Status of Coordinates in Norwegian Cadastre

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SUMMARY

The paper examines the status of coordinates in the Norwegian cadastre, including both the legal status and the accuracy and reliability of the coordinates. To clarify the legal status of the coordinates we discuss the historical reasons for introducing coordinates in the cadastre as well as the degree to which coordinates are emphasized by courts, directly or indirectly, when settling boundary disputes. Introduction of coordinates is found to be strongly linked to the development of surveying methods. In Norway, the coordinates were apparently regarded mainly as a tool to maintain the cadastral map, rather than as a means for defining a boundary. This is not entirely consistent with today's practice, in which boundaries are reconstructed from coordinates by municipal cadastral surveyors.

Further, we discuss the accuracy of the coordinates in the cadastre and the practical consequences of possible inaccuracy, both for the landowners and the public authorities. The cadastral maps of some selected Norwegian municipalities are analyzed and the registered accuracy is visualized using GIS-software. The accuracy of the registered boundaries in many cases is found to be too low to be regarded as "fit for purpose". This applies both to the landowner, who needs to know where the boundary lies, and to the public sector, which needs to know where the boundary lies in connection with planning and permits. We also compare the status of coordinates in the Norwegian cadastre with that of the cadastres of Sweden, Austria and Singapore.

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1. INTRODUCTION

Norway has a German-style cadastral system (Williamson et al., 2010). The Norwegian cadastre is a property-based system. Every land property has a unique number. The property and its owner are registered in the land register. A property may consist of several parcels. The geographic extent and the boundaries of the parcels are registered in the cadastre, and shown in the cadastral map. The cadastral map is neither complete nor guaranteed in any way. The geometry of the parcels may be wrong and the parcels may be misplaced or completely lacking from the map (Mjøs, 2016).

The geographical extent and boundaries of parcels are registered by means of coordinates in an official reference system. The coordinates are stored as latitude/longitude in the Euref89 reference system, as specified by the Norwegian mapping authorities. When displayed on a map, these coordinates are projected to the desired UTM zone. The UTM zone to be used is specified for each of the 19 Norwegian counties, but all of southern Norway uses UTM-zone 32. This zone is formally extended to include the most western parts of Norway. It is also used for the most eastern parts of southern Norway, even though these areas fall within zone 33 geographically. Euref89 is a realization of the ETRS, which is realized by a network of survey control stations called "Stamnettet". Stamnettet is considered homogenous and error-free in relation to cadastral surveying. Stamnettet has been densified by establishing lower-order networks, and the mapping authorities also offer a GNSS-network for real-time positioning, based on Stamnettet.
Cadastral surveying and cadastral mapping have been conducted for centuries in Norwegian urban areas. In rural areas, cadastral boundaries were not documented by surveyors until 1980. Historically these boundaries were only marked in the field and were documented by written descriptions (metes and bounds). From about 1960 onwards, rural boundaries were mapped as part of the national economic mapping using photogrammetry. These mapped boundaries were explicitly stated to be not legally binding. Later, the economic maps have been digitized and the boundaries transferred to the modern digital cadastral map. The data in the Norwegian cadastral map thus come from many different sources, with significant variability in both accuracy and reliability.

2. LEGAL STATUS OF COORDINATES

Norway does not have a coordinate cadastre like the cadastre of Austria, where coordinates are agreed upon by the landowners and guaranteed by the government (Abart et al., 2011). Another country with a sort of coordinate cadastre is Singapore, where coordinates are regarded as conclusive evidence in court (Andreasson, 2006). This is not the situation in Norway. Norway's system is not like that of Sweden, either, where an original survey sketch defines the property and its boundaries. Norway does not have licensed or authorized cadastral surveyors with authority to determine a boundary and settle a boundary dispute.

During land disputes, both the land consolidation court and the ordinary civil court can make decisions concerning boundaries. However, the court decisions will be based on various kinds of evidence. In some cases the registered boundary will serve as the main proof of where the actual boundary is located, while in other cases the cadastral map is set aside in favour of other evidence, such as actual land use. This may happen even if an accurate and modern survey has been carried out. The correct boundary may differ from the surveyed boundary, or the boundary may have been changed after the survey. The possibility of changing a boundary after the cadastral survey exists because of the freedom of contract. Unregistered boundaries may be legally binding. Landowners are entitled to agree upon a boundary change, even without a written agreement. This will be the actual boundary even if the old boundary originated from a court decision, and even if the authorities are not informed that the boundary has been changed. Of course, changing boundaries without registration has many disadvantages and is not recommended, but court decisions clearly document the existence of such a possibility (Borge, 2014).

