Towards Identifying the Course of a Route Mentioned in 1065

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According to a historical document dating back to 1065 AD, the medieval road known as *strata Coloniensis* connected the monastery of Essen-Werden with Cologne in Germany. Several alternative hypotheses concerning the course of this route were published, they only agree on a fairly small section south of Essen-Werden. The aim of the paper is to identify the most probable course of the medieval road between Essen-Werden and the river Düssel. In their arguments, the supporters of two hypotheses refer to historical maps. After outlining the hypotheses, the paper discusses these historical maps and additional earlier maps, several of them are available in online repositories. For each of the early maps considered, the roads or paths depicted were digitized, mostly on the basis of place names and water courses that could be found both on the old and a more recent map. The results allow assessing the accuracy of the maps and investigating the continuity of the roads. Visualization of high resolution elevation data and aerial images were applied to identify old road sections in some areas. However, these approaches are limited by substantial modern landscape modifications and a large proportion of built-up areas. Due to major changes of the relief, reliable least-cost path calculations to reconstruct the old route should not be based on modern digital elevation data. But it is still possible to estimate the effort of using an old road section by cost computations based on modern topographic data. A comparison of the different route alternatives is presented using these estimations.

Key words:
Geographical information systems, web map services, historical maps, online repositories.

CHNT Reference:
Irmela Herzog and Lothar Weller. 2018. Towards Identifying the Course of a Route Mentioned in 1065.

INTRODUCTION

According to a historical document dating back to 1065 AD, the medieval road known as *strata Coloniensis* connected the monastery of Essen-Werden with Cologne in Germany [Lacomblet 1840, p. 155, No. 205]. According to the text of the document, the rivers Rhine and Ruhr together with this road delimited a triangle. Two of the vertices of this triangle are defined in the document: (1) the location where the Ruhr joins the Rhine and (2) the Ruhr bridge in Essen-Werden. The third vertex is the place where the road traversed the water course known as Düssel (Fig. 1). The main aim of this paper is to investigate the plausibility of several alternative hypotheses concerning the course of this route between Essen-Werden and the Düssel by applying GIS methodology.

Essen-Werden, the starting point of the *strata Coloniensis*, is situated near a crossing of the Ruhr River used by important trade routes in early medieval times [Nicke 2001, pp. 186-187]. Saint Ludger chose this location for founding an abbey of the Order of Saint Benedict in the 8th century. This was to become an influential monastic community with large properties including Velbert, a settlement first mentioned in 875, located close to an old road connecting the rivers Wupper and Ruhr [Berger 1999, p. 282]. Other settlements in the study area that were founded before 1065 are Ratingen (mentioned in about 800 AD [Berger 1999, p. 233]), Gerresheim (a church dating back in the 9th century is very likely for this settlement [Wesoly 1994]), Hilden (developed from a single farmstead probably already in Merovingian times [Berger 1999, p. 145]), Homberg (9th century [Berger 1999, p. 150]), Himmelgeist (first mentioned in 904 AD [Dittmaier 1956, p. 152]), Hubbelrath (church in the 10th century [Dittmaier 1956, p. 226]), and Mettmann (near a Carolingian royal court [Berger 1999, p. 198]). Gruiten (first mentioned in about 1050 [Dittmaier 1956, p. 152]), and Wülfrath (first mentioned in the 11th century [Berger 1999, p. 300]) were probably also in existence in 1065. The settlement of Erkrath is most likely somewhat younger [Berger

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1999, p. 101]. Historians mention a close connection of Heiligenhaus with another old road known as Hilinciweg first mentioned in 875 [Dittmaier 1956, p. 91; Wesoly 1994]. A large proportion of the Heiligenhaus area belonged to the abbey Essen-Werden. The chapel erected in the 15th century was the nucleus for the settlement Heiligenhaus [Wesoly 1994]. Fig. 1 shows the churches in the study area that are listed in the Liber Valoris [Oediger 1967], a tax list of churches and monasteries set up in 1308. The settlements with churches depicted on the maps by Ploennies [1715] include the Liber Valoris churches, but also show some additions. The settlements on the map in Fig. 1 that have not been mentioned above are mostly not within the possible corridor of the *strata Coloniensis*. Some of these were also already established before 1065: the monastery of Kaiserswerth founded in 692 also held an influential position at that time [Dittmaier 1956, p. 139], Mintard (first mentioned in 874 [Dittmaier 1956, p. 139]), Sonnborn (first mentioned in 874 [Dittmaier 1956, p. 178]), Haan (first mentioned between 925 and 953 [Dittmaier 1956, p. 86]), Solingen (first mentioned in 965 [Dittmaier 1956, p. 200]), Wald (first mentioned in 1019 [Dittmaier 1956, p. 130]), Lintorf (first mentioned in 1050 [Dittmaier 1956, p. 22]), and Neviges (first mentioned in about 1050 [Dittmaier 1956, p. 154]).

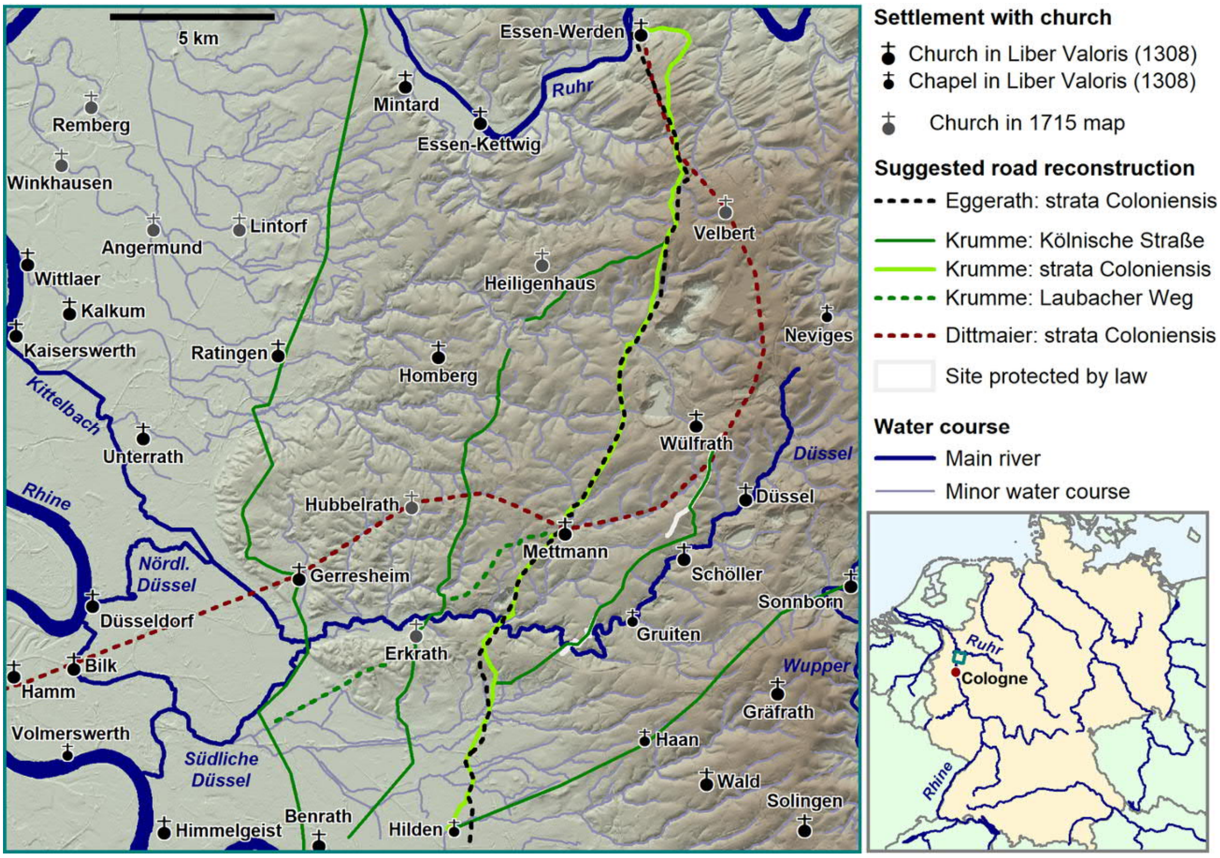

Fig. 1. The location of the study area in Germany (small map on the right). Large map: Several suggestions for the course of the strata Coloniensis and alternative old roads in the study area. Background: Modern elevation data, supplied by Geobasis NRW (© Irmela Herzog and Geobasis NRW)

After outlining the hypotheses concerning the course of the *strata Coloniensis*, the paper discusses several historical maps covering the study area or a part thereof, because most authors proposing courses of the *strata Coloniensis* rely on historical maps. This research greatly benefits from the fact that many historical maps are stored in open access web repositories. For instance, the earliest relevant map found dates back to 1598 but shows only a small part of the study area. Moreover, in North-Rhine Westphalia, the ordnance survey Geobasis NRW provides several web map services (WMS) that are useful for archaeological research: these include not only services based on historical maps created in the 19th century or later but also visualizations of Lidar data and orthophotos. The potential and limits of the historical maps and the WMS layers will be investigated in view of the aim of identifying the course of the road from Essen-Werden to the Düssel that was in use in 1065 AD.

Often, archaeologists apply least-cost path calculations for reconstructing ancient routes [e.g. Herzog and Schröer 2019; Herzog 2013]. Most of these approaches use a cost model that includes a slope-dependent component. The study area is quite hilly south of Essen-Werden, but major modern modifications changed the relief since the Middle Ages (Fig. 1). These are clearly revealed in a DEM with a resolution of 25 m provided by Geobasis NRW. The relief changes include motorways (e.g. west of Neviges), and large areas of bulk material extraction, for instance west of Wülfrath. Another deep pit is visible close to the Düssel south of Mettmann. Close to this pit, the Neanderthal skeleton was found in 1856 in the course of limestone quarrying [Goebel 1984]. Starting in 1849, large-scale limestone quarries destroyed the scenic topography of the Düssel valley in this area with caves and steep slopes (known as Neandertal, i.e. the valley of Neander), that had previously attracted travelers from quite a distance [Ploennies 1715, p. 88; Goebel 1984]. Lime production by farmers is already mentioned in the description of the Ratingen area by Ploennies [1715, p. 94]. In the Solingen area, he records precursors of the metal working industry [Ploennies 1715, p. 88] and in the Schöller area, black marble was quarried [Ploennies 1715, p. 90]. In 1838, a railway connection between Düsseldorf and Erkrath was opened, which was extended towards Sonnborn in the years to follow [Goebel 1984]. Therefore the modern DEM is not an appropriate basis for reconstructing the medieval route from Essen-Werden to Cologne. Nevertheless, the final section of this paper will present an approach for estimating the effort of using an old road section by cost computations based on modern topographic data.

HYPOTHESES CONCERNING THE COURSE OF THE STRATA COLONIENSIS

Several alternative hypotheses concerning the course of the route have been published, they only agree on a fairly small section south of Essen-Werden (Fig. 1). Dittmaier [1956, pp. 219-220, 311] based his reconstruction of the road on old place names. In his view, the *strata Coloniensis* connected Werden to Velbert, proceeded south of Wülfrath, afterwards traversing Mettmann, Hubbelrath, and Gerresheim before reaching the River Rhine south of Düsseldorf. This hypothesis is supported by Gechter [2000]. As Dittmaier mentions only the main settlements along this route, this could only be mapped digitally with low precision. Digitizing the routes suggested by Krumme [1961] and Eggerath [1992/93] was easier and more precise because they mention modern road names and farmsteads on historical maps in their descriptions of the route. Krumme points out that several old routes were known as "road to Cologne" (in German: Kölnische Straße), which is the translation of *strata Coloniensis*. In his publication he lists five old roads to Cologne, and numbers them from west to east. In his view, number 3 is the most probable *strata Coloniensis*. According to Krumme, the Kölnische Straße 2 coincides with the Hilinciweg referred to above in connection with Heiligenhaus. This road was mentioned nearly 200 years earlier than the *strata Coloniensis*. Again two authors suggest different routes for the Hilinciweg, but it seems that all authors agree roughly on the section between Velbert and the point where the river Anger is traversed, i. e. the northern part of Kölnische Straße 2 depicted in Fig. 1 [Dittmaier 1956, pp. 91, 220, 311; Wesoly 1994]. Krumme's research is based on 1:25,000 maps available in 1961, he tries to identify roads that proceed in roughly the same direction for a long distance. There is a gap in the Kölnische Straße 2 depicted in Fig. 1 because a limestone quarry interrupted the course on Krumme's map. Another publication by Krumme [1964] describes the old road Laubacher Weg which connects Mettmann with Erkrath. This alternative route from Mettmann to the Düssel, combined with the northern part of Krumme's *strata Coloniensis* is considered here as another possible course of the old route.

Krumme criticizes Dittmaier's hypothesis regarding the *strata Coloniensis* due to its not very direct course and the location of the Düssel crossing point. In his view, the route suggested by Dittmaier consists of several old road sections belonging to different long-distance trade routes. Eggerath's research is mainly based on old maps [Eggerath 1992/93] and her results coincide well with those of Krumme. The sites protected by law suggest another route, that is partly close to Krumme's Kölnische Straße 4. One of these sites was published in the web information system on cultural heritage KuLaDig [LVR-Amt für Bodendenkmalpflege im Rheinland 2017]. The documents describing the sites mainly refer to maps created in the 19th century, whereas Eggerath's argument relies on the maps by Ploennies [1715] and earlier maps covering a smaller area, supplemented by some historical data.

ROADS ON OLD MAPS

As mentioned above, the ordnance survey Geobasis NRW provides several WMS showing georeferenced historical maps. Moreover Open streetmap data was used for comparison. Fig. 2 illustrates that recent map data often does not allow to identify single farmsteads mentioned in historical sources. When comparing the three WMS layers created based on 19th century maps, the accuracy is best with the most recent layer and decreases when going back in time. It seems that the earliest maps are not adequately georeferenced but a systematic shift in western direction was introduced. Gaps and areas not covered are an issue with the earliest map sheets. Moreover, in the earliest WMS layer, one map sheet in the northwest of the study area was replaced by a sheet created about 20 years later. Often, the place names are hardly readable from the two earlier WMS layers, the black and white WMS layer providing maps from the final decade of the 19th century show place names more clearly, but also substantial landscape change due to bulk material extraction and other human impact.

