the basis for the historical surveyor fieldwork reports. This knowledge and information will be sustainably secured in the automated processing in the production process of the Reconstruction Map. Finally, the desired development contributes to a more efficient work process for the future through the sustainable securing of the underlying data, increased accuracy and improved accessibility.

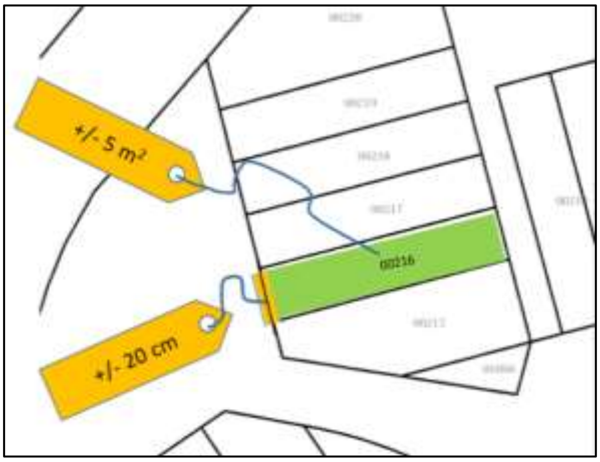

Figure 1. Possible metadata labels.

2. FROM DREAM TO REALITY

In order to turn the dream of an accurate cadastral map into reality, highly varied aspects need to be figured out. These include technical, organizational, communication and legal aspects. In order to maximize the chance of success, an integral and coherent approach to all of these aspects is required.

2.1 Reconstruction Map and Cadastral Map Next

The Reconstruction Map is a reconstructed cadastral map in which all of the available measurements are used in order to provide the most accurate location possible of the cadastral boundaries. The Reconstruction Map contains exactly the same parcels of land as the current cadastral map and, with that, is topologically identical (the same neighbours). The location of the boundaries, however, can vary. The Reconstruction Map is not homogeneous, because some (10%) of the boundaries lack accurate information and for a few extremely accurate measurements are available. The Reconstruction Map is the final product of the automated production process. The last step, called transition, is to replace the current Cadastral Map with the Reconstruction Map, which from then on constitutes the only valid cadastral map, the Cadastral Map Next. During the production process, there are two maps: the current, legally valid Cadastral Map and the topologically synchronized Reconstruction Map under construction. The transition is expected to take place on a given area basis, so the Reconstruction Map will also be constructed in that way.

2.2 Improved data structure

The current data structure of the Cadastral Map is based on line strings, for the boundary entity as well as for the parcel entity. We have a number of specific requirements for the

Reconstruction Map that require expansion of the model, with the most important requirement being the introduction of points as a separate entity, combined with a line definition using reference instead of separate coordinates. This enables considerable process automation, the application of geodetic calculations and with it, a geometrical quality description. Having points with their own quality description is also desirable for generating metadata, such as dispersion of parcel surface area. We have gained inspiration in this from the Land Administration Domain Model (LADM) [8].

For the sustainable management of 189-year-old measurement data, the construction of a database began in which this digital "gold" can be stored unambiguously. This database has been realized in the meantime and will be linked to the updated database of the Cadastral Map in the future. With that, it becomes possible for points in the Cadastral Map that have actually been measured (and not derived), to refer to the measurements. This also provides the basis for accessing relevant additional information of points and boundaries that were collected during measurements, via the map.

2.3 Better accessibility of source data and metadata

Providing a map with improved accuracy entails the obligation to clearly communicate the pattern of expectations per map element. In terms of geometric quality regarding the current map, we provide little more than a disclaimer that no rights can be derived from the map and that is why measuring, for example, is discouraged. In order to responsibly present a future quality with heterogeneous but known quality, transparency about quality is essential. That is why a package of metadata has been developed that can be used for the Reconstruction Map as well as for the current cadastral map. In addition to clarifying the quality, there is also a desire to access specific source data through the map. A plan has also been made for that purpose, with or without enrichment of these data. The choices to be made will have to go hand in hand with adequate communication.

2.4 Organization: communication and cooperation

What can be seen as a small technical step, can be a very large one in terms of communication and organization, this because many users do not want to be confronted with a line image that has suddenly changed. Understanding and acceptance will occur here only when this can be placed in the context of improved data quality, with more application opportunities and fewer uncertainties or discussions, now and in the future. For example, an improved map can lead to a better understanding of the parcel surface area, but if that is also a trigger to adjustment of the official surface area, then it will also require intensive communication in this regard to stakeholders. This means that a careful approach is required when guiding the changes.