The legal status of the coordinates in the Norwegian cadastral system is poorly defined and has not been discussed in depth (Nysæter, 2018). This stands in contrast to the great effort put into the process of measuring and calculating the coordinates. In this perspective, abandonment of the practice of registering boundaries relative to terrain details, as was done before coordinates were introduced, is also questionable.

3. INTRODUCTION OF THE COORDINATES

If studying today's practice does not suffice to clarify the status of the coordinates, another possibility is to investigate the introduction of coordinates as a means to define boundaries in the cadastral map. In Norwegian cities, cadastral surveying started long before the use of coordinates. Bergen is now the second largest city in Norway, surpassed by Oslo during the 1800's. In Bergen, coordinates were introduced on cadastral maps around 1929. Before that, the cadastral maps were made using plane tables and tape measurements. To locate boundaries, distances from terrain details to the boundary points were written on the maps. The maps of different parcels were united into a general cadastral map by trying to fit the pieces together manually, not by any kind of georeferencing into a reference system.

When Norway first established a reference system, the purpose was to map border areas close to Sweden in the easternmost part of the country. This effort was military in purpose, due to risk of war (Harsson and Aanrud, 2016). The central meridian of the chosen projection went through a fortress close to Sweden. The scale factor increased with distance from the meridian. In the cities on the west coast, the scale factor was as large as 2000 ppm. Because of this, the projection was considered useless for detailed mapping in the western parts of Norway (Gleinsvik, 1964).

As complexity of urban structures increased by the end of 1800's, so did the need for accurate maps. In Bergen it was the water and sewage authorities, together with the road authorities, who first argued for a coordinate-based technical city map. They argued that in order to be maintainable, the map had to be based on a reference system (Bergen Kommune, 1913).

In the same period, surveying instruments underwent rapid development. The theodolite became relatively more affordable, lighter and more accurate. In the late 1800's several Norwegian surveying companies owned theodolites.

The three largest cities in Norway got their own coordinate-based reference systems just after the year 1900. To avoid errors due to scale factors, local reference systems were defined. As these reference systems were only meant for local use within the city borders, no map-projection was needed. The systems were realized by establishing survey control stations, which were surveyed by triangulation. A baseline was established and the baseline distance was reduced to the geoid (Nysæter, 2018). In Bergen, the coordinate values were chosen such that the spire of the main cathedral was given the coordinates [x, y] = [6000, 6000]. In that way, all coordinate values within the city borders became positive.

During the 1900's the cities expanded, and the local coordinate systems were applied in areas larger than originally intended. This gave rise to new versions of the systems. In the same period a national Gauss-Kruger reference system was established that had acceptable values for distortion of distance and no distortion of angle. When the cadastral maps were transformed from a system without map projection into the new national reference system, this of course led to loss of accuracy. With the introduction of Euref89 a second transformation was carried out, with further loss of accuracy.

When arguing for introducing a coordinate system, the city council of Bergen stated: "Only within this absolute system can a fully reassuring determination of the property boundaries be provided for the landowners" (Bergen Kommune, 1913). That this "absolute" system would be changed twice within the next 100 years was not foreseen.

3.1 Cadastre in rural areas

Cadastral mapping of Norwegian rural areas was initiated in 1804-05, while Norway was still united with Denmark. This mapping project came to an end in 1815, after the union was dissolved. At that point only a small part of the central eastern areas was covered. The practice of marking the boundary points in the field, and describing the boundary in writing, continued until 1980 (Mjøs, 2016). This cadastral work was carried out by laymen.
Following the Second World War there was a greater need for maps for planning purposes, leading to the start of national economic mapping in 1960. Location of property boundaries was considered important for planning, so cadastral mapping was included in the economic mapping. The mapping was carried out using photogrammetry. All productive areas were to be

mapped in the scale 1:5000, and the rest in the scale 1:10 000. To make the property boundaries visible in the aerial photos, the landowners were required to target boundary points. White plastic or paper sheets measuring 60x60 cm were used as targets and placed on the boundary points. In some parts of the country, most boundary points were targeted, while in other parts, many boundary points were not targeted. The targeting had to be done after the snow melted, and the aerial photography had to be done before the trees leafed out, so there was only a short period available for setting out the target plates. If the boundary points were not targeted, the cadastral boundaries had to be drawn based solely on image interpretation. The targeted points were field checked by bringing the aerial photos out in the field, to verify that the visible white dots in the images represented the actual boundary points. Additional field notes were also made describing the boundary and boundary points. In some cases verification was easy, but in other cases it was very difficult. In some cases the work was done by professional engineers, but in other cases by it was done by laymen or students with just a short period of training. The accuracy and reliability of the mapped boundaries varied a lot. It was explicitly stated that the mapped boundaries were not legally binding, but only indicative (Haraldstad, 2013).