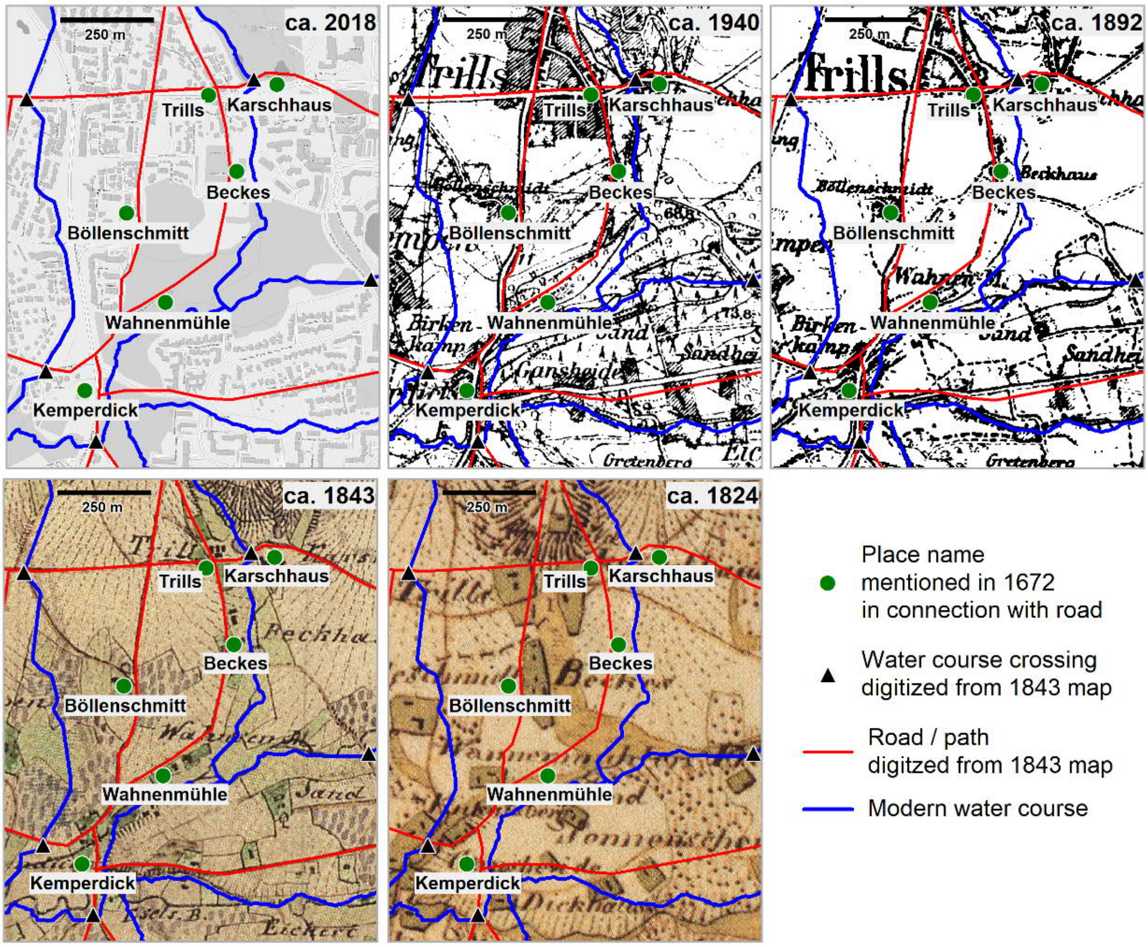

Fig. 2. Accuracy and other issues of WMS layers providing georeferenced historical maps. The place names mentioned by Eggerath [1992/93] were digitized from the 1892 map known as Preußische Neuaufnahme. WMS layers provided by Open streetmap and Geobasis NRW

The map set created by Erich Philipp Ploennies in the early 18th century [Ploennies 1715] covers a large part of the study area (Fig. 3). Very small settlements consisting of one farmstead only are depicted on these maps, but only the main roads are indicated so that many settlements appear disconnected. The distortion of this map set allows no straight-forward georeferencing, instead the roads were transferred approximately to modern maps taking all place names into account that could be found both in the 1715 maps and in later georeferenced WMS layers (see above). Typically, errors of 200 m or more cannot be avoided in this process. The results show that the courses of the *strata Coloniensis* suggested by Eggerath and Krumme agree well with a Ploennies road (Fig. 3 left). But also the sites protected by law are close to a Ploennies road. For the rest of this paper, the term site road is used for the Ploennies road connecting the protected sites. The course described by Dittmaier and Gechter is not quite as near to Ploennies roads as the routes suggested by the other authors. The older Hilinciweg is no longer depicted by Ploennies, this fact illustrates issues with continuity. Moreover, the majority of the road sections of the Cologne routes proposed by Krumme and the Laubacher Weg are not shown on the Ploennies maps.

The von Müffling maps created in about 1824 show many roads and paths. Initially, the aim was to digitize only the main roads, but it soon became evident that deciding on the relevance of a brown line drawn on the map is quite difficult. The authors of the map sheets vary and so does the style. This is one of the reasons why the density of the yellow road network in Fig. 3 (right) varies. Moreover the impact of the two issues mentioned above are clearly visible, i.e. the replaced map sheet and the systematic error. Nearly all sections of the suggested old roads coincide with a road or path depicted on a von Müffling map.

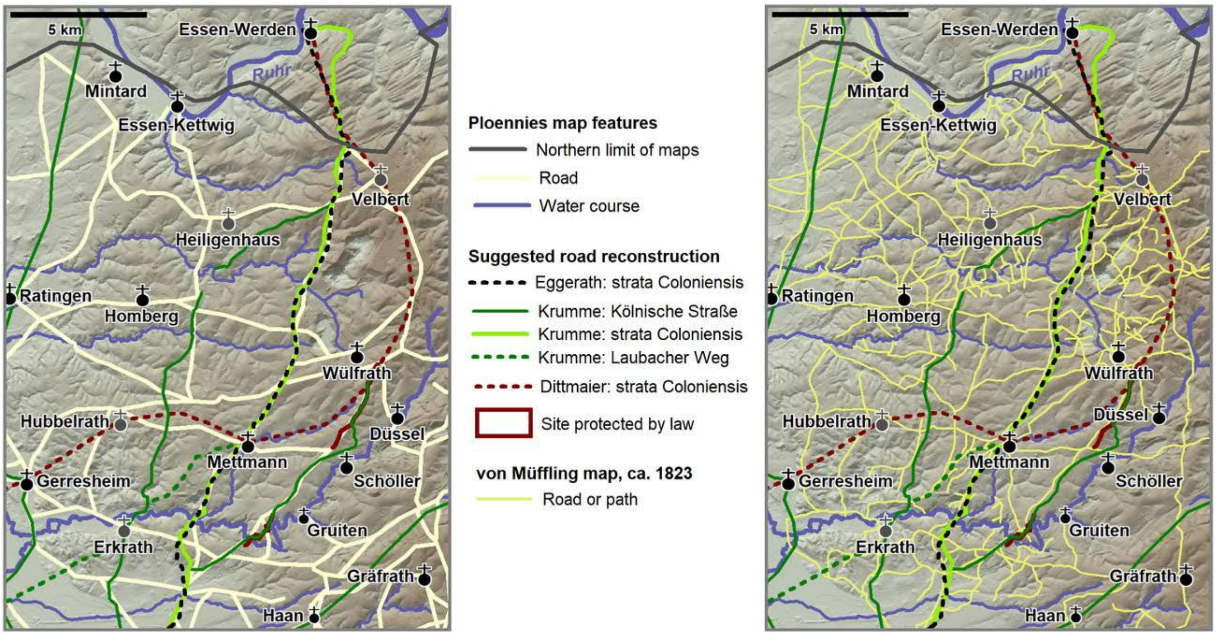

Fig. 3. Comparison of the suggested old roads with (a) Ploennies roads (left) and (b) roads or paths digitized from the WMS layer showing the earliest georeferenced maps (ca. 1824) in the study area (right). DEM data provided by Geobasis NRW

So neither the Ploennies map set nor the von Müffling maps provide a decision on the correct course of the *strata Coloniensis*. Therefore a search for earlier historical maps covering the study area and depicting roads was started. The earliest map meeting these requirements that came to our knowledge was created by Johann Michael Gigas (approximately 1582-1637?) in 1620 (Fig. 4). However, this map does not show any roads starting at Essen-Werden. Moreover, some errors are evident: Homberg is depicted west of the road connecting Essen-Kettwig with Ratingen, though this town is located east of Ratingen (cf. Fig. 1). Gruiten is shown south of the Düssel River, but in fact is located north of this water course.

The image data base of Amsterdam University presents a relevant map published in an atlas attributed to Henricus Hondius (1597–1651), which dates between 1636 and ca. 1680 [Hondius 1636]. This map is probably based on earlier maps by Gerardus Mercator, because Jodocus Hondius, father of Henricus, bought Mercator’s plates after the death of the famous German cartographer [Garfield 2014, p. 150]. A slightly modified copy of this map is available in an online repository of the Bern and Basel Universities [Valck and Schenk ca. 1670/1690]. According to the metadata for this map, Gerard Valck (1651–1726) and Pieter Schenk (1660–1711) are the authors/contributors.

This map shows a road connecting Werden with Hilden via Mettmann. So this map seems to support the hypothesis of Eggerath and Krumme. However, even on the historical map this road is not as direct as the other roads depicted. There is a detour near the town of Haan which is even more striking when drawing the road on a modern map background taking the locations of places into account that could be identified both on the historical and a more recent map (Fig. 5). 70 corresponding place names were found, allowing to assess the map distortion.

Fig. 4. Section of a map by Gigas [1620] showing the study area and some roads

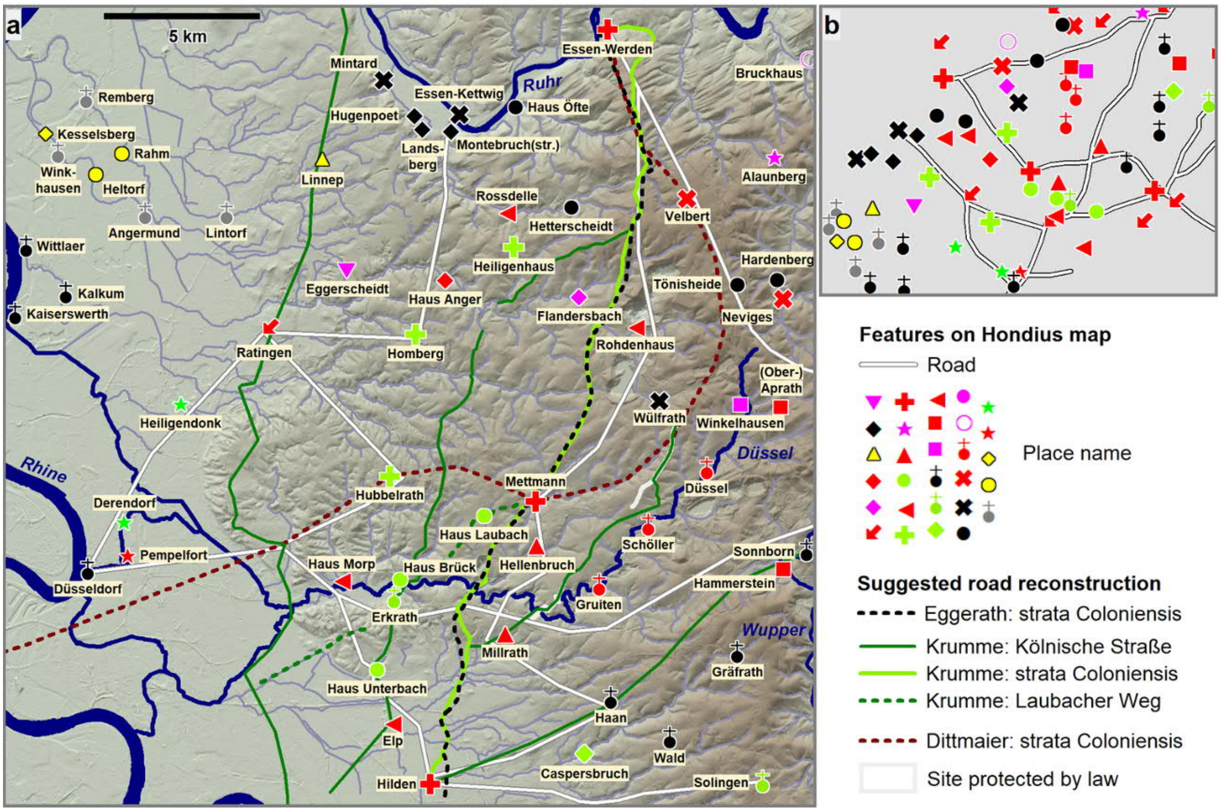

Fig. 5. Result of identifying places on the Hondius map and a more recent georeferenced map. On this basis, the roads shown on the Hondius map (b) were digitized on a modern map background (a). Comparison of the symbol pattern on the Hondius map and the modern map shows distortions and gross errors

The Hondius map shows roughly the same road between Essen-Kettwig and Ratingen as Gigas, the error concerning the location of Homberg is also visible in the Hondius map. So these more general early maps are not reliable. Therefore more detailed early maps covering a small part of the study area were considered with a focus on maps showing Düssel crossings. About 3 km west of Erkrath, the Düssel is split in several water courses; this probably has not changed since 1065, although some modifications of the rivers and creeks can be seen when comparing modern and historical maps. A plausible assumption is that the *strata Coloniensis* crossed the River Düssel before the split point because only the river name is mentioned in the document without any additional specifications. Between the split point and Gruiten more than twenty bridges or fords could be digitized from the 1843 maps (Fig. 6).

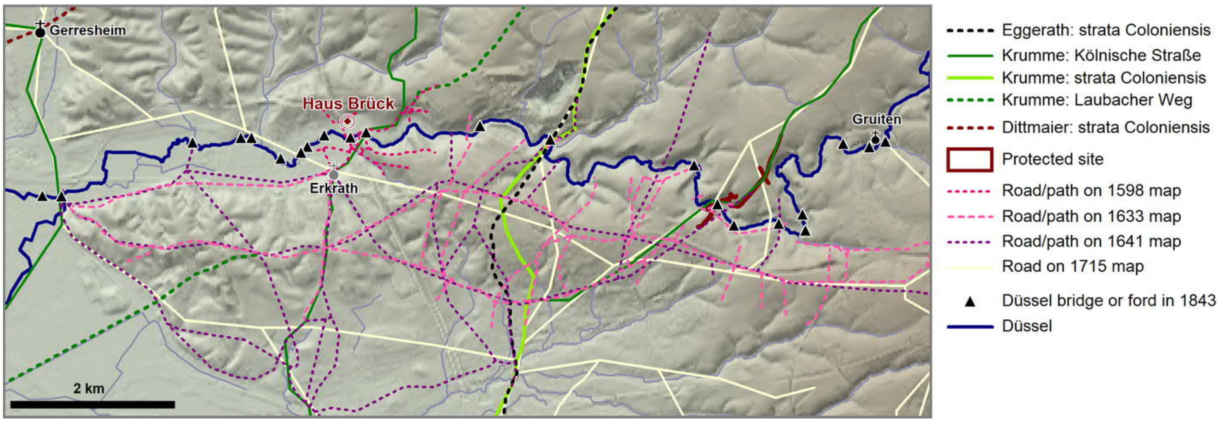

Fig. 6. Düssel crossings depicted on historical maps and suggested by authors discussing old roads to Cologne. DEM data provided by Geobasis NRW

The earliest map showing a Düssel crossing found shows the property of Haus Brück north of Erkrath [Mercator 1598]. This map was created in the course of legal proceedings. According to Osmann [2016], the fortified house Haus Brück is closely related to a stone bridge and was first mentioned in 1258. An earlier date for the first mention is given by Dittmaier [1956, p. 90], i.e. 1148. Berger [1999, p. 73] mentions that German place names ending with brück usually indicate locations where water courses could be traversed with the help of a bridge and that these places are often found close to old trade routes. However, the bridge depicted on the Mercator map leading to Haus Brück seems to be of local importance only. The roads and paths on this map were transferred to a modern map background as described above (Fig. 6). The Laubacher Weg and the Kölnische Straße 2 use a bridge near Haus Brück, and the 1598 map shows paths running in the direction of the Laubacher Weg. A small bridge east of Haus Brück might belong to this long distance route, but most path sections roughly coinciding with the Laubacher Weg appear like minor local paths on the old map.