Aspects such as legal certainty and trust play a large role in the approach. It is critical that confidence in the authority will be maintained and will be guaranteed when changes in the data are introduced. Transparency about quality must be closely associated with increasing visibility for users so that it becomes more comprehensible and more reliable. The old one was good enough for a long time, but now it is no longer. Cooperation with local governments will have to be configured due to the alignment with other map products and the communication with individuals.

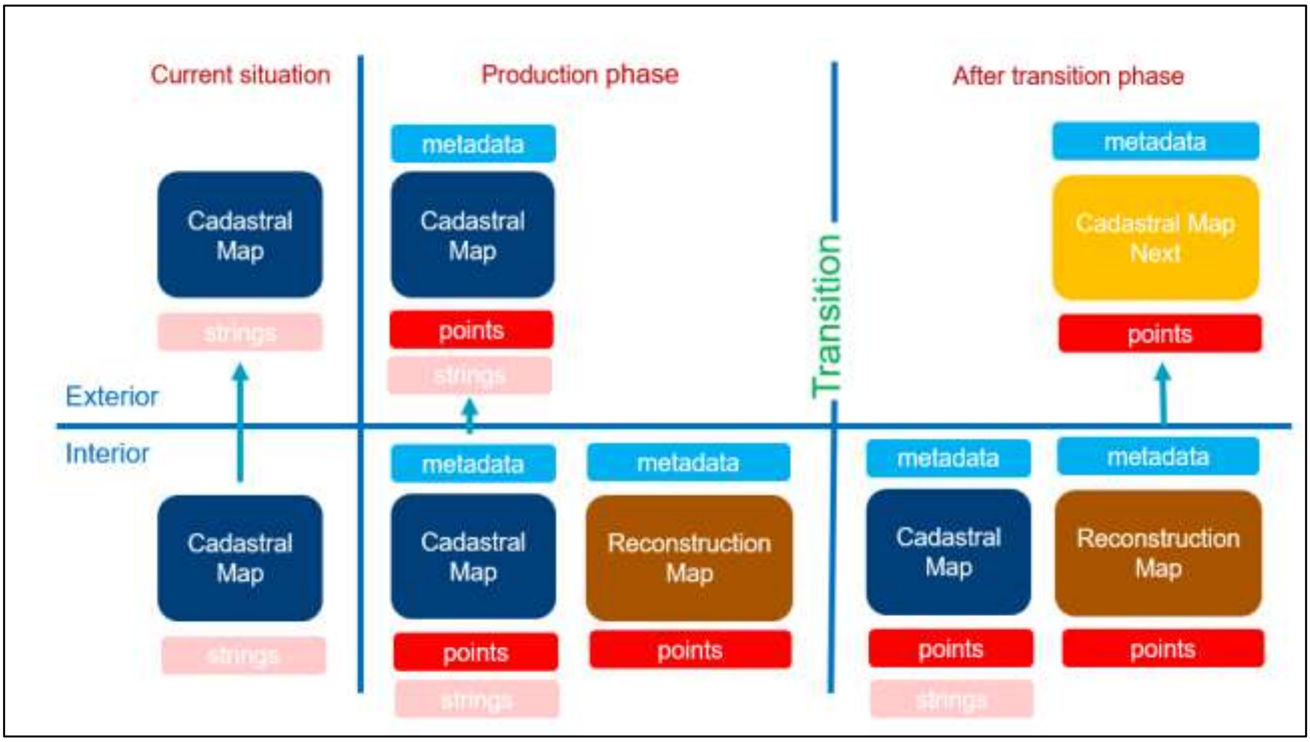

Figure 2. Aspects and phases.

2.5 Cohesion of the aspects

There are three phases to be distinguished over time: current, development of Reconstruction Map, and transition. The interconnection of these components is shown in figure 2. Note that there is only one valid cadastral map at a time.

2.6 Course of the research programme

The technical research conducted in the last two years regarding the feasibility of significant automated processing of the old surveyor fieldworks into a new Reconstruction Map (it involves roughly 5.1 million old digital measurement sketches) has provided promising interim results. The technical feasibility has been demonstrated by a production line prototype and will be scaled up in a subsequent phase into a pilot for the production environment.

The basic principle when designing the production process is significant automation. After the conclusion that we need all of the fieldwork reports (including the historical ones), the focus has been first on the automatic reading of the analogue fieldwork reports. Two companies specialized in Artificial Intelligence, without a background in geodesy, have demonstrated with a proof of concept (2017) that it is potentially possible to extract a high percentage of the data automatically (figure 3).

The follow-up development for the production process of the Reconstruction Map was done in-house by developing a prototype that involved specialists from various companies (2018–2020). In addition to vectorizing and reading the fieldworks, the automation of the linking and calculating of fieldwork reports was included in the prototype. Both process steps have additional (supporting) manual work, where the challenge lies in the manual work and with it, reduction of the costs by increasing the degree of automation. The research has been concluded with a production pilot and a study of social costs and benefits that provide the crucial information for responsible decision-making.