From the mid-1980s, the same boundaries have been digitized using digitizing tablets, and are now found in the Norwegian cadastral map. The process of digitizing has of course resulted in some further loss of accuracy. The accuracy of the digitized boundaries is now considered to be about 2-4 meters, for boundaries that were targeted and correctly identified in the aerial photos (Mjøs and Leiknes, 2007). Boundaries drawn on basis of image interpretation have also been digitized and added to the cadastral map. It is difficult to estimate the accuracy of such boundaries, but they are now registered with standard deviations of 5 to 15 meters.

In 1980, Norway introduced a new cadastral law. Cadastral surveying became mandatory in the rural areas, and the new law also applied to the urban areas, replacing the former building act from 1965. The municipalities became responsible for surveying new boundaries and new properties. There was no intent to totally renew the cadastral map, nor any plan to accurately map existing boundaries. Surveying was mandatory only when new properties were created by subdivision, and not when transferring title of existing properties. The accuracy of the resulting cadastral map was hugely variable. New boundary points were to be surveyed with high precision using total stations and with control measurements to provide reliability. Further renewal of cadastral law in 2010 did not change this situation. New boundaries are still surveyed using the newest methods and equipment, while existing boundaries remain inaccurate. In fact, the 2010 act contains a paragraph that requires a survey to be carried out when a property without surveyed boundaries is transferred to a new owner, but this paragraph has not come into force. The concern is that lack of municipal surveying capacity would severely delay property transactions (Onsrud, 2013).

For properties surveyed prior to 2010, a survey certificate (*målebrev* in Norwegian) was issued. It shows the course of the boundaries, along with a list of the boundary points with description of boundary marks and coordinates. After 2010, survey certificates were no longer made, but the landowners receive a report from the digital cadastre containing the same type of information as the previous survey certificate.

A survey certificate or a report from the digital cadastre documents the boundary that is registered in the cadastre. In disputes, this serves as one of many kinds of evidence that may be used to decide the location of the boundary in the field. As mentioned above, the cadastral survey is not legally binding for the landowners. They can agree on a different boundary without informing the authorities (Mjøs, 2016). The purpose of the coordinates is mainly to maintain the cadastral map (Nysæter, 2018), but the coordinates can also be used to reconstruct boundaries and serve as evidence in court. However, if demarcations in the field and boundary descriptions are in conflict with the map and coordinates, the former will usually be given greater weight (Mjøs, 2016).

4. CALCULATING AND REGISTERING COORDINATES AND THEIR ACCURACY

The current standards for cadastral surveying in Norway require equipment checking, measurement control through redundant observations, and adjustment computation using blunder detection and reliability analysis. The calculated result consists of the coordinates, their standard deviation, and the external reliability. The external reliability is an estimated value of the maximal deformation of coordinates caused by undetected blunders in the observations (Ghilani, 2010). In urban areas, external reliability has to be less than 10 cm. When registering the coordinates in the cadastre, the registered measurement of accuracy, according to the standard, will be the standard deviation of the coordinates (Nysæter and Leiknes, 2014). The fact that the registered measurement of accuracy is mathematically different from the accuracy requirement that the surveyor needs to fulfil, seems to have caused errors in the registered accuracy in the cadastre. If the surveyor has surveyed according to the standard and achieved the demand for external reliability less than 10 cm, the standard deviation of the adjusted coordinates can be assumed to be less than 4 cm. When the method of surveying is registered as RTK-GNSS, using the mapping authorities' own CPOS reference network, the standard deviation of a single measurement is expected to be around 3 cm, and thus less than 3 cm for a coordinate calculated by least-squares adjustment of single measurements. However, in the cadastre one will find that most of the boundary points measured by RTK-GNSS are registered with a standard deviation of 10 cm. This is shown in the following section. In this specific case, it seems that the accuracy requirement for external reliability has been entered into the field named standard deviation. But it is the calculated standard deviation of the actual point that should have been entered.