Another old map recently found in a federal archive covers the relevant part of the Düssel River [Landesarchiv NRW Abteilung Rheinland 1633]. The map was created in 1633 in the course of legal proceedings concerning hunting rights. In view of this purpose, geographic features important for delimiting the hunting territory are shown, whereas other features are missing or drawn sketchily. For instance, east of the town Gruiten, the River Kleine Düssel (small Düssel) joins the Düssel River, but only a very small part of the Kleine Düssel is depicted on the map. Moreover, no bridge close to Haus Brück is mapped. On the map, a bridge crossing both the Mettmanner Bach and the Düssel River close to the point where these two streams join appears disconnected from the road network. This bridge is near the Düssel traversing location of the *strata Coloniensis* routes suggested by Krumme and Eggerath. Another Düssel bridge depicted is within or very close to one of the protected site areas. But the road traversing this bridge does not proceed in southern direction but seems only of local importance. The only road traversing the Düssel with a continuation in southern direction on the map is shown west of the steep cliffs of the Neandertal. After about 700 m, this road joins another road proceeding in southwestern and later in western direction. No section of these roads coincides with roads shown on Ploennies maps. In general, the agreement between the Ploennies map roads and those depicted on the 1633 map is fairly low (Fig. 6). Additional Düssel bridges depicted on the 1633 map can be found (i) near Winkelsmühle only about 250 m west of the protected site area, (ii) near Bracken, about 800 m east of the protected site area, and (iii) close to Eigen, about 400 m north of Winkelsmühle.

Another local map showing Düssel crossings originated from 1641, a copy drawn in 1811 was scanned and the roads shown transferred to a modern map background [Kaehsman 1641]. The map depicts three paths that traverse the River Düssel: one of the Düssel crossing locations agrees quite well with a protected site, another one is located close to the place where the *strata Coloniensis* routes suggested by Krumme and Eggerath traverse the Düssel. But south of this crossing location the distance between the roads transferred from the 1641 map and the course suggested by Krumme and Eggerath exceeds 500 m. It is unlikely that this large difference was caused by an error in the transferring process. The roads running in west-east direction on the 1633 and the 1641/1811 map coincide quite well. But the differences with respect to the Düssel River crossing locations are substantial. This might be due to updates introduced by the person copying the 1641 map in 1811.

Nearly all roads and paths depicted on the 1598, 1633 and 1641 maps are also visible on the map created in about 1843, suggesting that a large majority of paths and roads established in the past remained in use, though the importance of some of them decreased. But the Ploennies roads do not agree as well with the roads and paths on the earlier maps as expected. Therefore it is very difficult to assess the continuity of the routes used in medieval times.

ARCHAEOLOGICAL EVIDENCE

Most of the old road sections protected by law are in use today. An exception is the area depicted in Fig. 7. The Geobasis WMS combining orthophotos taken in the time interval between 1988 and 1994 shows crop marks indicating the course of the road that is depicted on historical maps created in the 19th century. In 2006, an excavation consisting of four trial trenches with a length of up to 54 m recorded remains of a sunken road (Fig. 7). Only modern artifacts were recorded during this excavation, the trial trenches did not provide any evidence for the *strata Coloniensis*.

This example illustrates the fact that dating of the routes detected in aerial images often is an issue. Moreover, there are some minor differences between the two 19th century maps, which may be attributed to small changes of the route layout or to inaccuracies of the older map. The way the road is drawn on both maps suggests that this part was a sunken road at that time, maybe the course of a deeply incised sunken road bordered by fields cannot be changed easily? The number of presumed sunken road depictions on the 19th century maps is quite large. However, most of these features are no longer visible in modern Lidar data due to industrial development and new settlement areas. In the study region, even the Lidar visualizations of areas used by agriculture often show the impact of past human activities. If sunken roads can be detected at all in modern Lidar data, these are mostly still in use and their slopes are often maintained so that they appear more regular than in their initial state.

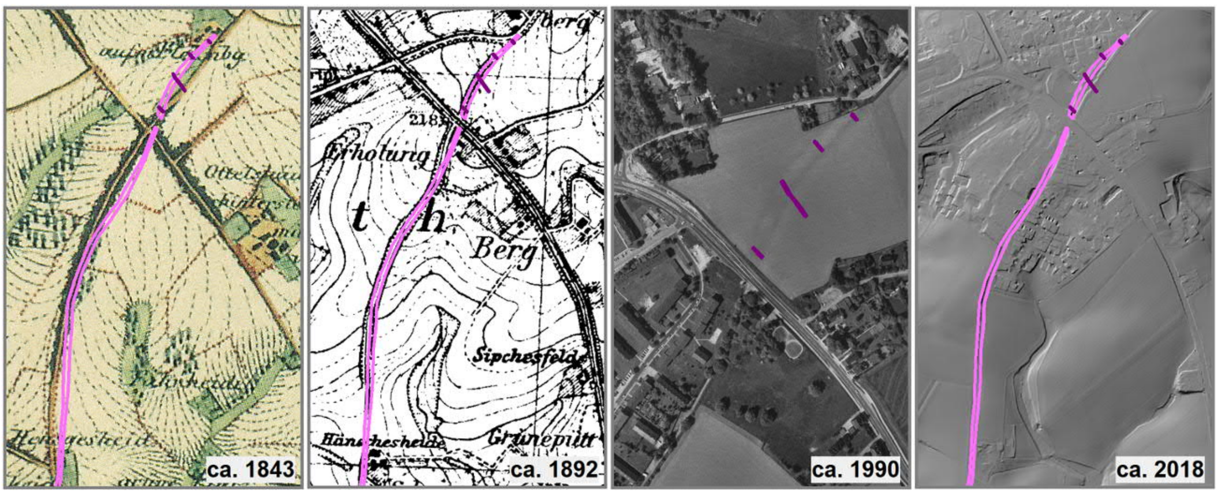

Fig. 7. Location of part of the protected site and some trial trenches carried out in 2006. The length of the longest trench is 54 m. WMS layers provided by Geobasis NRW.

The trial trenches covering a section of the Hilinciweg did not produce any finds, only a ditch was documented that could be related to an old road. The sites and monuments data base of the Rhineland Commission for Archaeological Monuments and Sites in Bonn records many other archaeological investigations in the study area close to the courses of the roads considered. Most of these resulted in early prehistoric finds (highlight: Neanderthal skeleton) or documented remains of early industrial activities. Some report forms of archaeological investigations mention medieval structures or finds in the vicinity of the road courses discussed in this paper, but only the general term Middle Ages is used. So the archaeological evidence does not clearly support any of the hypotheses concerning the course of the *strata Coloniensis*.

COMPARISON OF THE DIFFERENT ROUTE SUGGESTIONS

The suggested routes agree approximately for the first part until a location about 1.5 km northwest of Velbert is reached. Only the part immediately after leaving Essen-Werden differs somewhat: the map created in 1843 shows a detour avoiding the steep slopes south of the settlement. But the townscape drawn in 1572 shows sunken roads coming down the hills [Nicke 2001, pp. 186-187]. Moreover, a map of the Werden area created in the first half of the 17th century shows a direct road towards the south [Wesoly 1994, Plate 4]. Therefore the more direct route seems more plausible.

The comparison of the different route suggestions presented in the next paragraphs focuses on the section between the point about 1.5 km northwest of Velbert mentioned above and the Düssel crossing. The comparison includes five routes: (1) the route suggested by Eggerath, (2) the route suggested by Eggerath from Essen-Werden to Mettmann, afterwards using the Laubacher Weg until Haus Brück, (3) the site road, (4) Kölnische Straße 2 as described by Krumme, and (5) the route suggested by Dittmaier and supported by Gechter.

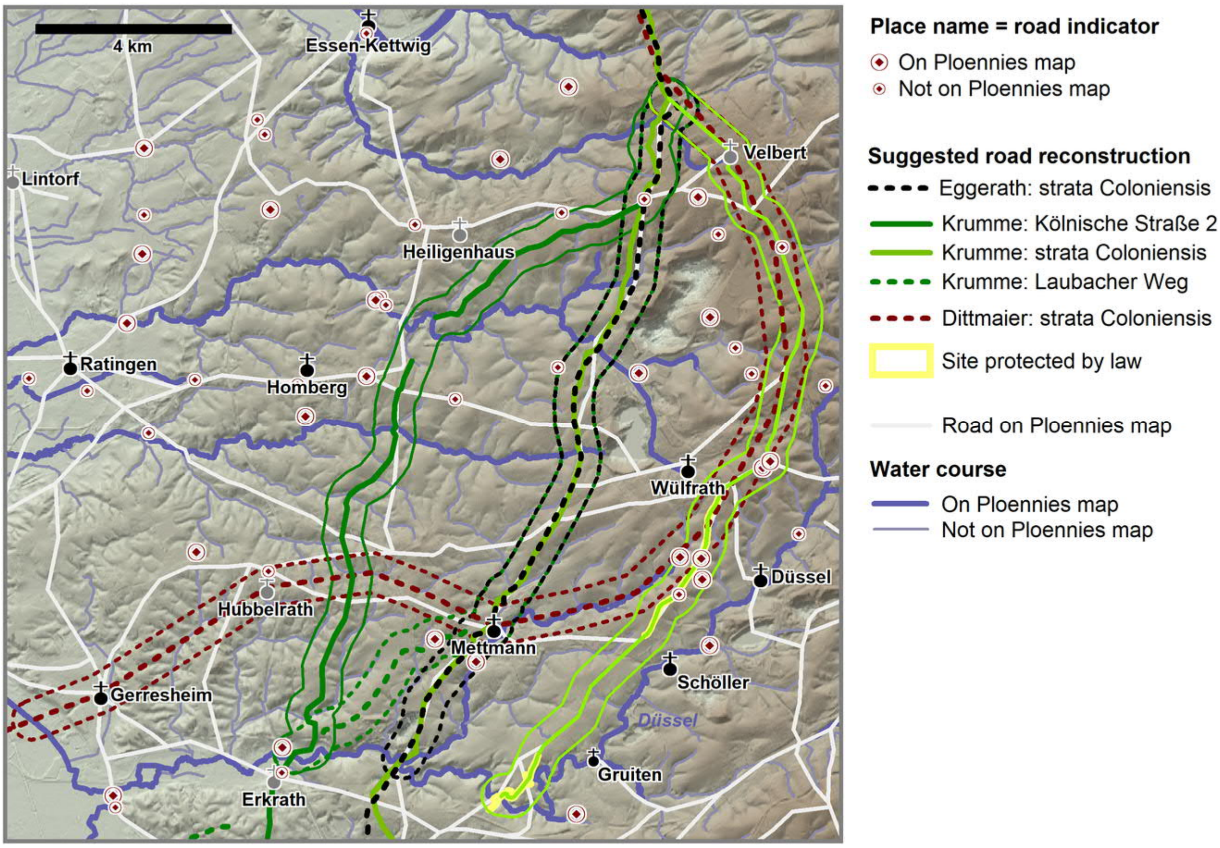

Fig. 8. Map showing 400 m buffers for the sections of the suggested road reconstructions to be compared and place names indicating roads found on historical maps

The first criterion used for comparison is the number of place names indicating the presence of a road in the vicinity of a suggested route. The location of 85 place names referring to bridges (such as Haus Brück mentioned above), fords, roads, and check points at boundaries were digitized from the WMS layers providing georeferenced historical maps (Fig. 8). Out of these place names, 40 were already recorded on the Ploennies maps, and these are considered more significant than the rest. For each of the five routes to be compared a 400 m buffer was constructed and the number of road indicating place names counted. The largest number of such road indicators was found for the site road (Tab. 1).

Additional criteria are derived from the research aiming to reconstruct old roads by least-cost path calculations in the hilly region south of the study area. It was found that both crossing of water courses and slope have an impact on route selection [Herzog 2013]. The old routes were created by a tradeoff between (1) length of the path, (2) number and difficulty of traversing water courses, and (3) avoiding steep slopes. The *strata Coloniensis* course suggested by Eggerath seems to be the shortest option of the routes considered, not only for the section to the Düssel crossing, but also when taking the straight-line distance from the Düssel crossing to the cathedral in Cologne (i.e. the final destination of the road) into account (Tab. 1). Another criterion for the road layout is the number of water courses traversed. The water courses depicted on the maps by Ploennies are considered more relevant than the rest, so these are counted separately. The lowest number of water course crossings was found for the site road (Tab. 1).

The total elevation difference indicates the presence of relevant gradients. Due to the human impact on the landscape mentioned in the Introduction, reliable calculations of the total elevation difference of the hypothetical old routes should not be based on modern digital elevation data. The first topographic map set covering the study area with contour lines was created towards the end of the 19th century (Fig. 2 – ca. 1892). But the relief at that time already differed significantly from the medieval relief. Therefore the time-consuming task of digitizing the contour lines from the late 19th century maps seemed not worth-while. Besides, tests in areas with only minor changes in the topography showed that these contour lines are of limited accuracy [Lechterbeck 2008].

Table 1. Comparison of the different route suggestions

Feature	Eggerath	Eggerath + Laubacher Weg	Site road	Köln. Str. 2	Dittmaier
Number of 1715 road indicators within 400 m band	1	2	5	1	3
Total number of road indicators within 400 m band	2	3	6	2	5
Length → length of 1936-45 route	15.7 → 15.9 km	17.5 → 17.8 km	18.0 → 18.3 km	18.0 → 18.2 km	25.5 → 27.0 km
Straight-line distance from Düssel crossing to the Cologne cathedral	31.7 km	31.8 km	31.0 km	31.8 km	33.3 km
Number of Ploennies water course crossings	3	3	0	3	0
Total number of water course crossings	5	6	0	7	6
Total elevation difference	715 m	764 m	554 m	926 m	1037 m
Tobler's time estimations [Tobler 1993] for walking in both directions	197 min; 205 min	219 min; 228 min	222 min; 229 min	230 min; 240 min	336 min; 345 min
Düssel crossing efficiency of modern road/path	0.75	0.86	0.57	0.86	
Median road slope of Düssel crossing	6.5 %	3.1 %	8.9 %	3.1 %	
Median DEM slope of Düssel crossing	28.2 %	4.4 %	20.0 %	4.4 %	

The approach for calculating the elevation difference should take into account that the precision of the digitized routes is fairly low for some route sections as mentioned above. Therefore, for each of the route candidates considered, a nearby route using the closest road or path shown on the map set created in the years 1936 to 1945 (scale 1:25,000) was digitized, thus ensuring that steep natural or man-made steep slopes such as gravel pits close to the past road are avoided. In general, the 1936 to 1945 route is longer than the approximate route, both lengths are given in Tab. 1, separated by an arrow. For each 1936 to 1945 route, the total elevation difference is calculated on the basis of the modern digital elevation model (DEM) with a resolution of 25 m. The lowest total elevation difference resulted for the site road (Tab. 1).