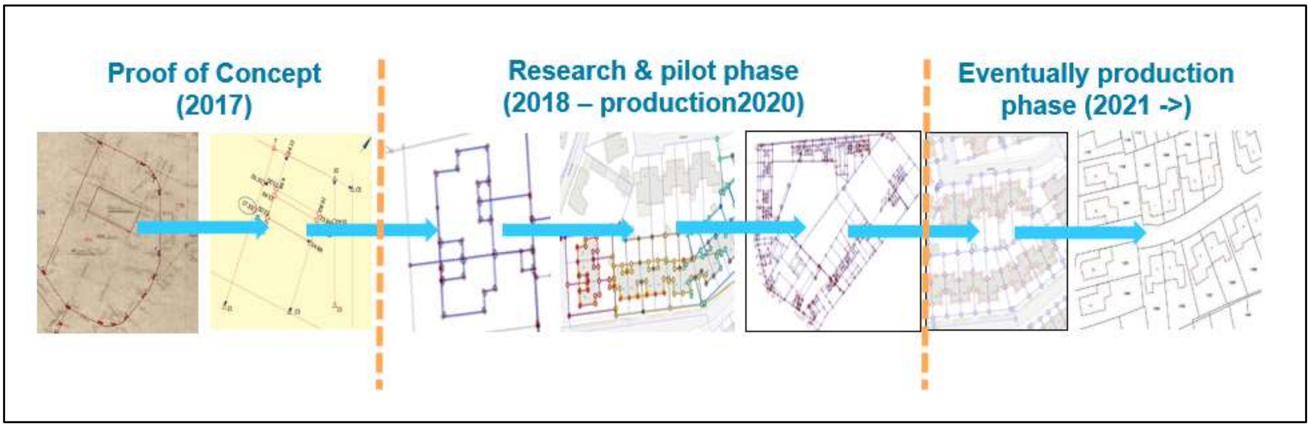

Figure 3. Research program, development in time.

3. PRODUCTION PROCESS

3.1 Design of the production process

In order to create a Reconstruction Map, all of the measurement data from the fieldwork reports need to be extracted, measurement data from different fieldwork reports have to be linked to each other and the entire network has to be calculated. Then, the current boundaries will have to be identified from the lines where the historical boundaries and buildings are also included. For this purpose, the current cadastral map serves as a reference. In figure 4 these steps are explained in more detail. The big challenge is the investigation into whether significant automation of the necessary manual processes is possible when reading analogue fieldwork reports and the calculation of the fieldwork reports in relation to each other. Software will be used for the calculation that allows completely automatic quality checking and description.

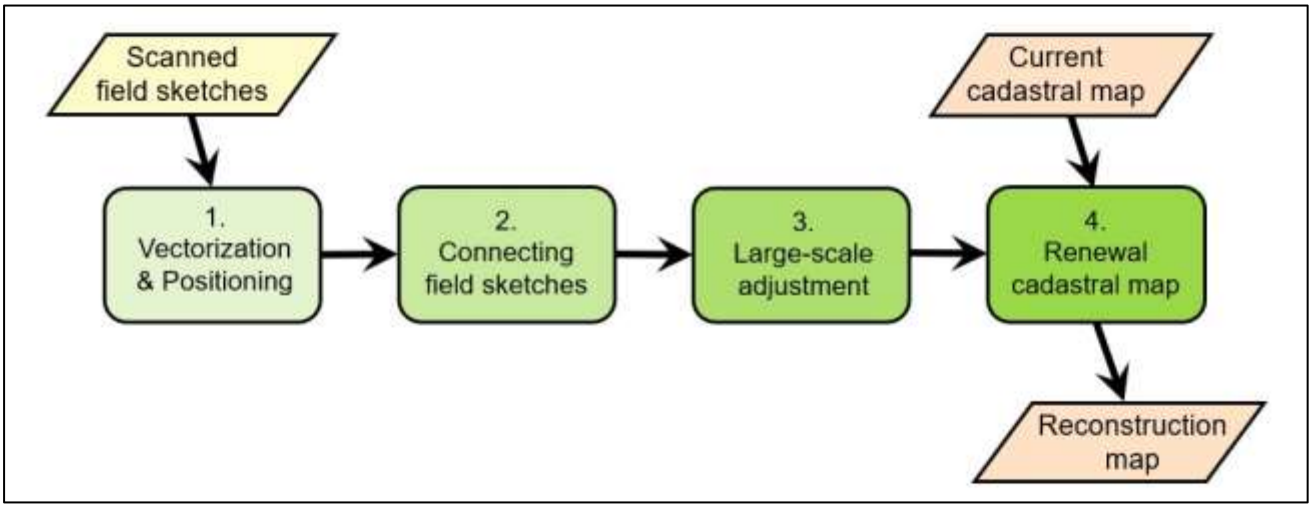

Figure 4. Overview of the four-step approach to renewal of the Cadastral Map [1].