5. CURRENT STATUS OF NORWEGIAN CADASTRE

The figures below illustrate the status of the Norwegian cadastre. Figure 1 shows the distribution of boundary points in the municipality of Stord, sorted by method of measurement and registered accuracy (for a complete overview of the measurement methods, see Kartverket, 2019a). The two most common methods are "theodolite with electronic rangefinder" (12) and "total station" (11). The majority of points are registered with standard deviation 10 cm, and this includes the majority of points measured with RTK-GNSS (method no. 96). The yellow sector shows that about 10 % of the 52395 boundary points have been digitized from paper maps and are registered with a standard deviation of 200 cm.

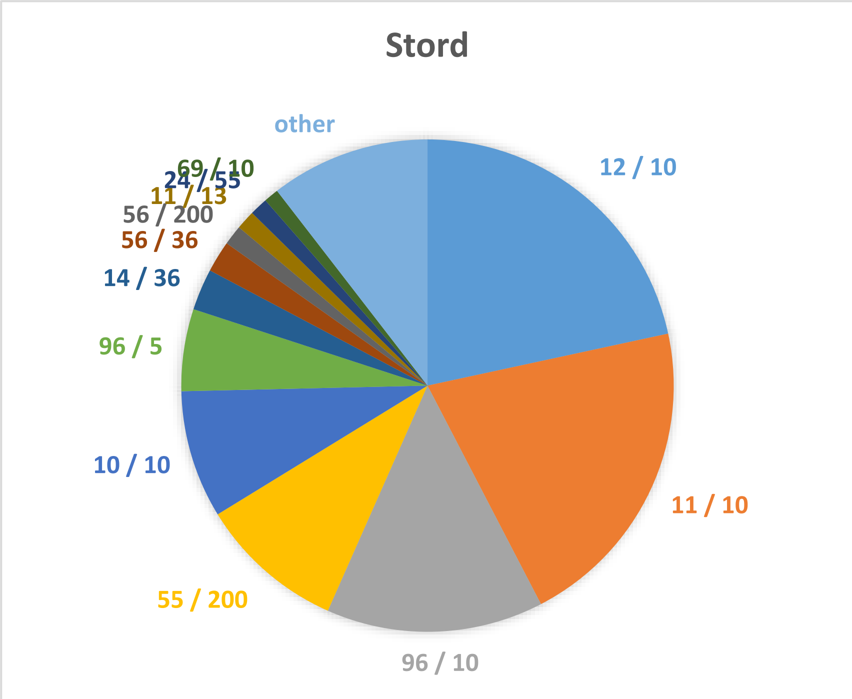

Figure 1: Distribution of boundary points in the municipality of Stord, by "method of measurement" / "standard deviation".

Stord is a former rural municipality, now containing a significant amount of urban settlement. It is located on a west-coast island south of Bergen. For the most part, cadastral surveying started with the cadastral law in 1980, but some properties in urban areas had been surveyed prior to this due to requirements in the building act from 1965.

Figure 2 shows the same kind of diagram for the municipalities of Bergen and Oslo. The municipality of Bergen includes the city of Bergen, where cadastral surveying has been carried out for centuries, and also some of the surrounding rural areas, where cadastral surveying started