The distribution of slopes derived from the 1936 to 1945 route elevations are illustrated in the left part of Fig. 10. The boxplots show that the slopes of the site road are significantly lower than those of the other route alternatives. The gradients of the Dittmaier road are in general lower than those of the Eggerath route options, and the slopes of the Kölnische Straße 2 mostly exceed those of the other routes considered.

Estimating the time required for travelling a road based on a slope-dependent function combines the two criteria “length of the road” and “avoiding steep slopes”. For the two directions of each 1936 to 1945 road the well-known Tobler hiking function [Tobler 1993] was applied in order to calculate the time needed in minutes. The Tobler function was chosen because it was successfully applied in several least-cost studies and does not have some of the disadvantages of other functions used for estimating walking time. This function models a fast walker, with a speed of 6 km/h when descending a gradient of 5 %. Walking velocity depends not only on slope, but also on the age, health, and load of the walker, gender, vegetation, weather conditions, size of the group and some other factors. The time estimations given by the Tobler hiking function can be regarded as the lower limit. The route suggested by Eggerath results in the lowest travelling time estimations (Tab. 1). Deviating from the Eggerath route by walking the Laubacher Weg to Haus Brück takes 10 % longer according to the Tobler estimations. The time penalties for taking the site road is only slightly higher and the trade-off with the number of water course crossings might have led to a decision in favor of this route. The route suggested by Dittmaier is much more time-consuming than the other alternatives; therefore this course of the *strata Coloniensis* is highly unlikely.

However, it is not known if the decision for a route was based on walking time or if other means of transportation were more important for route selection. Unfortunately, functions estimating travelling time depending on slope for carts or wagons, pack animals or for riding on horseback are not readily available. But it is well-known that the critical slope for humans is higher than that for wheeled vehicles: whereas well-trained walkers ascend gradients of up to 45 % directly, most vehicle roads avoid slopes beyond 12 or 15 %, hairpin turns are often found when steep slopes are to be negotiated by such roads. If transport by humans prevailed initially and wheeled transport became more important later on, the steeper routes may have been replaced by longer, but less cumbersome roads. Therefore the site road might be later than the other routes.

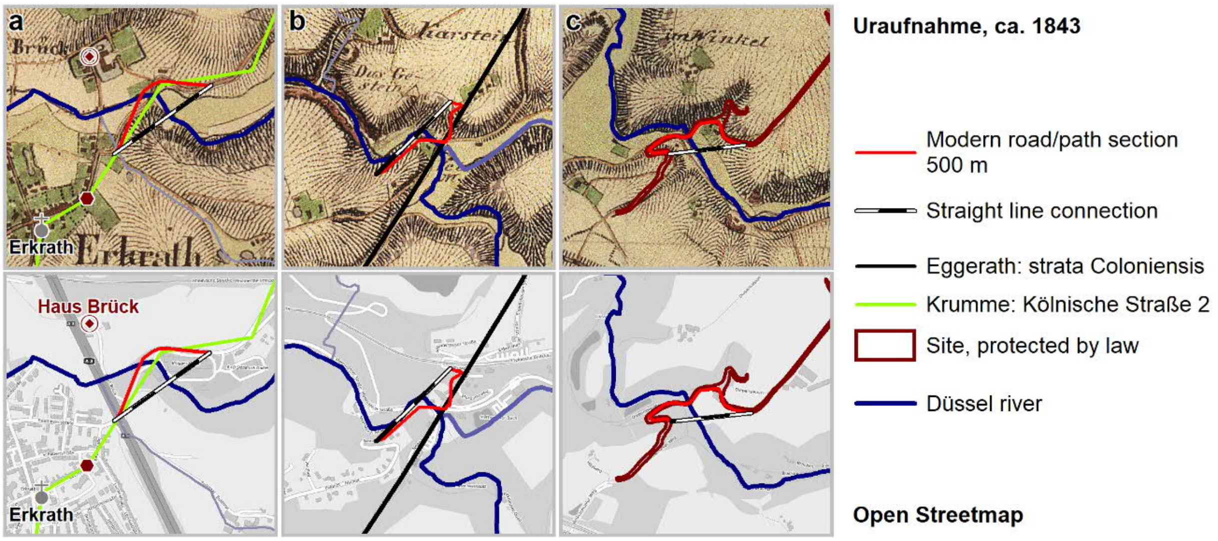

Fig. 9. Düssel traversing locations: a) Haus Brück, b) Neandertal, c) protected site

The difficulties of crossing the Düssel might have been decisive for selecting the route. Therefore the Düssel traversing locations close to Haus Brück (Kölnische Straße 2, Laubacher Weg), Neandertal (Eggerath and Krumme) and the site road are analyzed in more detail; the Düssel crossing of the Dittmaier course was not considered because its location is unclear and this route seems quite unlikely when considering the criteria presented above.

In the final three rows of Tab. 1, three key figures are presented that assess the difficulties of the Düssel crossings. Due to lack of reliable historical data, these figures are based on a modern DEM with a cell size of 25 m and modern roads, therefore underestimating the obstacles of traversing the Neandertal. For each Düssel crossing location, the modern road or path traversing the river was digitized for about 500 m, with the Düssel separating the road section in two parts of approximately equal length (Fig. 9). The efficiency is calculated by dividing the length of the straight line connection between the two end points of this road section by the road section length. The optimal efficiency is 1, i.e. no detour was necessary to traverse the river. The efficiency of the Düssel crossing close to Haus Brück is best (Tab. 1).

For each 500 m road section, the median slope was computed (Tab. 1). The boxplots with label "Road slope" in Fig. 10 illustrate the distribution of these slopes. The road slope close to Haus Brück is considerably lower than that of the other crossing locations considered. The slope of a road on a contour line is 0, but to the left and right of the contour line steep slopes may be found. This slope is derived from the DEM by GIS software and is in general steeper that the road slope.

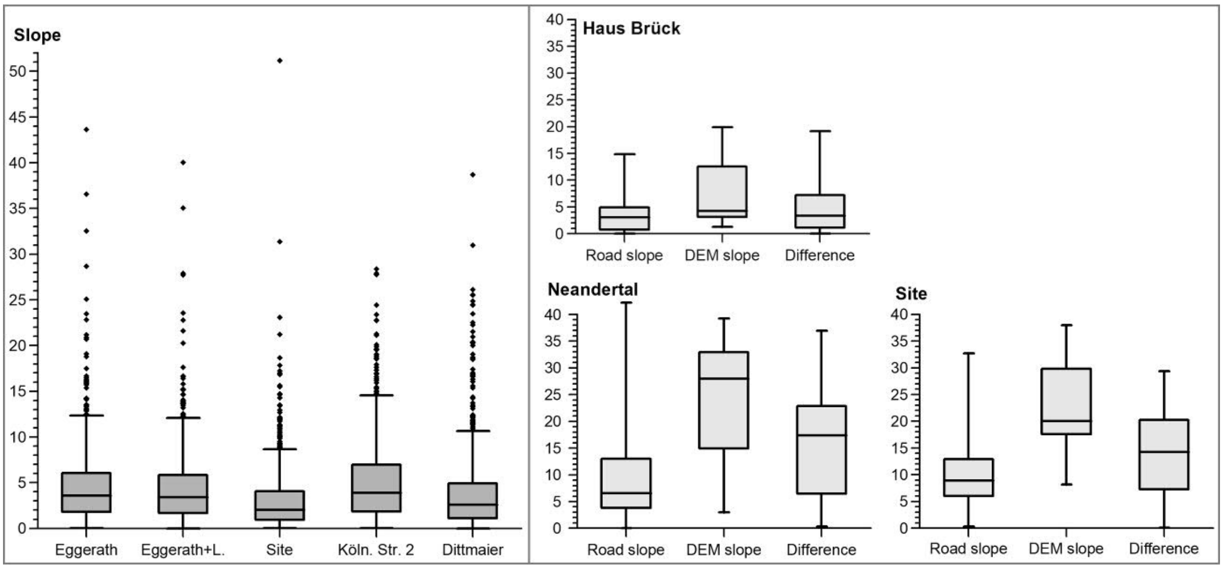

Fig. 10. Left: boxplots illustrating the distribution of slopes for the five alternative routes considered. Right: boxplots showing the slope distributions at the Düssel traversing locations

The median DEM slope of the Neandertal and the protected site Düssel crossings is a lot higher than that of Haus Brück (Tab. 1), this difference is also clearly visible in the corresponding boxplots (with label "DEM slope" in Fig. 10). The effort of road construction is considerable if the difference between road slope and DEM slope is high. For this reason, the difference between the two slope values was calculated as well (Fig. 10). The outcome of the computations outlined above clearly shows that the Düssel crossing near Haus Brück is easiest.

CONCLUSIONS

Although a lot of data was compiled and analyzed with the aim of deciding on the course of the route between Essen-Werden and the Düssel mentioned in a historical document in 1065, no final decision could be reached. Some archaeological evidence of old roads can be found close to every suggested course of the *strata Coloniensis,* but conclusive finds dating these road remains are still to be detected.

The WMS layers combining georeferenced sheets of 19th century maps show a large number of roads and paths that fit quite well to all hypotheses published concerning the course to the *strata Coloniensis*. The earliest more general maps that cover the study area and show some main roads were created more than 500 years after the road was first mentioned. Hardly anything is known about the continuity of medieval roads, so the main routes depicted on these maps may be later, and the initial routes still in use at that time, but of minor importance. Besides, the location of several places is misrepresented on these maps, therefore transferring the roads to a modern map does not provide reliable results. The Ploennies maps [1715] cover nearly the complete study area, record every farmstead and do not show any gross errors. It was possible to transfer the main roads depicted on these maps to a modern map background. The course of the *strata Coloniensis* suggested by Eggerath and Krumme, but also the course implied by several protected sites coincide quite well with Ploennies roads. But the Hilinciweg first mentioned in 875 is not shown on a Ploennies map, though all authors discussing this old route agree upon the fact that this old road is still visible on 19th century maps. It seems plausible that this route was used all the time, but was less important in 1715 than in 875. Consequently, the *strata Coloniensis* might not coincide with one of the Ploennies roads. Early local maps showing also minor roads are probably more relevant than more general maps depicting only the most important roads of that time. The roads and paths of three such maps covering part of the study area surrounding the Düssel River were transferred to a modern map background. Some of the Ploennies roads running through these map areas are not depicted on the older maps. This underlines that continuity of roads is not to be taken self-evident for the study area considered.

Three places for crossing the Düssel are analyzed in the final section of this paper. The analysis reveals that the slopes near Haus Brück are lowest, for the two alternative Düssel traversing locations, steep slopes may present a significant obstacle. But the elevation differences to be negotiated on the way from Essen-Werden to the Düssel crossing is lowest for the route implied by the protected sites. Depending on the criterion considered, either the course suggested by Eggerath and Krumme or the site road performs best (Tab. 1). Therefore it is quite likely that one of these two courses coincides with the *strata Coloniensis*, and both courses are depicted on the Ploennies map, so they were created at least 300 years ago.

The additional Düssel crossings documented on the map created in 1633 suggest some future research: in the area of Eigen sunken roads are visible in the Lidar data supplied by Geobasis NRW. These roads are running in the direction of the river Düssel north and south of the river. So this Düssel crossing location might also have been in use for quite some time. West of the Neandertal, the steep slopes north of the Düssel show some traces of sunken roads in the Lidar visualizations as well, further traces can be detected south of this potential crossing location. For a final assessment of the exact location, the chronological time frame, and the importance of the Düssel crossings discussed in this paper, additional historical documents or archaeological investigations are required.

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Imprint:
Proceedings of the 23rd International Conference on Cultural Heritage and New Technologies 2018.
CHNT 23, 2018 (Vienna 2019). http://www.chnt.at/proceedings-chnt-23/
ISBN 978-3-200-06576-5

Editor/Publisher: Museen der Stadt Wien – Stadtarchäologie
Editorial Team: Wolfgang Börner, Susanne Uhlirz
The editor's office is not responsible for the linguistic correctness of the manuscripts.

Without History no Climate Adaptation. The Importance of Historical-System Analyses in Changing Environments. A Case Study from the Netherlands

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Over the last few decades the impact of climate change and coinciding weather extremes in the Netherlands increasingly has become evident. In order to better protect the country against these extremes the Dutch government has initiated an intergovernmental ‘Delta’ program. Through this initiative cities are obliged to develop planning policies that cope with weather extremes such as extreme rainfall or droughts. Besides traditional flooding, heat has become an increasing problem for cities in the Netherlands. Not only damaging buildings, but also risking the health of especially the sick and the elderly. In order to help cities develop (spatial) adaptation policies coping with these extremes, the ‘stress test climate adaption’ was developed. Built-up out of several GIS-based models, this test depicts possible bottlenecks for flooding or inner-city heat. Despite being multidisciplinary, these models are solely based on contemporary variables and contain almost no historical data on geophysical setting or town development and morphology. Consequently, the current models ignore crucial spatiotemporal variables essential for accurate climate stress-test calculations.

In order to increase the chronological resolution of these climate adaptation stress-test models a number of municipalities, reflecting a large part of the old historical towns in the Netherlands, have asked the Cultural Heritage Agency of the Netherlands (RCE) for additional historical (spatial) data. This way the GIS-based models will not only be more accurate but also better equipped for incorporating town-specific heritage situations.

In this contribution we will present several examples of expanded stress test climate adaptation models incorporating historical water systems, natural-landscape dynamics, climate change and urban morphology. The resulting models show the essentiality of integrating (1) cultural and natural data, and (2) modern and historical data. Additionally, these models underline the importance of cultural-heritage research for modern policy and planning purposes.

Key words:
Water management, historical water systems, urban climate adaptation strategies, historic GIS, GIScience, climate policies in the Netherlands.

CHNT Reference:
Menne C. Kosian and Rowin J. van Lanen. 2018. Without History no Climate Adaptation. The Importance of Historical-System Analyses in Changing Environments.

INTRODUCTION

Situated in the northwest-European delta, the Netherlands is generally low lying and characterized by the presence of some of the largest European rivers (e.g. Rhine, Meuse). On the one hand these rivers always have provided good transportation and communication routes between coastal regions and the hinterland, providing flourishing trade and the rise of merchant cities (Fig. 1).