The Cadastral Map renewal process comprises four steps:

1. Vectorization and positioning. Digital scans of the field sketches are vectorized, resulting in digitized survey measurements. The vectorization is largely automated by the application of machine learning techniques. However, due to variation in content and quality (field sketches can be almost two centuries old), a manual correction step is needed, for which interactive tooling has been developed. This tooling also enables the digitized field sketches to be georeferenced using features still present in the current map, often buildings.
2. Connecting field sketches. In this step all information is gathered for a geodetic network adjustment over an area with multiple field sketches. Here, homologous points between the field sketches are identified. Besides the connection between field sketches, the connection to the reference point field representing the national coordinate system (called Rijksdriehoekstelsel) is established. This reference point field consists of several million points usually measured with GPS. This step is finalized with a network adjustment that aims at validating the measurements.
3. Large-scale adjustment. With this step we aim at integrated adjustment of the measurements of hundreds of field sketches. However, it is not feasible to adjust all observations in one step, as we anticipate in the order of a billion observations for the

whole country. This implies that an approach for dealing with discrepancies between results of neighbouring large-scale adjustments is to be developed.

4. Renewal of the Cadastral Map. The large-scale adjustments result in a nationwide point field, the quality of which is known from the adjustment results. Furthermore, the relation between the Cadastral Map and this point field is established. This involves more than the detection of homologous points: many cadastral boundaries are defined by survey points that do not represent a parcel corner, but just lie on the boundary or its extension. When the relations between the two point sets have been established, an adjustment is set up in which all points of the Cadastral Map are updated, accounting for the quality of both sets, resulting in the so-called Reconstruction Map.

The first two steps of the process are described in more detail in Franken et al. [2]. There, the tooling developed for the digitization of the field sketches and the interactive environment for validation and coupling is discussed. In all four steps, quality assurance is applied and integrated in the tooling. Especially step 2 aims at detection of vectorization and measurement errors. The approach adopted is the Delft school of Mathematical Geodesy and is described in more detail in van den Heuvel et al. [1]. In that paper the focus is on the geodetic aspects of the renewal of the Cadastral Map and present initial ideas on steps 3 and 4: how to update the Cadastral Map based on adjustment results of many millions of historic survey measurements.

3.2 Vectorization, positioning and linking

A large portion of the current boundaries were created in the past and are located on fieldwork reports such as those shown in figure 5. These contain a diagram of the measurement scheme (surveying line interconnections), associated measurement data, and additional information such as parcel numbers. The purpose of the research program was to automatically extract the measurement data and the interconnections so that they could be calculated as one measurement. For this purpose, various elements must be recognized, such as line elements and text elements, the lines must be cut to intersections, the text elements read and then the interrelationship between the elements derived.

Figure 5: Fragment of a field sketch [2].

The sketches below show the various elements detected. It is shown how the prototype user interface indicates the choices made. Finally, the conclusion is that full automation is not possible due to the high complexity, but a relatively high percentage is possible (up to 80%). It also shows how elements such as buildings and symbols can be automatically recognized. From a production perspective, it is important to develop the automation as well as the optimal support of the additional manual work. A good user interface with considerable focus on process support can help with efficiency, but also with quality assurance. The result of this first step in the process is a line image to scale and a well-structured set of measurements.

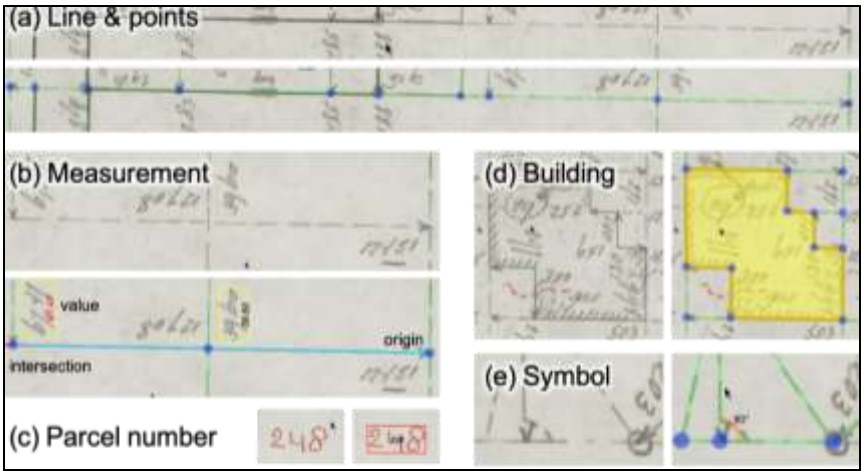

Figure 6: Information units extracted during vectorisation using the AI-based solution [2].