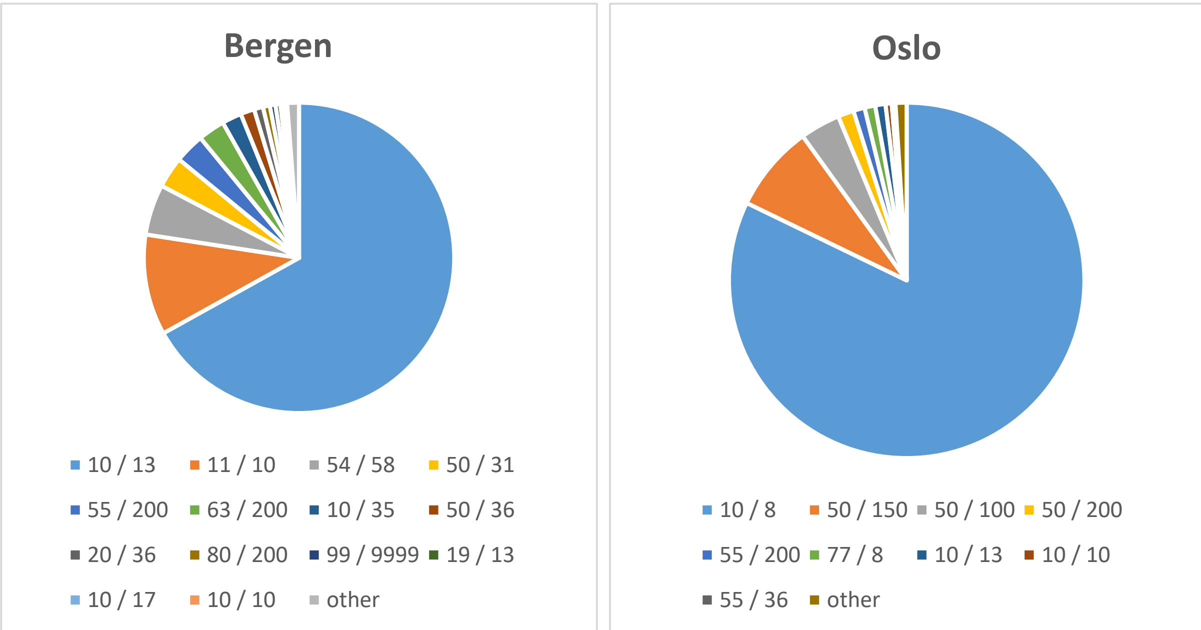

Figure 2: Distribution of boundary points in the municipalities of Bergen and Oslo, by "method of measurement" / "standard deviation".

later. The diagram shows that two thirds of the boundary points are registered with standard deviation 13 cm. This accuracy is based on the accuracy of the original surveying method, here registered as "measured in terrain" (10), plus the estimated loss of accuracy caused by transformation.

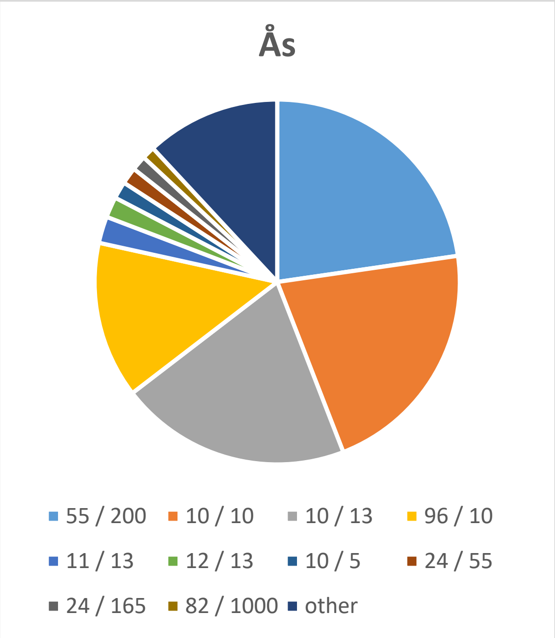

Figure 3: Distribution of boundary points in the municipality of Ås, by "method of measurement" / "standard deviation".

In Oslo, the total number of registered boundary points is slightly less than in Bergen. The distribution diagram is similar. The diagram shows an even larger majority of points registered with the number 10 for surveying method. But the registered standard deviation is 8 cm, compared to 13 cm in Bergen. We also find that within Oslo, around 50 000 points are registered with a standard deviation of 100 cm or more.

Ås is a rural municipality south of Oslo, which hosts the former Agricultural University of Norway, now the Norwegian University of Life Sciences. The distribution of boundary points in this municipality is shown in Figure 3. The largest category here is 55/200, indicating the survey method "Digitised on dig.table from paper copy" and registered standard deviation of 200 cm. More than 10 000 boundary points are registered based on the national economic mapping that started in the 1960s. We also notice that the category 96/10 is about the same relative size as in the other rural example, the municipality of Stord.

The last example is the municipality of Tromsø, where we find the largest city in northern Norway (Figure 4). Here 35% of the boundary points are registered with surveying method "Theodolite with electronic rangefinder" and standard deviation of 12 cm. Tromsø municipality's official website states that boundary points with accuracy 12 cm or better can be established in the field by a municipal