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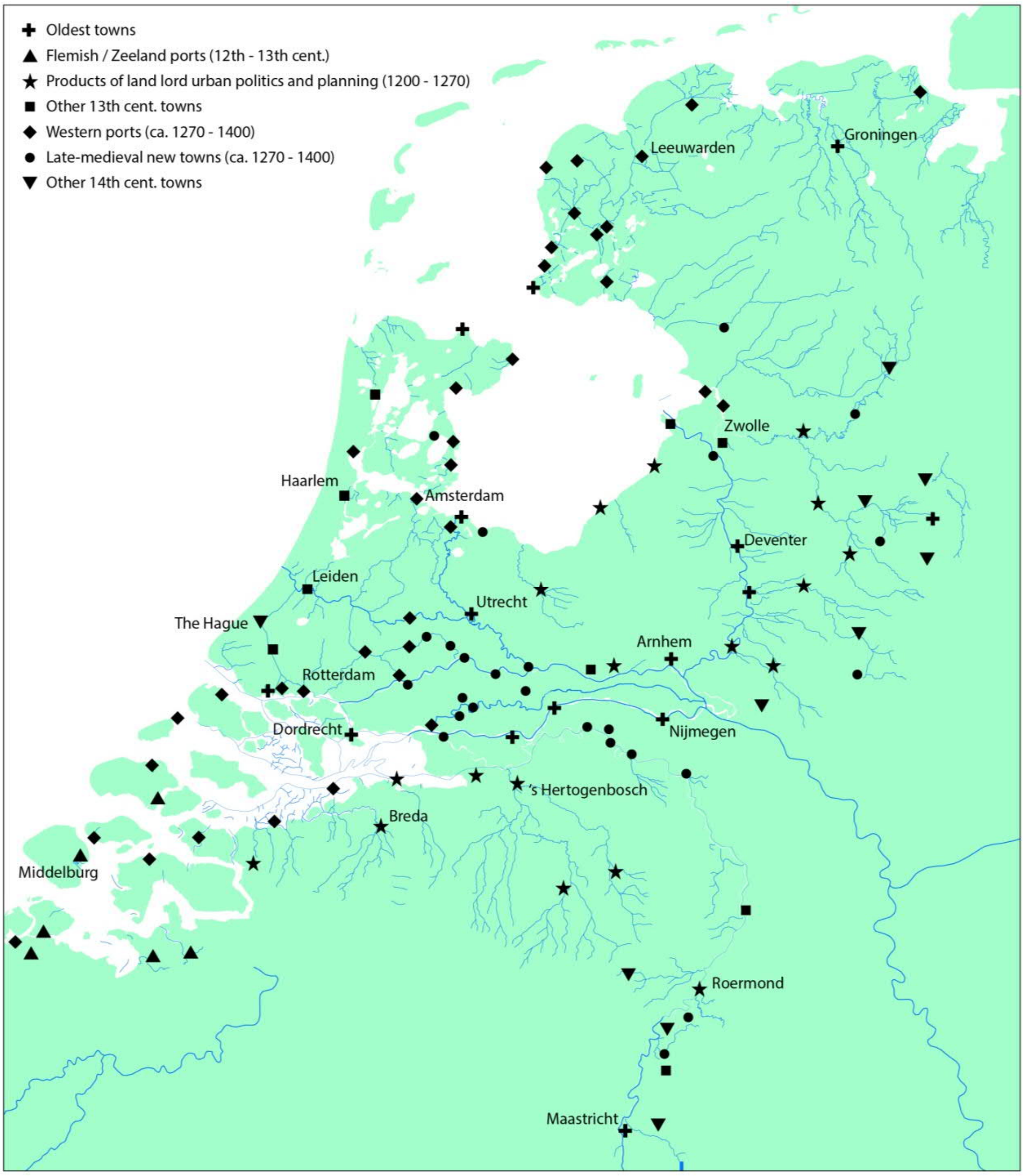

Fig.1. Dutch medieval cities and their relation to water

On the other hand, this landscape setting made these newly developed cities prone to flooding and required continuous adaptation on their part.

Even to the present day, these cities are confronted with these kinds of threats. For example, due to climate change the Dutch cities have to adapt not only to rising water levels from sea and rivers, but also to extreme weather conditions, like long periods of heavy rain or heat and drought. Since these adaptations vary through time and place, they have greatly influenced the development of individual cities. Consequently, the layout and appearance, and therefore their character, of the Dutch cities were in large part defined by their adaptation strategies.

Modern climate adaptation strategies, however, often only rely on modern technical engineering solutions, without taking into account specific local historical characterizations. These kind of technocratic solutions often don't find a support with the local population, lacking character. Besides, proven historical solutions that have worked for that specific city or area are not incorporated. This potentially makes these modern solutions ill-fitted, unnecessary complex and often too expensive.

This paper will show how integrating knowledge of historical water engineering works into present-day engineering models provide better-suited solutions for adapting to environmental changes in urbanized areas.

SOCIO-POLITICAL FRAMEWORK

Fuelled by climate change, we are increasingly confronted with weather extremes, rising sea levels and notable temperature excesses. Adaptation to these changes is vital for a low-lying country such as the Netherlands. Therefore the national government has defined an overall strategy in order to develop adaptations to these changes, namely the Deltaprogram Spatial Adaptation. [Deltaprogramma Ruimtelijke Adaptatie 2018] One of the main goals of this program is to assess the risks concerning themes like water safety, water quality, heat stress in cities and drought. Based on these risk assessments several implementing plans can be executed. For climate adaptation, these plans are coordinated within the National Adaptation Strategy. [NAS 2018]

This national policy calls for all cities to perform several so-called stress tests. These are not physical tests on several aspects of climate change, but models to assess which areas in a city have higher risks of flooding or heat stress. Based on these assessments the local politics can then address the risks with specific adaptation policies.

However, these stress test-models often only take present-day surface aspects into account and neglect historical information. For instance, a model on flood risks by heavy rain only calculates the maximum water levels based on the amount of rain and the altitude variations within the city's streets. Sewer systems, (historical) watercourses and other urban morphological features are not taken into account. (Fig. 2)

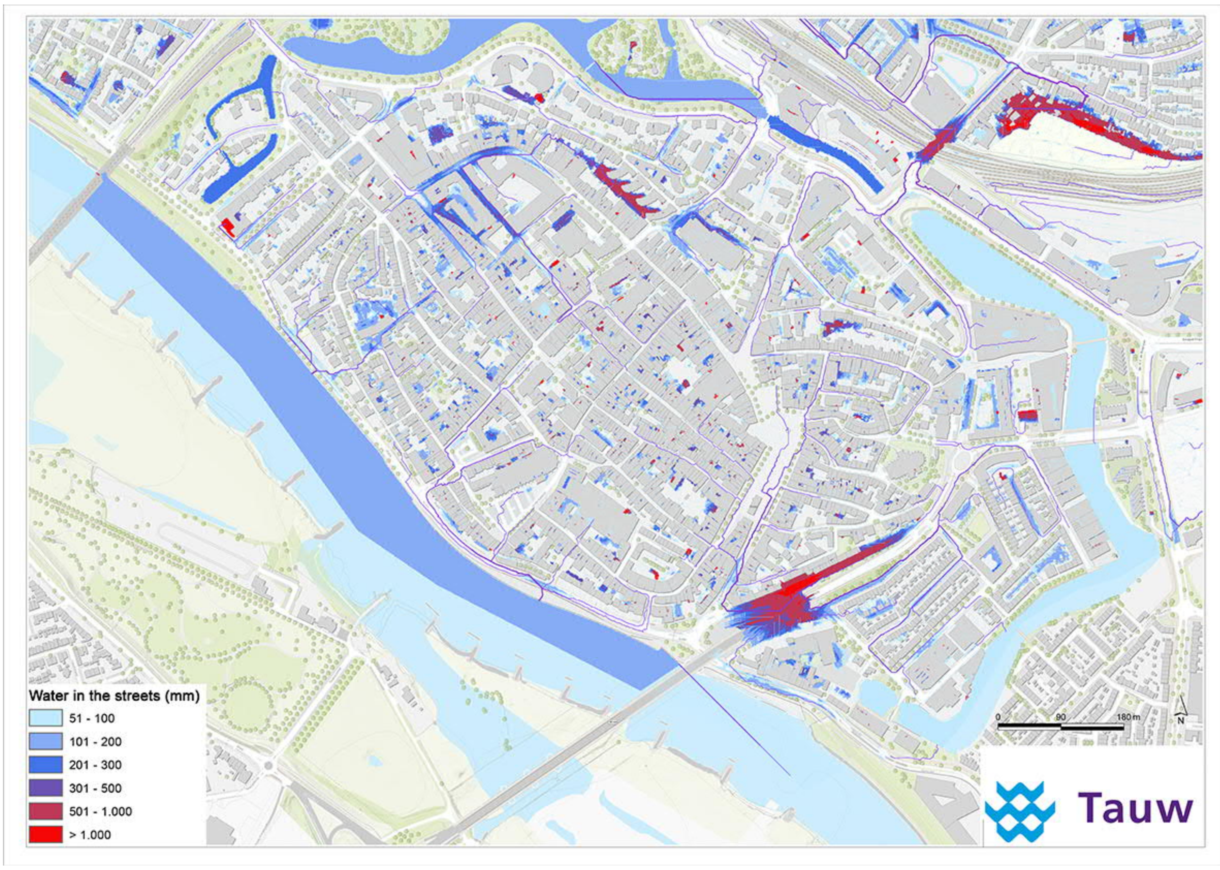

Fig.2. Flood risk-model of the city of Deventer depicting areas in severe risk (dark blue to red). Sewer systems and natural drainage are not taken into account

Even cities equipped with archaeological and historical departments often miss integrality and historical context.

The Cultural Heritage Agency of the Netherlands aims to help these parties integrating historical knowledge into both these stress tests as well as the resulting policies. These ambitions are formulized in the national line of policy “Kiezen voor Karakter” (Choosing for Character) [Ministerie Onderwijs, Cultuur en Wetenschap 2011] part of the larger program “Visie Erfgoed en Ruimte” (Vision on Heritage and Environment). [Rijksdienst voor het Cultureel Erfgoed 2017]

METHODS & MATERIALS

Because of its geographical positioning, inhabitants of the Netherlands traditionally have a strong relation with water. Consequently, almost all of the historical Dutch cities arose near to, and because of, streams and rivers. These waterways gave the emerging cities vital means of transport and communication and made them, already from their earliest beginning, what we nowadays call ‘water adaptive’. In the Netherlands, we are in a very fortunate position that we have accurate maps of almost all of our cities as they were at the end of the Middle Ages. In the sixteen hundreds, the surveyor and mapmaker Jacob van Deventer (ca. 1500-1575) started to map the cities of the Netherlands (Fig. 3).

Fig.3. The city of Deventer ar the IJssel river by Jacob van Deventer mapped between 1557 and 1559 [Rutte and Vannieuwenhuyze 2018]

Initially probably self-employed, he soon was granted a formal commission by King Philip II of Spain, the then ruler of the Netherlands. This commission gave him access to all the cities under Spanish rule and a travelling pass through the troublesome areas of the country (during the beginning of the Dutch revolt against Philip, 1568-1648). [Rutte and Vannieuwenhuyze 2018]

The revolt against Spain resulted in the emergence of the new Dutch Republic in 1609. This young country needed accurate descriptions and maps and because of the economic boom, known as the Dutch Golden Age, had the financial means to commission these. Combining these maps with the earlier Van Deventer-maps allows us to accurately model the growth of the cities during the 17th century. At the end of the Dutch Golden Age most of the cities reached their peak and had grown to the size which they kept until the end of the 19th century. These areas are what we now refer to as the historical city centres. [Abrahamse and Rutte 2016]

Next to these urban-development models, the Dutch also have a long history of soil and landscape research resulting in not only high-resolution soil maps, but also providing enough geological data to create detailed paleo geographical maps. Through these maps, we can assess the landscape conditions and much of the water risks the early cities in the past must have faced. Landscape features like amongst other river dunes and levees proved to have been important location factors. Cities in the lower western areas are mostly situated in or nearby marshy peat lands, with rivers and canals as main location factor for trade. In these areas huge water engineering projects were undertaken to drain the land and make it suitable for habitation and agriculture (mostly cattle). [Vos et al. 2018]

In order to able to maintain these elaborate engineering systems a separate political layer was installed from the Middle Ages onwards, the water boards. As maintenance organisations they, too, developed high-resolution maps. Today these water boards still function and all their engineering and policy information are preserved in their archives.

The Cultural Heritage Agency of the Netherlands is in a continuing process of disclosing this kind of historical-environmental data. In 2016 the digital dataset Nederland in 1575 (the Netherlands in 1575) was presented. [Kosian, Van Lanen and Weerts 2016] This dataset provided georeferenced and vectorised city maps of Jacob van Deventer, combined with the contemporary landscape and soil type, main waterways and a first reconstruction of the main land routes and roads. [Kosian and van Lanen 2017] At present, a similar project is being carried out for the western part of the Netherlands, mapping the water system, dikes, cities and economic landscape over four periods; late Middle Ages (around 1600), the end of the Dutch Golden Age (around 1730), the end of the Industrial Revolution (around 1900) and the present day. [Kosian and van Lanen submitted]

Important and handy as this information might be, it still is mainly the work area of historians. Merely disclosing these datasets does not automatically mean they are going to be used and certainly not by civil servants and municipal engineers dealing with climate assessments and stress tests for their city. These are often rather small task forces with limited means and limited historical knowledge.

The main challenge is to have municipalities adopt heritage information as an integral part of their climate-adaptation policies. Not as something to care for and deal with, but as a valuable source of information, an inspiration and sometimes as (part of the) solution. This means that disclosure of historical information should also give means to include this information in other then academic studies. In order to do so we have not only vectorised and combined historical maps, reconstructed soil conditions and historical water engineering information, but also devised several ways to integrate these, mostly qualitative data, with quantitative models.

As a pilot we took on to build a GIS model for the city of Deventer. This GIS should provide insight in the actual development of the urban area through time, but also to the changes in land use of the modern area of city centre and direct surroundings, as well as water management and heat management through green spaces.

First four period maps were selected for digitalisation. The first was the map by Jacob van Deventer from ca. 1557-1559. This is not only the oldest map of the city, but it is also highly reliable as the research of Rutte and Vannieuwenhuyze and Kosian et al. Showed. [Kosian et al. 2016, Rutte and Vannieuwenhuyze 2018] This medieval map not only gives a good representation of the city, but also rather detailed information on land use and soil conditions during this period. Comparing the several Van Deventer maps give insight in the humidity of the soil since Van Deventer had made a uniform colour legend on land use and aridity. [Kosian et al. 2016, Rutte and Vannieuwenhuyze 2018] This map was georeferenced by matching the centre lines of the roads as drawn by Van Deventer to those of the still existing roads in the old centre of the town. This line model of the road network served later also as a basis for georeferencing other, less exact, historical maps. [Abrahamse and Kosian 2014]

The second map was the map by Joan Blaeu from 1652, the map of the city of Deventer at its maximum size during the Dutch Golden Age in the mid-17th century. Although the Blaeu map is less geometrically exact [Rutte and Vannieuwenhuyze 2018], the digital road network map digitized from the Van Deventer map could be used to georeference the map and correct the geometrical oddities. The last historical map used was the, again highly exact, Dutch land registry map from 1832. This map is not only geometrically exact, but has already been digitized in the

HISGIS project, a nationwide project aiming to digitize into GIS the whole of the 1832 land registry maps and information in the Netherlands. [HISGIS]

The last map in the series was the topographical map from the Dutch Topographic Register, the for the Netherlands standard 1:10,000 digital topographical map.