Based on information about the global location (parcel numbers in the map), the line image will be positioned in the correct context. By matching with reference information such as historical cadastral and topographical maps, the line image will be brought to the proper location and orientation. For this purpose, a second user interface was built, with which the position and linking can be fine-tuned manually after a first, automated approach. The process consists of the following steps:

1. Orientation of a fieldwork report using the cadastral and building map.
2. Linking a fieldwork report to adjacent ones and to recent GPS measurements (figure 7).
3. Specification of an area with sufficient coverage for validation and formal testing with geodetic calculation software.

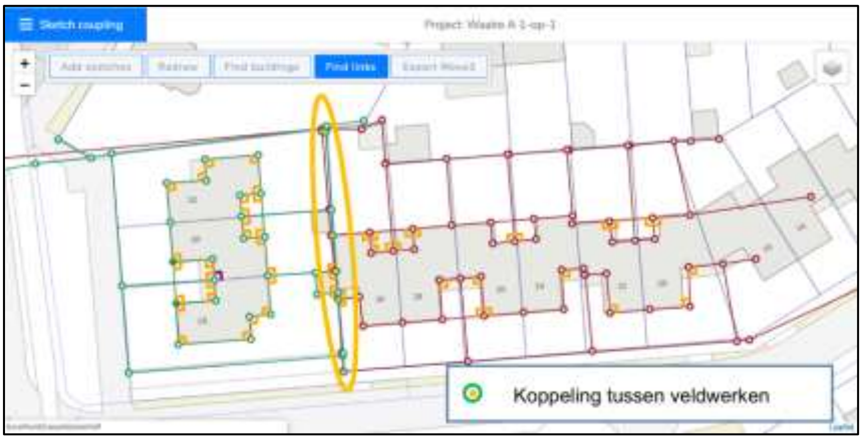

Figure 7. User interface VeCToR, links between two field sketches [9].

3.3 Calculation of larger networks (geodetic concepts)

In order to be able to make a useful map adjustment, larger areas must be formed, because only then their interrelation can be determined. In the example, an area with eleven fieldwork reports were linked together and calculated using a reduction in accordance with an LSA (Delft method). This is the basis for a quality analysis, where precision of the points in the network can be specified. The average standard deviation achieved in this area is better than 5 cm. That result is representative for the other trial areas and demonstrates the feasibility of constructing a reconstruction map from analogue fieldwork reports. In particular, the linking of the information from fieldwork reports typically results in a network for which the standard deviation remains limited to approximately 5 cm, which is an excellent qualitative result. In Salzmann et al. [3], Teunissen [4][5], Baarda [6] and Verkuijl [7] more information about the control methodology can be found.