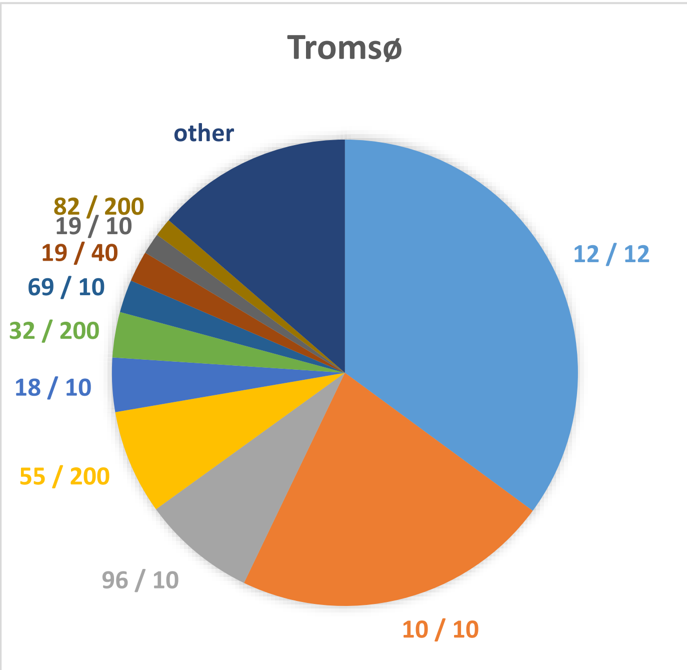

Figure 4: Distribution of boundary points in the municipality of Tromsø, by "method of measurement" / "standard deviation".

surveyor. Other points cannot be determined directly, but only established through a more elaborate process (Tromsø kommune, 2014).

For all of the municipalities mentioned above, we notice that the data fall into various categories of accuracy. This applies more or less to the whole cadastre in Norway, and is contrary to the mapping authority's own standard, which states "The accuracy specified on the object should be as close to the accuracy of the data object in relation to the real object as possible" (Kartverket, 2019b). For points surveyed a long time ago and with uncertain accuracy, use of categories is understandable, but for points surveyed according to today's standards it is hard to see any reason for not registering the calculated accuracy for each individual point.

The standards of cadastral surveying in Norway specify method for both surveying and calculation. If these standards are followed, and the demand for external reliability less than 10 cm is fulfilled, the standard deviation of the coordinates should not be greater than 5 cm. Unfortunately, the diagrams above indicate that hardly any of the boundary points in the Norwegian cadastre are registered with standard deviation 5 cm or less.

Some may argue that the data are deliberately misinterpreted in the above section. The current Norwegian cadastre is a mixture of data from different sources based on different professional opinions and traditions. In this perspective, it should be obvious that many of the numbers specifying accuracy cannot be interpreted as actual standard deviations, but instead as tolerance limits. This is probably correct, but such knowledge is now totally separate from the data, and in conflict with current metadata. Although the actual standard deviations from the underlying data may be more correct than those in the cadastre itself, there is a potential and need, in my view, to improve the data in the cadastre itself.

6. FIT FOR PURPOSE

Which coordinate accuracy would fit the purpose of the cadastre? That depends on several factors. One of the most important is whether boundary marks or monuments exist in the field. If boundary marks exist, the surveyor will normally use the coordinates to find the boundary mark that defines the boundary. If boundary marks do not exist, the coordinates need to be just as accurate as the boundary needs to be located in the field. A problem with this is that the need for accuracy varies from place to place, and may change with time. In areas with population growth and urbanization, boundaries that previously went through land with no value, now set the limits for large construction projects. If in such cases old boundary marks can be found, the former unimportant boundary can now be established exactly. If only the coordinates exist, their accuracy may turn out to be too low to prevent future conflicts. Some maps from the aforementioned municipalities will illustrate the situation in the Norwegian cadastre,