After this digitalization process we placed a 10 by 10 meter grid over these maps in order to be able to quantify land use and the capability of water absorption or drainage of the top soil. Land use was classified into 11 classes that could be compared through time. (Fig. 4)

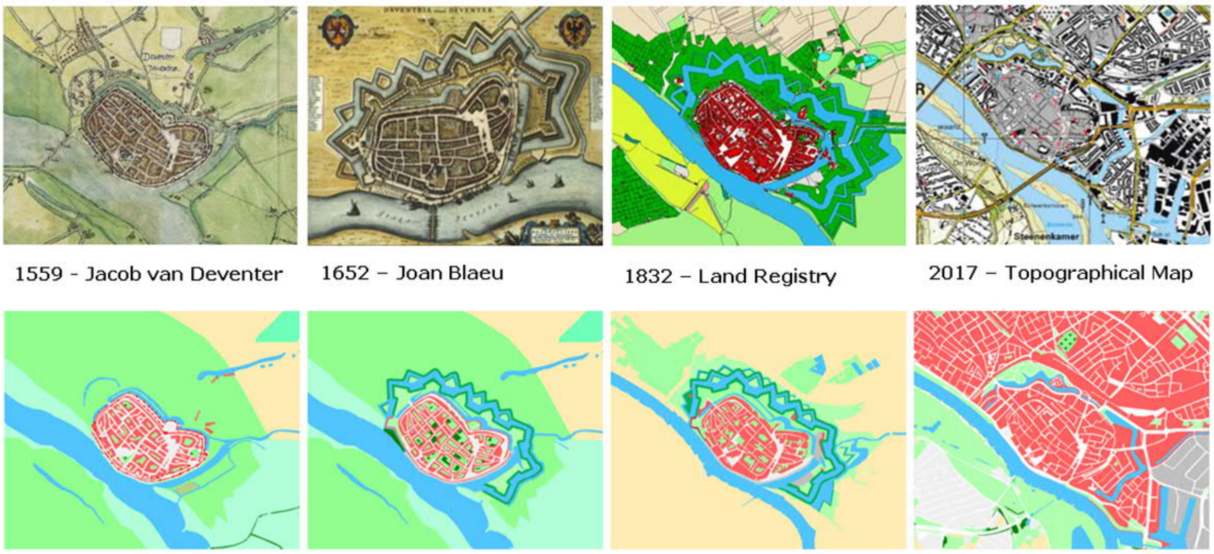

Fig.4. Historical maps of the city of Deventer put into a GIS as an uniform land-use model. The water absorptive qualities of the several areas are not shown in this figure

Based on soil map and paleo geographical data we also had information on the water storage capacity of the several classes. For instance, modern infrastructure are mainly hardened surfaces with engineered water drainage, while the medieval and even 17th century streets mostly were paved with loose stones, if paved at all. This gave water the opportunity to seep into the ground. Of course, in gardens and fields this absorptive quality was higher than in the streets, but modern infrastructure has no absorptive qualities at all. (Table 1)

Table 1. Classification of land use and water absorptive qualities as used in the historical quantitative GIS model of the city of Deventer

Land use class	**Water absorption class**					
	1559	**1652**	**1832**	**2010**	**Absorption class legend**	
Built-up area	-2	-2	-2	-2	No or indirect drainage	-2
Industrial area	-1	-1	-2	-2	Mainly indirect drainage	-1
Infrastructure	1	0	-1	-2	Moderate absorption	0
Park or garden	1	1	1	1	Absorption	1
City wall	-2	-2			Direct drainage	2
Ramparts		0	0	0	Non-existent	
Agriculture	1	1	1	1		
Grass and meadows	1	1	1	1		
Peat area	2	2	2			
Dry nature area	1	1	1	1		
Water	2	2	2	2		

This way we could not only classify land use, but also enrich the attribute table with a basic water absorptive classification. This gave a comparable GIS model of the city over four different time periods. And since the attribute table was uniformly classified, we could also give insight into the deterioration or, in some cases, amelioration of the water absorptive qualities over time. Fig. 5a shows the land use in 1559 and Fig. 5b the land use in 2010. It immediately is clear that the built-up area is dramatically increased, but when we compare that to the water absorption index, we could see that has become even worse, since not only green areas have diminished, infrastructure has no longer a absorptive quality (Fig. 5c and 5d) Subtracting 2010 from 1559 we can map those areas that have deteriorated the most (Fig. 5 c-d)

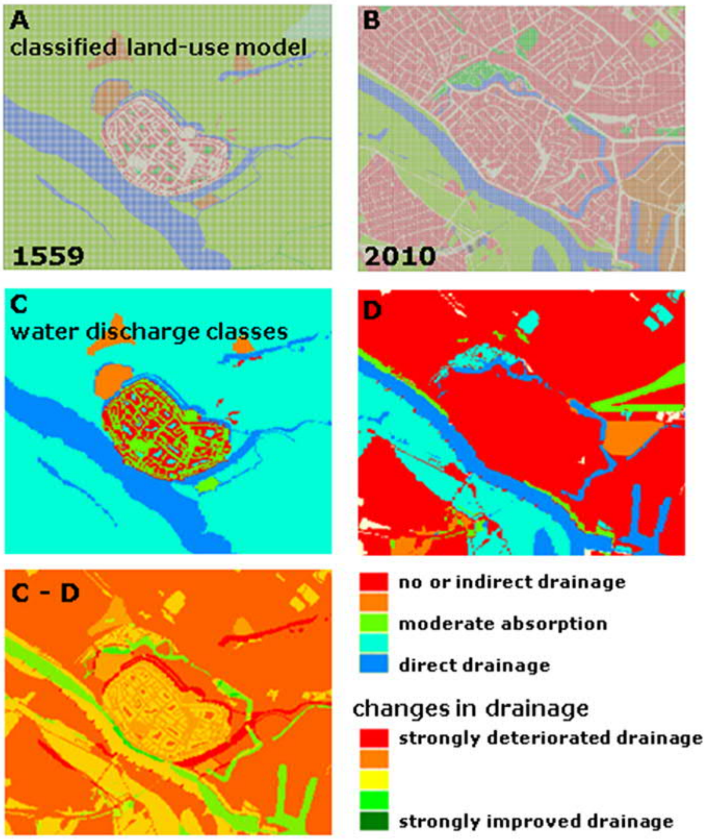

Fig. 5. Classified drainage and absorption model devised from the historical model and enriched with soil information. The top line represents land use in two periods, 1559 and 2010, the middle line represents the absorptive qualities of the areas and the lower map gives the deterioration of absorptive qualities by subtracting 2010 index from 1559 index

The model could not only give insight into the water absorption of several urban areas, but can also provide an inspiration for heat-stress solutions. Were we see the modern, ancient, inner cities as completely built-up, densely populated areas this was not always the case. In fact, a lot of the medieval town consisted of open areas: squares and gardens were everywhere, and a lot of cities even had urban farms within their walls. Since the GIS has an uniform legend for land use over time, it could show the changes in inner city green and open areas. (Table 2) Trying to re-match the old percentages of green spaces in the city could help to adapt the urban area to the heat effects of climate change. One could think, for instance, on grass-filled open concrete as surface parking spaces, or green roofs on inner city apartment stores that are often build on former “useless” squares or inner-city greens.

Table. 2. Red-green-blue ratio during several periods for inner city Deventer (see aereal photo above). A lot of the innercity green areas or squares have been filled in with closed building blocks. A lot of the gardens within the medieval and 17th century buildings are used as building plots as well, making the city centre far more dense than it has been originally

Land use	1559	1652	1832	2010
Built-up areas	27,23%	15,40%	22,40%	46,76%
Green areas	21,67%	28,79%	40,98%	15,98%
Infrastructure	17,80%	12,60%	8,77%	17,56%
Water	33,31%	43,21%	27,85%	19,69%

Adding geomorphological data to the GIS enriches the data even more. Deventer, for instance, was originally built on a river dune along the IJssel river. Only a small brook, the Schipbeek had broken through the dune to discharge into the IJssel, just south of the medieval city. Water northeast of the city had to be diverted, either via the Schipbeek, or via canals leading to the north to discharge further downstream into the IJssel. Until the 19th century there was a harbour where the Schipbeek flowed into the IJssel. Today, both the harbour as well as the Schipbeek have been moved further south, and the old harbour area has been filled-in and become the access to the bridge over the river. This modern road, however, has good sewer systems in place, reducing the risk of flooding in this former harbour area. However, it blocks off the area just north of it, today the train station, where there is a risk of flooding. Combining this historical GIS with the risk-assessment models give policy makers a far more detailed view on the areas at risk. The risk-assessment model alone indicates for Deventer two major (red coloured) areas of risk, while the combined model shows that one of these areas is the, low lying, former harbour. This area lights up in the risk-assessment, only because of its low-lying position. This area has actually no water problem. (Fig. 6)

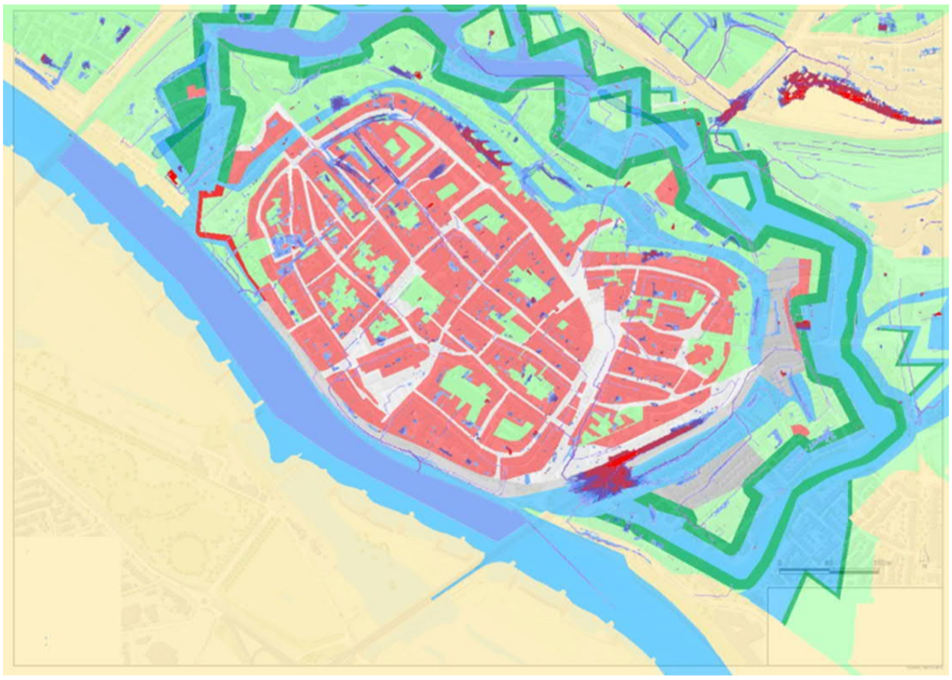

Fig. 6. Integrated map of the standard risk-assessment water-shed model with the historical GIS. The red-blue areas show areas at risk of flooding according to the risk-assessment water shed map. The southern of these areas clearly is situated in the old harbour, the location of the modern IJssel-bridge ramp and the N344 carriageway. The northern risk area, however, is cut of from draining into the IJssel river by the natural river dune on which the city sits, and the before mentioned N344

The most important part is to get everybody in the city administration involved. For example, a potentially high-risk flooding area recently also could have been supplied with large capacity sewers. Therefore it is important to involve all departments and agencies and integrate knowledge both historical and modern as well as political and technical. This new interdisciplinary and interdepartmental approach is the main focus point of the "Cultural Heritage Agency Method", an integrated method published as a manual on climate adaptation. [Rijksdienst voor het Cultureel Erfgoed 2018]

RESULTS

Most of the work of including heritage information into urban politics is not just the disclosure, but mainly creating awareness of heritage as a mean, rather than a hindrance. In order to do this we have published several manuals and guidelines. Within the program "*Visie Erfgoed en Ruimte*"[1] we have developed several guidelines: *Nederland kavelland* (the Netherlands; Fields Country) on heritage and agricultural changes, *Nederland energieland* (the Netherlands: Energy Country) on heritage and energy transitions, *Nederland waterland* (the Netherlands: Water Country) on heritage and adaptive water management and *Nederland stedenland* (the Netherlands: City Country) on heritage and climate adaptation in cities.

Next to these guidelines we also gave courses and lectures at municipalities, to show, hands on, the advantage of multidisciplinary and multi-departmental approaches and of course we still offer the historical datasets as service or downloadable GIS data.[2].

[1] More on the program can be found on the site of Erfgoed en Ruimte https://erfgoedenruimte.nl. The several guidelines and folders are published on https://www.cultureelerfgoed.nl/publicaties/publicaties/2017/01/01/nederlands-cultuurlandschap-in-vier-tijdlijnen. The Manual Water, Heritage and Environment is published on https://www.cultureelerfgoed.nl/publicaties/publicaties/2018/01/01/manual-water-heritage-and-environment (all consulted Feb. 11, 2019)

[2] https://www.landschapinnederland.nl (consulted Feb. 11, 2019)

DISCUSSION

As discussed before, since all cities have their own character and specific history, a general template for adaptation and change policies is impossible and undesirable. This is not only true for modern engineering solutions, but equally for the implementation of historical data. The method presented in this paper is not a strict rule, but much more a guideline and a source of inspiration. The maps of Van Deventer and Blaeu[3] can provide insight into the urban development of many cities, but they are not the only maps to be taken into account. For example, several of the cities in the province of Holland grew more rapidly than other cities and therefore more high-resolution maps exist depicting their development. For these specific cities, these maps should also be included. Additionally, if cities have been profoundly altered in recent times, it is essential to incorporate younger maps. This is the case for example in the cities of Rotterdam and Nijmegen, where, although still having their original layout recognisable in their modern city plan, the bombings of the Second World War completely changed the cities appearance and (underground) infrastructure. In these cases the post-war damage assessment maps and restructuring plans should be taken into account as a major source.

Besides urban-development models incorporating overarching data on water systems are also essential. The intricate system the water boards developed over the years extended far beyond the city limits. Research currently being executed at the Cultural Heritage Agency on water discharge systems in the west of the Netherlands shows the importance of system thinking when dealing with local problems. This system thinking however necessitates the consultation of local water boards and accesses their data when performing stress tests.

The historical map analysis also gives an insight on the amount of open, green spaces within the cities. Insight in where these spaces were located in the city centre can be an inspiration for modern planners to open these spaces up again, helping against heat stress in cities. The datasets provided by the Cultural Heritage Agency might not be sufficient for all towns and cities, but will give at least an insight into what kind of data, and what kind of data sources can, and should be used.

CONCLUSIONS

In order to develop customized local policies for climate adaptation cities in the Netherlands should assess the risks of these changes to their specific situation. When only done in a technical engineering way, policy makers might lack information needed to sufficiently prepare their city for these future threats. Heritage in this respect can be applied both as inspiration and as a mean towards the solution. After all, we have dealt with water related problems for ages. Many of the newly-designed solutions have been tried and tested before. Taking this information into account not only ameliorates the technical solution, but also respects the character and history of the city. Helping to preserve heritage and create support with local inhabitants. The here presented method is a base for such a history integrated solution. However it is not a strict rulebook. It wants to be a guideline that gives insight into how historical data can be useful, how it can be integrated into modern designs and political processes. Next to these guidelines, the method also generates practical data which is publicly shared. Although these datasets are far from complete, they are at least a good starting point to carry out city-specific heritage and history integrated multi-disciplinary risk assessments for future politics.