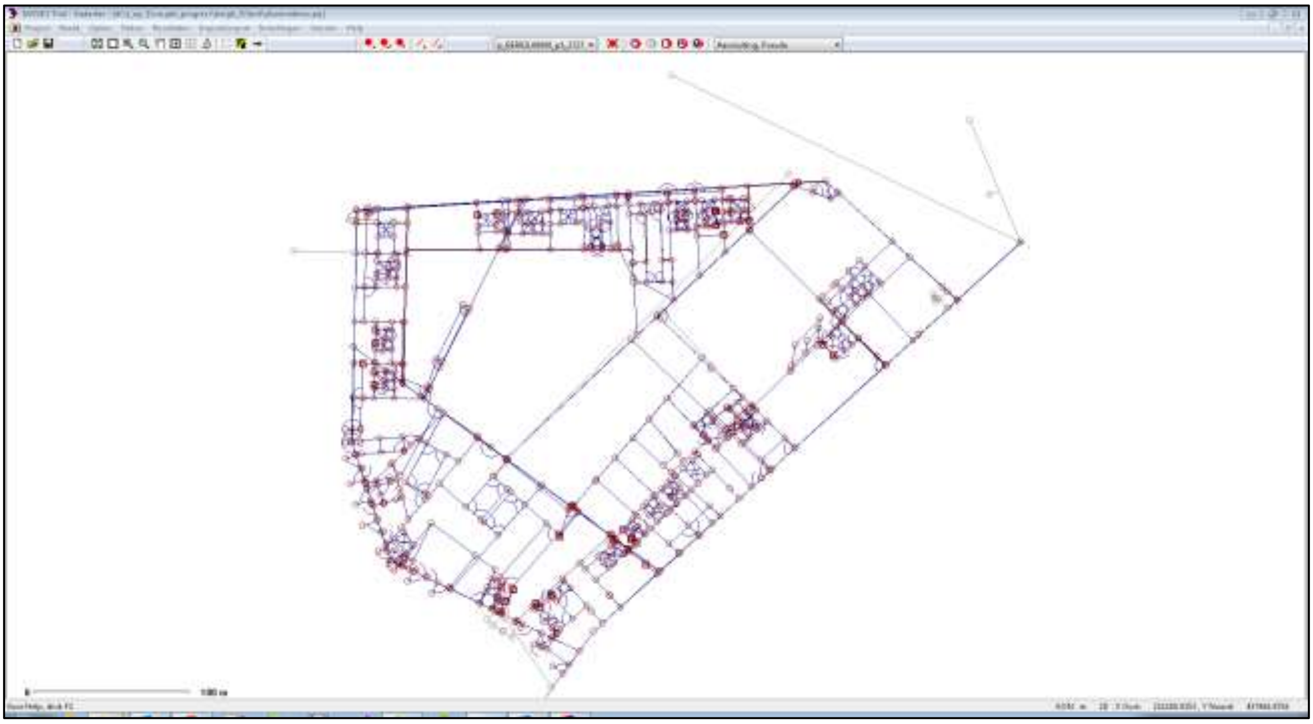

Figure 8. Eleven connected field sketches forming a geodetic network [9].

In order to be able to construct the map, the local accurate measurements will also have to be linked to the RD system. We achieve that by enlarging the areas of linked fieldworks so that there are sufficient and well-distributed recent GPS measurement data (from 2005) within the area for the connection to be made. This manner of working contributes to a (fully automatic) quality description of all of the individual elements in the map.

The last part of the process that translates the combined calculated information into the Reconstruction Map is expected to be fully automated. A few exploratory studies were done that confirm that expectation. An important aspect of this is the early clarification of the different elements in the line image. Another aspect is the integration of the Cadastral Map itself into the reduction process. It has been decided to realize this development only when there is a final decision about the production of the Reconstruction Map for large parts of the Netherlands.

3.4 Production Pilot

The operation of the production line has been tested by having two external companies process a substantial collection of fieldwork reports with the prototype, supplemented by adjustments to the software by the contractors. As a result, we have gained a better sense of the usability of the designed solution, of its efficiency and of the collaboration with an external party. The pilot was a great success, both companies succeeded in getting the software to work and to process all the documents in a qualitative sufficient way. We were very impressed by the fact that they went on during the first months of the Covid-19 pandemic. We will present the results at the FIG seminar later this year.

4. TRANSITION TO CADASTRAL MAP NEXT

4.1 Transition Process

The decision to replace the current Cadastral Map with the more accurate line image of the Reconstruction Map (the transition to the Cadastral Map Next) must be accompanied by the following three measures:

1. Informing and cooperating with local governments so that they can act as a communication partner towards the public. Alignment with the other map products, especially the agencies responsible for the topographical mapping.
2. The general public must be aware of the actual (current) quality and the improved quality. As already stated in paragraph 2.4: transparency about quality must be closely associated with increasing visibility for users, so that it becomes more comprehensible and more reliable. This requires an awareness campaign that must be established nationwide.
3. Individual users will have to be guided in the event of questions or complaints. This can become a significant task due to the large scale of the change.