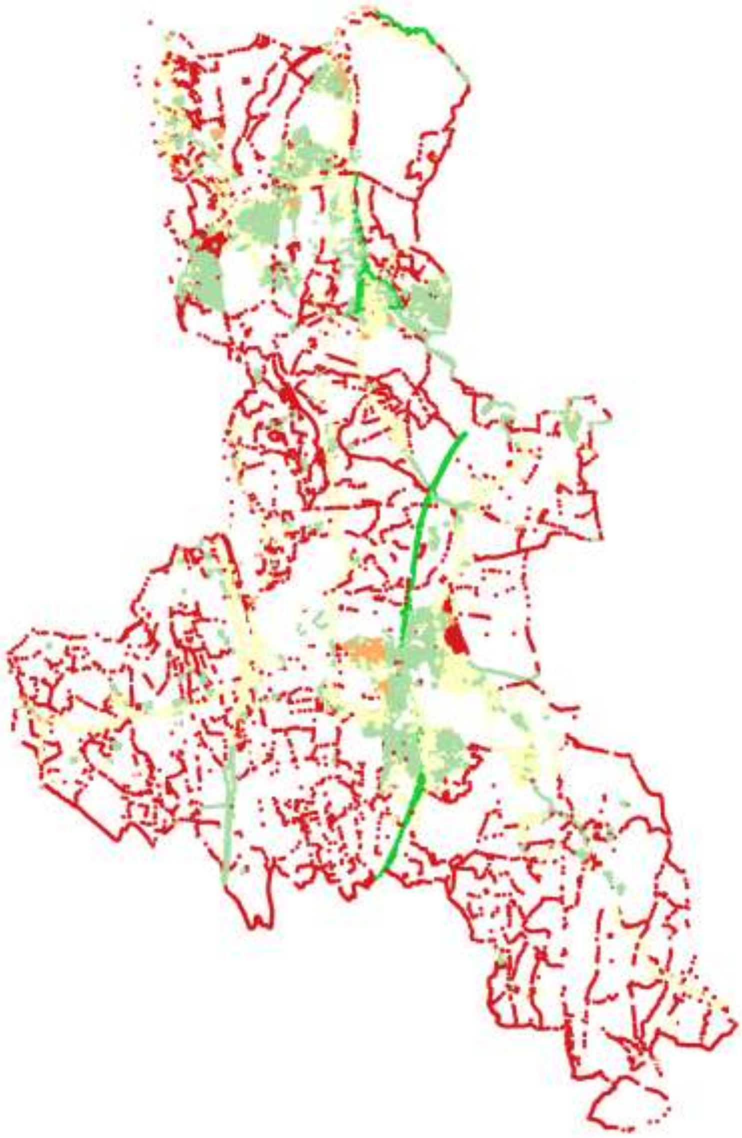

Figure 5: Boundary points in Ås municipality, coloured from red (worst) to green (best) by registered accuracy.

Figure 5 shows boundary points in the municipality of Ås, coloured by registered accuracy. The red points have a standard deviation of 50 cm or more, most of them 200 cm (as shown in Figure 3). These points originate from the national economic mapping project. By zooming in on one of the areas with red points, we get the picture shown in Figure 6.

Figure 6: Detail from Ås municipality

The boundary lines are drawn in red and a buffer of 3 times the registered standard deviation is constructed on each side of the line. According to the data, the correct boundary lies within the buffer area with a probability of 99.7%. It will be hard to tell whether the building in the centre of the picture is partly within the same property as the road.

Figure 7 shows a neighbourhood in central Oslo. Buffer zones are constructed as in Figure 6. The registered boundaries here will hardly suffice to solve any boundary dispute. We also notice that some of the more accurate boundaries differ a lot from the fences and other natural boundaries visible in the aerial photo.

Figure 7: Situation from Oslo. Buffer showing accuracy of lines (3 times standard deviation on each side of the line), colours showing standard deviation of points (green: 8 cm, red: 100-150 cm).

Figure 8 shows an overview of the city of Oslo, with boundary points coloured by registered accuracy. Points in red are registered with accuracy of 50 cm or worse. We see that the less accurate points are mostly located in the central parts of the city.