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Imprint:
Proceedings of the 23rd International Conference on Cultural Heritage and New Technologies 2018. CHNT 23, 2018 (Vienna 2019). http://www.chnt.at/proceedings-chnt-23/
ISBN 978-3-200-06576-5

Editor/Publisher: Museen der Stadt Wien – Stadtarchäologie
Editorial Team: Wolfgang Börner, Susanne Uhlirz

Spatial Data Infrastructure for Urban Heritage Conservation in Afghanistan: The Case Study of Herat

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The development of "Spatial Data Infrastructure" (SDI) in the field of urban conservation in Afghanistan is a new and little explored topic. This article studies the framework of an SDI to provide a platform for sharing, assessing and discovering data by users and spatial data providers located in the public and private sectors. This paper not only contextualises these tools and methods in the old city of Herat, a city in western Afghanistan that contains important Timurid architecture, but it also describes the preparation phase and data management in the research project "Regeneration and Preservation of the Historic Urban Fabric of Herat." After archiving and managing various forms of spatial and non-spatial data related to the site, which have been produced by different institutions since 2001, the project develops an SDI by combining satellite images, spatial datasets and attribute data (e.g., social survey and household survey). It offers several conceptual models and also a geoportal to visualise, modify and discover the historic urban fabric of Herat. To reach this aim, the standards of ISO and OGC have been utilised. The product of this study enables key institutions in the field of heritage conservation to access the portal to obtain, modify and contribute data. Taking the strengths and limitations of SDI into consideration, especially in Afghanistan, this research aims to support researchers, urban planners and managers in proper decision-making and to protect Afghan heritage.

Keywords:
Spatial Data Infrastructure (SDI), GIS, Cultural Heritage, Spatial Analysis, Decision Making.

CHNT Reference:
Reza Sharifi and Alireza Ibrahimi. 2018. Spatial Data Infrastructure for Urban Heritage Conservation in Afghanistan: The Case Study of Herat.

INTRODUCTION

In Afghanistan it is difficult to gather data related to cultural heritage that can be used to manage and preserve historical sites. Since 2001, following the collapse of the Taliban regime in Afghanistan, various institutions, including governmental and non-governmental organisations and private companies, have produced different kinds of spatial data concerning places of historical value. At the same time, because of long-lasting armed conflict, the country has lacked institutions to manage data for documentation and conservation. In theory, such a process entails "interdisciplinary work where all the specialists involved in detailed investigations on an object of interest collect, interpret and share the data and the results of their interpretations [Rinaudo et al. 2007].

In June 2010, President Hamed Karzai (then-president of Afghanistan) issued a directive guideline relating to spatial data management. In article 2, paragraph 3, the Independent Department of Geodesy and Cartography was appointed to establish a spatial data infrastructure (SDI) among ministries and governmental and non-governmental institutions [GDCG 2010]. However, in the field of heritage preservation, to gather data individual organisations have spent millions of dollars and invested time and human resources. They usually have kept their data in private archives and seldom shared it with other organisations. After 2013, when the coalition led by the US started to leave Afghanistan, a substantial number of non-governmental organisations and private companies could no longer sustain their projects and also left the country. Two main questions arise in the wake of their departure:

a) What kind of data does each organisation have?

b) To what system could they transfer their data?

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Once the Afghan government understood the importance of digital data, they rushed to create databases. That encouraged many public institutions, including the government, to speed up accumulating data. This sudden interest also produced several challenges. First, multiple data centres have been established with the same objective but located at different institutions and using different formats, platforms and even different software. Second, this redundant work in the field has meant the loss of financial and human resources for the institutions involved and for the government, which suffers from a shortage of income. As a response to these challenges, a “spatial data infrastructure” (SDI) was developed to assist in the conservation of “Afghanistan’s heritage” (AH). A GIS-enabled database, AH-SDI was deployed using the open-source solution GeoNode 2.8.

Heritage managers consider SDI an instrument for the inventory, documentation and management of knowledge concerning cultural heritage and as in many other fields they have accepted SDI as part of the natural advancement of more traditional databases. Furthermore, the underlying GIS technology is an efficient tool for storing, managing and analysing cultural heritage data. GIS technology has become widespread. It also offers appropriate 3D tools for cultural heritage visualization and mapping. Recent advances in GIS have included development of the proper instruments for both central and local authorities responsible for cultural heritage to build corporate information systems having this type of information technology as one of the essential infrastructure components [Petrescu 2007].

SPATIAL DATA INFRASTRUCTURE

Spatial data is significant in everyday decision-making and especially in economic, social and political decisions. Many of the goals and activities of organisations require access to convenient and integrated spatial data; this is especially the case with large-scale planning. Recognition of the importance of access to spatial data led to the development of SDI as platforms for empowerment in geo-information communities at various levels. SDI—internet-based technologies for the coordinated production, discovery, and use of geospatial information in the digital environment—have diffused worldwide in the last two decades [Budhathoki et al. 2008].

Rajabifard and colleagues [2004] state that an SDI “*will provide a base or structure of practices and relationships among data producers and users that facilitates data sharing and use.*” They also describe an SDI as “*a set of activities and new ways of accessing, sharing and using geographic data that enables far more comprehensive analysis of data to help decision-makers chose the best courses of action*” [2004]. An SDI can make it much easier for different organisations to share data and resources. An SDI makes it possible to avoid redundant work, enhance the capabilities inherent in spatial information and increase the efficiency of investments and using the resources.

Viewing the core components of SDI as policy, access network, technical standards, people (including partnerships) and data, different categories can be formed based on the nature of interactions taking place within the SDI framework [Rajabifard et al. 2002]. In designing this structure, it is important to establish proper access methods and a framework for cooperation and collaboration among the organisations [Toomanian 2012]. Fig. 1 shows how managing data can affect people using SDI and vice versa.

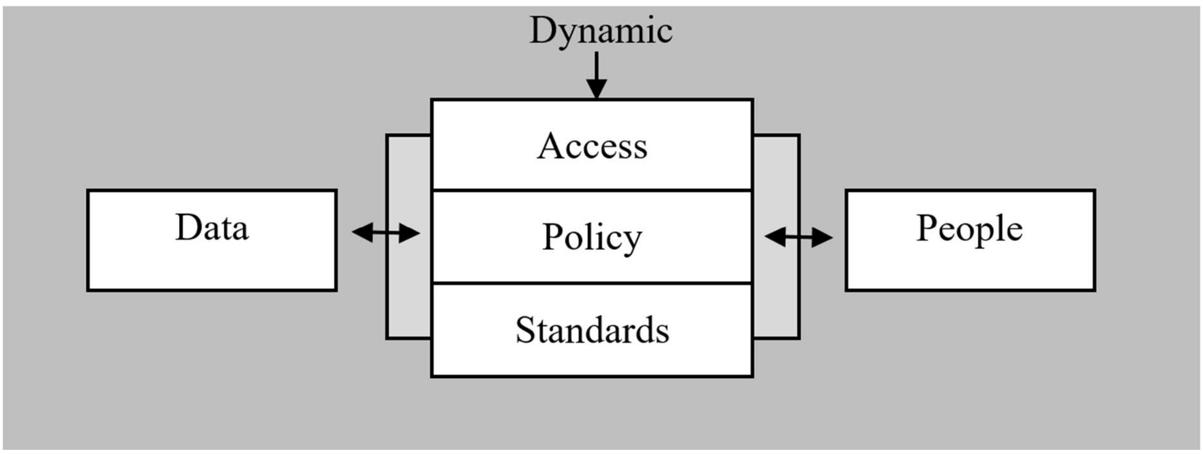

Fig. 1. Nature and relations between SDI components (adapted from Rajabifard et al. 2002)

MATERIALS AND METHODS

For managing heritage-related data, a suitable tool was required that could cope with the particular situation of Afghanistan, a post-war country with unreliable access to sites and with different types of data located in various places. The users also want user-friendly software that offers more than just a database and can be used for sharing data with internet-based space where data can be saved, edited, shared and worked with. The Afghan Ministry of Urban Development and Land proposed the idea of an “Afghan Heritage SDI” (AH-SDI). This is a software project, available to selected organisations through a geoportal, that is, *“a web application which acts as an access point to the shared Geographic Information [GI]”* [Xin et al. 2012]. According to Tait [2005] a geoportal can have four main functions including searching, mapping, publishing, and administration. To identify the tasks that need to be completed by participating organisations, as a first step, AH-SDI provided a list of GIS tools and basic data requirements. To collect this information, a desk study and interviews were carried out.

Herat was selected as a pioneer research project for three main reasons. First, the government of Afghanistan enlisted the city of Herat in the tentative list of World Heritage sites that has been compiled by UNESCO since 2004. The city is situated in western Afghanistan and is home to many historical monuments, including those *“from extensive development ordered by Queen Gawharshad during the 15th century AD, which resulted in a remarkable and unique ensemble of monuments in the Timurid style”* [UNESCO 2018a], among them the Mausoleum of Gawharshad and the Musala complex with minarets representing the peak of that style (see Fig. 2).

Second, local people in Herat pressured the central government to fulfil the demands of UNESCO for listing Herat as a World Heritage site. The AH-SDI project could satisfy some of the UNESCO demands, particularly those pertaining to heritage documentation and project preparation.

Finally, local people who are living in the historic urban fabric are suffering from lack of public facilities, including water, sanitation and electricity. To obtain those services they are willing to destroy their traditional houses and build new ones, which in many cases is illegal (see Fig. 3). Consequently, there is considerable interest in facilitating an appropriate culture-based regeneration of the urban fabric (see Fig. 3).

To enrich the AH-SDI and to gather reliable data, a variety of institutions were contacted. “Aga Khan Trust for Culture” (AKTC) was the first, because in recent decades they have been working in Herat. Besides their conservation work, they conducted a property survey between May 2005 and July 2006 [AKTC 2006] that provided the project with suitable metadata on the historic part of Herat.

Fig. 2. Part of Musala Complex including the minarets in Herat. (© R. Sharifi)

Fig. 3. Historic urban fabric of Herat. (© R. Sharifi)

With compiled baseline data, tools with necessary functions were designed in AH-SDI, these tools consisting of:

GIS tools

Tools for stakeholders are divided into eight categories. Each organisation requires some of these tools to work with GIS data (see Table 1).

Table 1. Types of tools users need

Type of data	Type of tools	Examples
Vector data	Basic	Zoom, pan, select, measure, search, create map, print, add data to vector layers, etc.
	Geoprocessing	Buffer, clip, intersect, union, merge vector layers, etc.
Attribute data	Attribute data	View, select, find, replace, modify, print, and delete tables
	Advanced attribute data	Create a graph, chart and report, statistical tools, etc.
Raster data	Satellite images	Zoom, pan, select, measure, create map, print and search
3D vector data	Basic 3D	View, zoom, pan, select, measure, search in 3d view, etc.
	3D analysis	Creating contour line, extrusion, rendering, elevation, etc.
	3D modelling	Fly through, export 3D model, animation, etc.

Basic data:

Users of AH-SDI, to work with this geoportal, need some essential information. A list of such primary or baseline data from our case study has been identified for the old city of Herat (see Table 2):

Table 2. Types of basic data users need

Items	Explanation	
Base Map	Providing geographical context for the objects shown on a *map* (e.g. Open Street Map, Google Map, Google Earth and so on).	
Basic feature data (For this part AKTC data centre)	Boundaries	Shapefiles of Afghanistan (provinces and state)
	Population	Residents and families
	Residential	Historic house, traditional house, modern house, ruin/open space
	Commercial	Market (modern), serai (traditional), shop, workshop, restaurant/ hotel
	Service / Public Building	Clinic, police station, cistern, governmental building, traditional bath, godown/storage, school/madresseh
	Religious	Mosque, shrine, takya khane (traditional mourning house)
	Drainage	Khandaq (traditional water channel)
Basic documents	Reports, charts, maps, surveys and pictures of Herat	
Basic satellite imagery	In the field of cultural heritage management, heritage practitioners can benefit a lot from satellite imagery. The latter can be used in survey, planning and implementations. Substantial data on our case study was received by us on Herat, from AKTC with a license for utilizing in AH-SDI.	
Basic aerial imagery	*Aerial* imagery is the taking of photographs from an aircraft or another flying object. It is high-resolution imagery and useful in urban management and cultural heritage. This image was received from AKTC with a license for use with AH-SDI	

Software architecture:

In developing the geoportal, the work was organised the way software development is organised. A small number of framework activities were identified to establish the foundation of our platform. For many software projects, framework activities are worked on iteratively, as a project progresses. That is, communication, planning, modelling, construction and deployment are applied repeatedly through many project iterations [Pressman 2010].

There are several ways to develop web applications, such as a geoportal, via an ‘incremental process model’ (see Fig. 4). Here, “the first increment is often a core product” [Pressman 2010]. The customer uses the product, and the next incremental model will be planned based on customer feedback, and the “process is repeated following the delivery of each increment until the complete product is produced” [Pressman 2010].

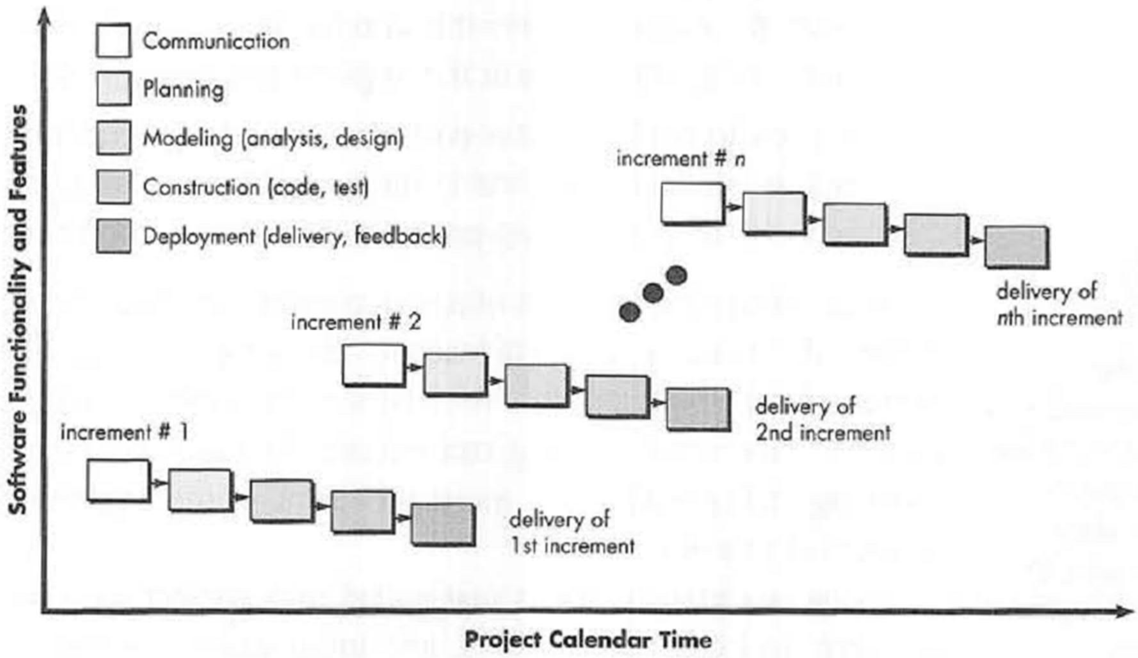

Fig. 4. Incremental Process Model (Pressman 2010)

Several types of spatial software can be used to implement a geoportal (see Fig. 5). They are either commercially or freely available. In this project, because of a lack of funding, the absence of legal support for such software in Afghanistan and limited access to required products and supporting offices that could help when problems arose with particular products, a free and open source online solution was chosen. Our experience was consistent with the conclusion that *“free and open source solutions support a wide range of industry standards that ease interoperability between SDI components”* [Steiniger and Hunter 2012].