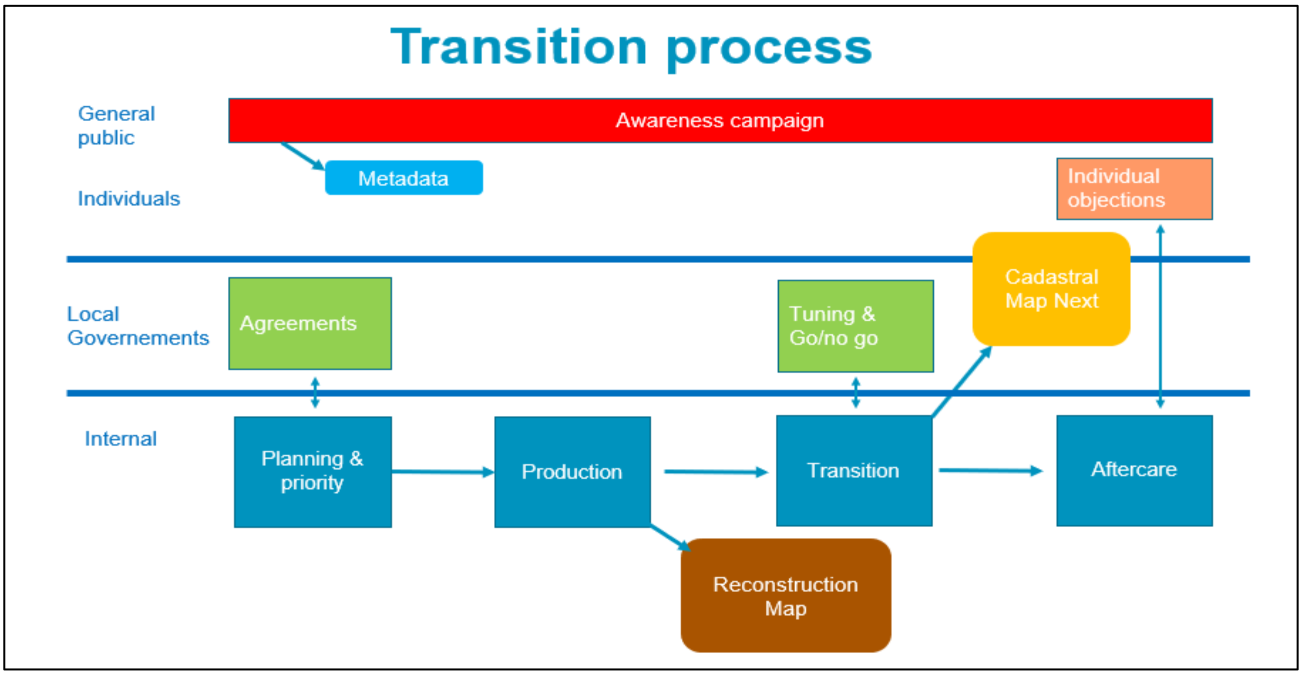

Figure 9. The transition process.

4.2 Legal and communication aspects

Communication and provision of information are increasingly important in the current society. The right communication at the right time is also vital for Kadaster, which has a societal function. Communication is important in order to maintain the confidence in the legal certainty, to maintain the cadastral organization and to inform users of the significance and added value of the advocated changes, also compared to the existing situation.

At first look the legal impact of the changes is limited: the Cadastral Map is only a graphical representation and we have the right to changes the boundary representation in the map within the reliability limits. However, the new cadastral map can give better estimations for the calculated parcel areas. This can lead, when differences exceed a certain level, to changes in the officially registered parcel sizes. If that’s the case, we have the obligation to officially inform the owners, a potentially difficult situation when parcel sizes decrease.

4.3 Information layer on the cadastral and reconstruction map

The information layer (metadata) is meant to indicate the quality of the Cadastral Map using existing data sources. For this purpose, the relevant data from several data sources are linked to the data from the Cadastral Map, providing a semantic enrichment of the cadastral data with metrics. This produces a more complete and clearer picture of the cadastral boundaries and parcels. This information layer is an important resource in the indication of quality and in the communication with the public about map quality.

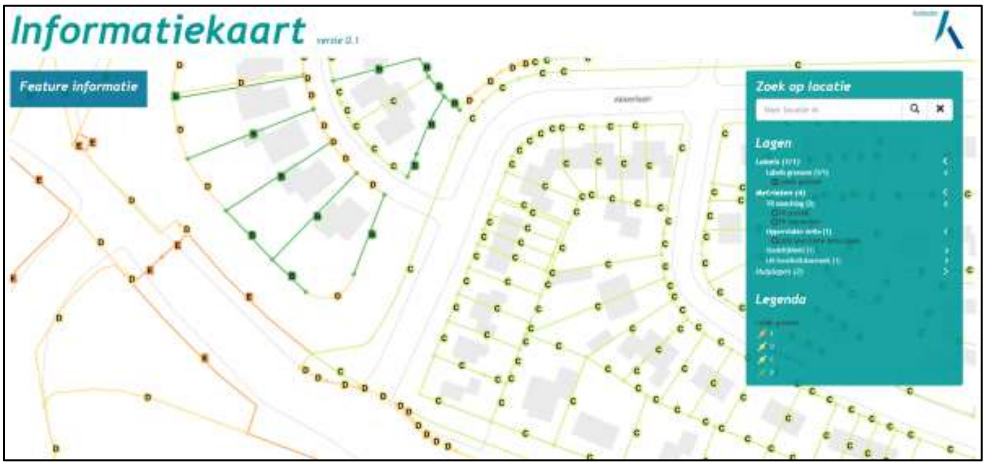

Figure 10. Information layer on the current cadastral map

In the example above the default values D (urban, 20 cm) and E (rural, 40 cm) are shown. If measurement information is avaliable, a better quality can be concluded (B, 5 cm), otherwise if some other conditions, calculated by metrics, are fulfilled, the default quality D can be upgraded to C (10 cm).