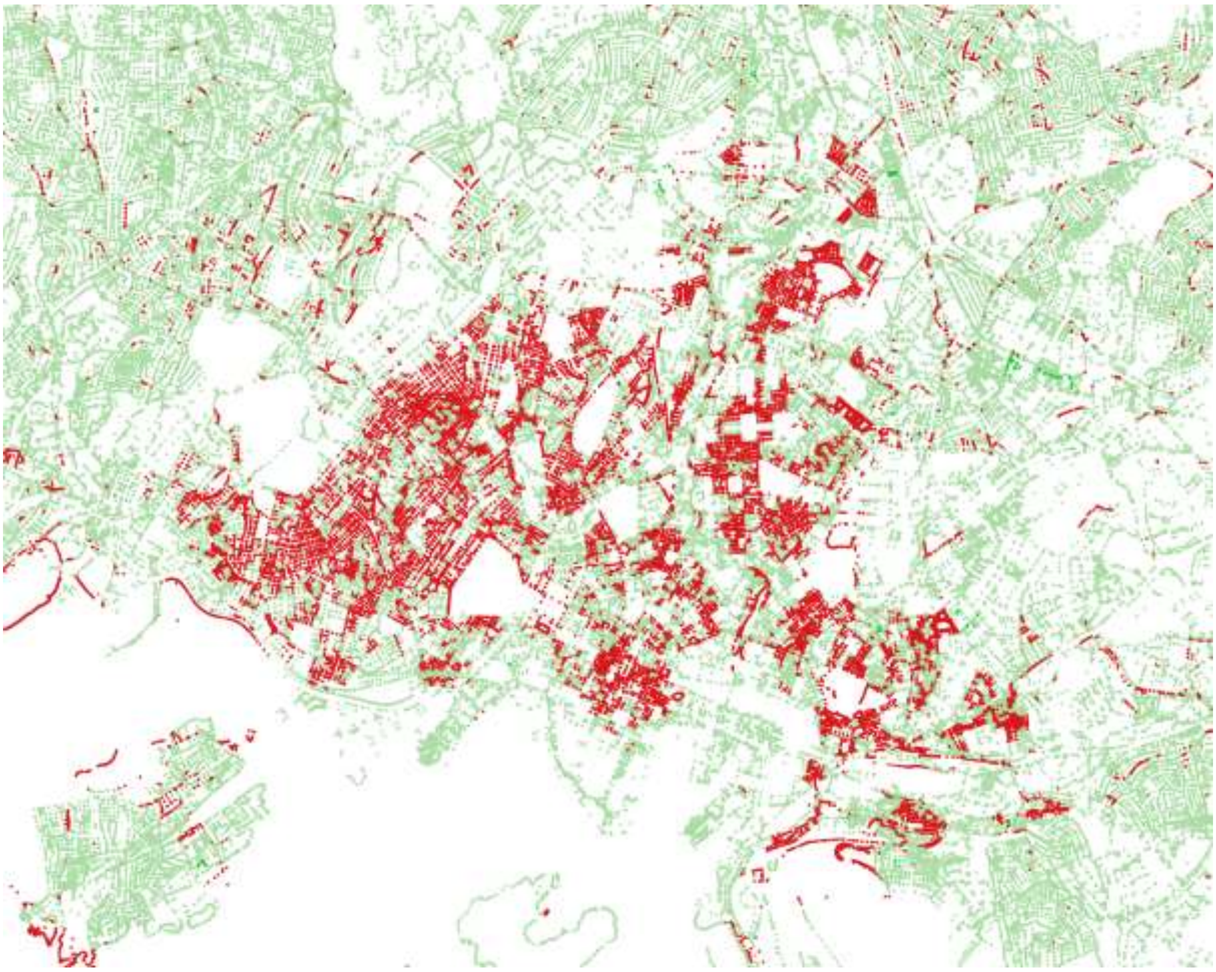

Figure 8: Boundary points in central Oslo, coloured by registered accuracy. Red points are less accurate, green points are more accurate.

Protection of landowners against errors is another aspect of the issue of coordinate accuracy that should be considered. As the registered accuracy is based on statistics, nothing can be 100% guaranteed. According to the statistics, one third of the coordinates will differ more than one standard deviation from the true value. Every twentieth boundary point will have coordinates more than two standard deviations away from the true value. The probability of the registered coordinates to be within three standard deviations from the correct position is 99.7%. This means that 0.03% of the boundary points are registered with a position that is more than 3 times the standard deviation away from the correct position. In the municipality of Bergen, with 460191 boundary points, the 0.03% amounts to 1381 points. In Norway, the landowner can complain about errors within a limited time period following the cadastral survey. After that, no one guarantees the accuracy of the cadastral map, and no cadastral surveyor can be held responsible for possible errors.

7. CONCLUSION

It is important for the reliability of the cadastre that the metadata describe the data correctly. The registered accuracy of boundary points in the Norwegian cadastre is inhomogeneous. First, the points themselves have varying accuracy. Second, even points that are measured in the same way and probably have the same accuracy are registered with significant differences in accuracy. Professionals today will probably be able to account for many of these differences, The data in the cadastre should be harmonized before the history behind the data is forgotten.

Some countries already have, and other countries are moving towards, a coordinate-based cadastre without necessarily having physical boundary marks in the field. It is hard to tell what level of accuracy of coordinates will be considered fit-for-purpose in the future. The uncertainty should probably not exceed the dimensions of a physical boundary mark. We should also learn from history that systems described as absolute when introduced, are often changed later on. One cannot rule out that our present regional reference systems will be replaced by other systems, perhaps global and dynamic ones, in the future.

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BIOGRAPHICAL NOTES

Helge Nysæter is assistant professor at Western Norway University of Applied Sciences since 2006, where he has been teaching land surveying, mathematics, cadastral systems and Geographical Information Systems. He graduated in mapping technology from the Agricultural University of Norway in 1994. He has also studied history and pedagogy at university level. Current research interests are cadastral surveying and cadastral mapping.

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