4.4 Analysis of costs and benefits for society

In order to make optimal decisions it is important to quantify the benefits for society in terms of money. Because the project is potentially time and money consuming it is important for the Dutch government to have an independent check on the overall efficiency of the project. Therefore this task is done by a firm that is specialized in calculating cost and benefits on long term and on effects that are difficult to estimate. Next to financial effects societal effects will be described.

5. RESULTS

We showed our research plans at the 2017 FIG working week in Helsinki. We can now show the first fully fledged research results and draw preliminary conclusions. Hopefully, we will be able to show practical results in 2023. The preliminary results are:

5.1 Technical

- Reading as well as interrelating fieldwork reports can be automated significantly, which means a huge innovation and certainly brings closer the feasibility of large-scale production.
- A 100% automation is not expected to be achieved and is even undesirable for some parts. In addition to the automated processing, manual work is necessary. However, this can also be supported to a large degree through tools focused on maximum efficiency.
- The reconstruction map sustainably secures the analogue fieldwork archive for the future and with that, the wealth of knowledge and information that is contained in that archive. The risk of losing this knowledge can be ameliorated with this process.
- In addition, the conversion from analogue to digital makes the historical surveyor fieldwork reports much more accessible, resulting in a much broader scope of application. For example, making measurements oneself.

5.2 Societal

- The map forms part of the cadastral duty and purpose and meets a societal need, as long as it is accompanied by the proper communication.
- The provisions that make the map possible also facilitate internal improvements.
- The two previous points are sufficiently in balance with each other to justify the investments to date. Going forward, scenarios are now being developed for further steps that aim for that same balance.

We will present the results presented in this paper and eventually board decisions during the upcoming FIG seminar. Note that a corresponding paper (2020) was also available in French [11].

REFERENCES

[1] Van den Heuvel, F, et al., *Rebuilding the Cadastral Map of The Netherlands, the Geodetic Concept.* FIG working week, 2021.

[2] Franken, J, et al., *Rebuilding the Cadastral Map of The Netherlands, the Artificial Intelligence Solution.* FIG working week, 2021.

[3] Salzmann, M, et al., *Handleiding voor de Technische Werkzaamheden van het Kadaster*, Kadaster, 1996

[4] Teunissen, P.J.G., *Adjustment theory, an introduction*, Delft University Press, 1st ed., 2000.

[5] Teunissen, P.J.G., *Testing theory, an introduction*, Delft University Press, 1st ed., 2000.

[6] Baarda, W., *A testing procedure used in geodetic networks*, Netherlands Geodetic Commission, Publications on Geodesy, New Series 2(5), 1968.

[7] Verkuijl, G, *user manual MOVE3*, Sweco Nederland B.V, 2016.

[8] Lemmen, C, *A Domain Model for Land Administration*, Ph.D. Thesis, Technical University Delft, 2012.

[9] Hagemans, E, et al., *Programmarapport 1-op-1-kaart 2018/2019*, Kadaster, 2019.

[10] Hagemans, E, *The cadastral map of The Netherlands improved*, FIG working week, 2017.

[11] Hagemans, E, et al., *Reconstruction du Plan Cadastral des Pays-Bas: le Concept Global*, FIG working week, 2020.

BIOGRAPHICAL NOTES

Eric Hagemans is since 2014 working as a geodetic specialist and innovation advisor at Kadaster in The Netherlands. He is responsible for the content of the KKN program and on the innovation of cadastral surveying and corresponding registrations. Before he worked as teacher and manager at the University of Applied Science in Utrecht and as geodetic engineer at the engineering companies Arcadis and Sweco. He studied geodesy at the Technical University in Delft.

Ruben Busink studied Physical Geography at the Utrecht University. He has over 25 years professional experience in Geographical Information Systems and information management. He has fulfilled several management positions in this domain, among which Head GIS and Information department of Royal HaskoningDHV. Since April 2018 he is the Program Manager for the 'Cadastral Map Next' program at Kadaster in the Netherlands.

Jeroen Grift is working as a GIS developer at Kadaster since 2018. Within the KKN project, he is responsible for developing methodology that adds geometric quality data to the current cadastral map. Before he worked at CycloMedia as a GIS-specialist. He studied Landscape History at the University of Groningen and Geomatics at the University of Gävle.

Frank Schouten is a Senior Geo-ICT Consultant at Merkator BV in the Netherlands since June 2015. He was responsible as project manager at Kadaster for a market survey and feasibility study of the KKN program. Currently he is product owner for two teams in the KKN program. Before joining Merkator Frank held several positions such as project manager, consultant and information engineer. He has over 25 years of experience with GIS software and database technology. His knowledge gives him the ability to form the link between business and the geo-ICT technology.

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