The project has benefited from a number of services. The essential one is GeoNode 2. which is open source software for deploying an SDI and a web-based application and platform for developing “Geographical Information Systems” (GIS):

> *GeoNode core is based on Django web framework with few more dependencies necessary for the communication with the geospatial servers (GeoServer, pyCSW). GeoNode is configured to use PostgreSQL/PostGIS for its persistent store.* [Geonode 2019]

GeoServer, which is one of the main components of GeoNode, is open-source geodata middleware written in Java that allows users to share geospatial data and control access to geodata repositories. OpenLayers, a free mapping library, is integrated into GeoServer, making map generation quick and easy. “Web Map Service” (WMS) standard GeoServer also conforms to the “Web Feature Service” (WFS), “Web Coverage Service” (WCS), “Catalogue Service” (CSW), “Web Map Tile Service” (WMTS), and “Web Map Context” (WMC) standards [Geoserver 2019]. A map of Afghanistan appears in the GeoNode environment in Fig. 6.

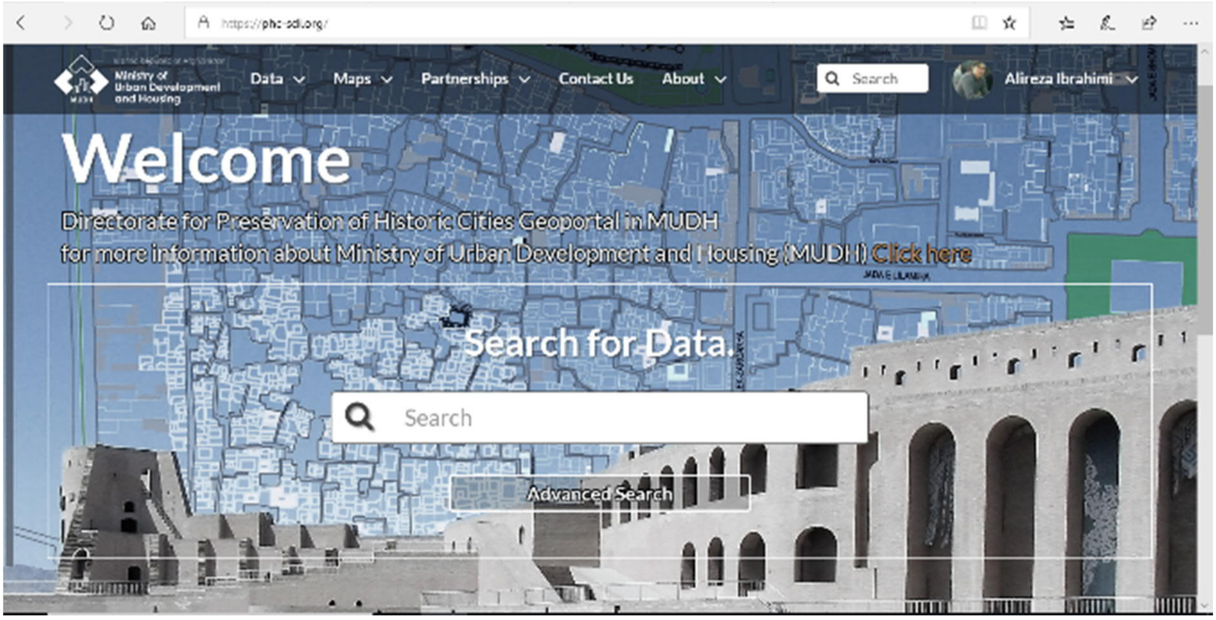

Fig. 5. AH-SDI Geoportal Homepage and login page

Data gathering:

To collect our data, beside the desk study, short-term fieldwork and interviews were conducted focused on select central institutions in the field of heritage preservation in Herat. The aim of the research was to figure out what type of baseline data these institutions require. It became evident that they need five primary data types (see Table 2), and eight tools (see Table 1). Table 3 shows the source data each institution needs.

Table 3. List of tools and primary data that organisations require

Name of the Institution	**Methods of Collecting Data**	**Demanded data**	**Tools**
Aga Khan Trust for Culture (AKTC)	Desk study	Base map Basic feature data Documents Satellite images Aerial images	Basic Tools Geoprocessing Attribute data Advanced attribute data Satellite Images Basic 3D 3D analysis
Turquoise Mountains Foundation (TM)	Interview	Base map Feature data Documents Satellite images Aerial images	Basic Tools Attribute data Satellite Images Basic 3D 3D analysis
Florence University-Italy	Interview and desk study	Base map Feature data Documents Satellite image Arial image	Basic Tools Geoprocessing Attribute data Advanced attribute data Satellite Image Basic 3D 3D analysing 3D modelling
Directorate of Historical city in MUDL	Interview	Base map Feature data Documents Satellite images Aerial images	Basic Tools Geoprocessing Attribute data Advanced attribute data Satellite Images Basic 3D 3D analysis 3D Modelling
Strategic Development Project (SDP) at the MUDL	Interview	Base map Feature data Documents Satellite Images	Basic Tools Geoprocessing Attribute data Satellite image Basic 3D 3D Modelling

Directorate of Survey and Study at MUDL	Interview	Base map Feature data Documents Satellite images	Basic Tools Geoprocessing Attribute data Advanced attribute data Satellite Images Basic 3D
Avicenna University-Kabul	Interview	Base map Feature data Documents Satellite images	Basic Tools Geoprocessing Attribute data Satellite Images Basic 3D 3D Modelling

RESULT AND IMPLEMENTATION

The AH-SDI project was accommodated within the “Directorate for Preservation of Historic Cities” (DPHC) at the “Ministry of Urban Development and Land” (MUDL). The former is a new department that, by presidential decree, was created within the structure of MUDL specifically for the conservation of historic cities in Afghanistan [Presidential Decree 2017]. AH-SDI is the first project of its kind in Afghanistan, dedicated to documentation and preservation of urban heritage all over the country. It allows users to upload GIS layers and documents and to define permissions for the viewing, editing and downloading of their data. Also, users can log in to the geoportal, search within GIS data and documents (Fig. 7), view data that other users have uploaded, and edit and create maps from data (Fig. 8). In terms of copyright and the ownership of data, several approaches have been identified in terms of limiting access to the uploaded data.

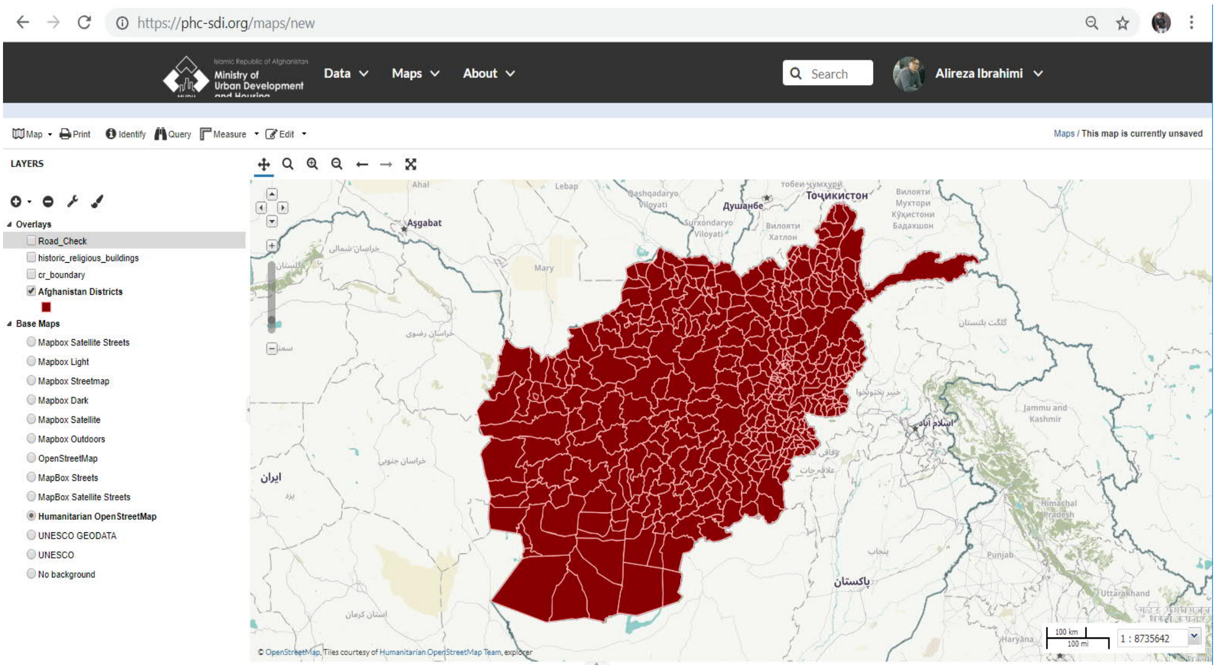

Fig. 6. Screenshot of layer preview with a base map

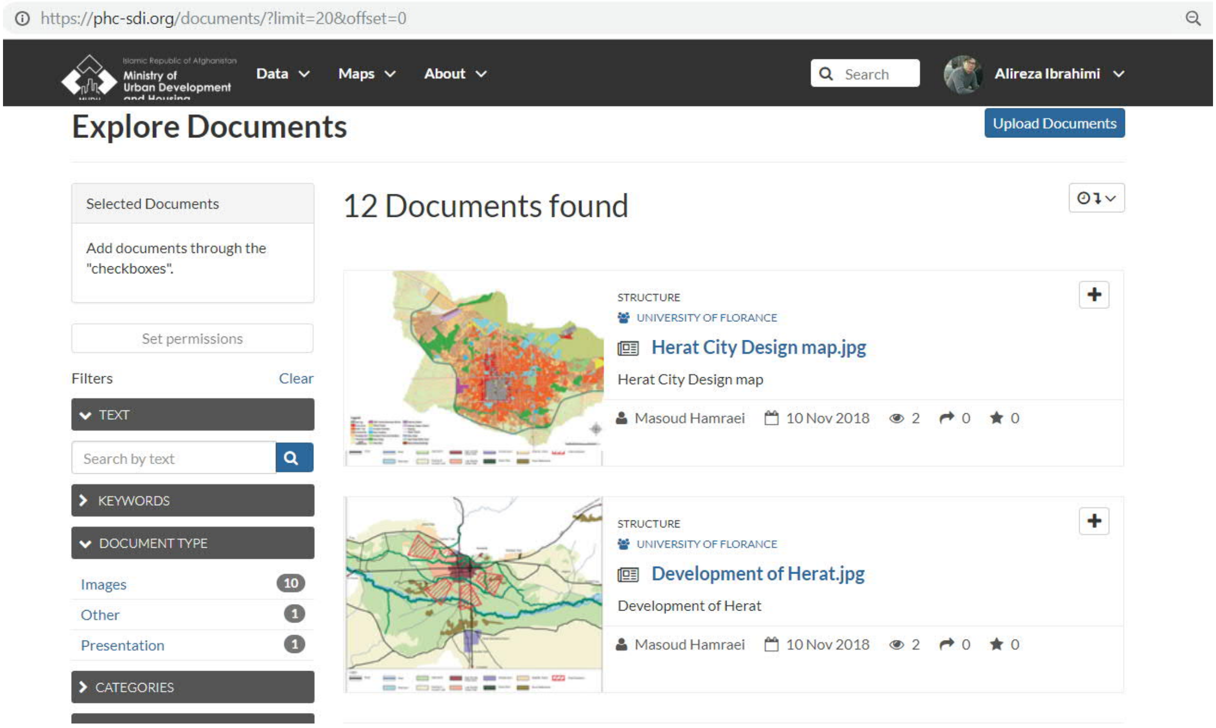

Fig. 7. Research documents about Herat in AH-SDI Geoportal

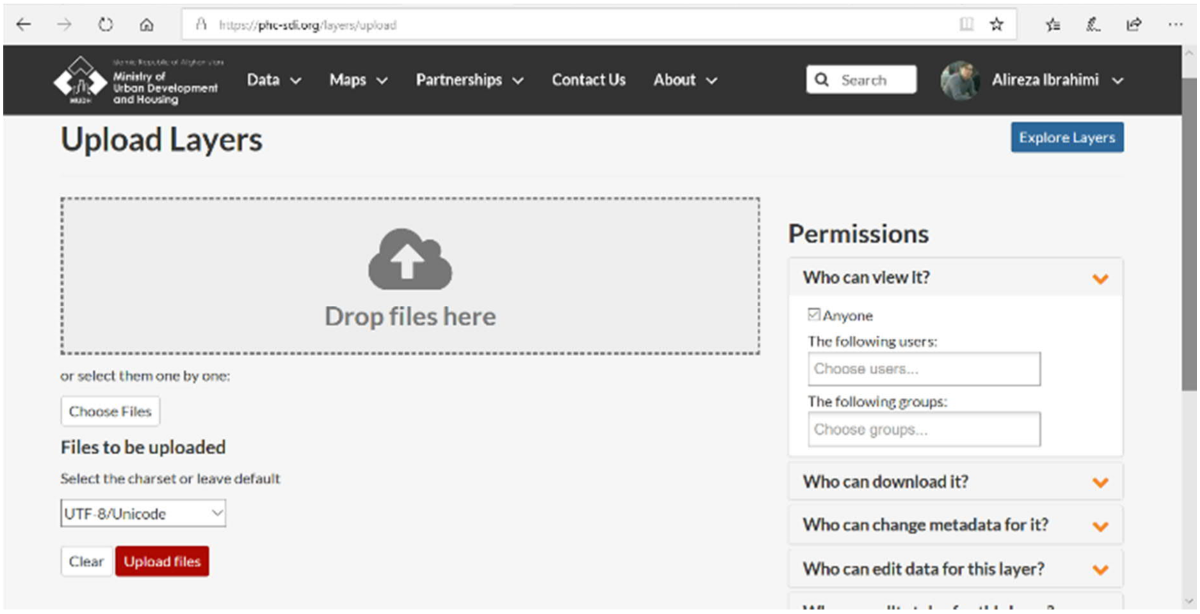

Fig. 8. Screenshot of Upload Layers page and permissions

Deployment:

To implement projects in a country like Afghanistan, with its insecurity and armed conflict, it is necessary to use a suitable approach. Two essential problems are a lack of proper infrastructure and a lack of specialised staff. DPHC had to change its data server three times, which included one instalment at the IT centre of MUDL, one commercial host in Spain, and, finally leading to a viable solution, an agreement of cooperation with the "German Archaeology Institute" (DAI) which allowed the project to use server hardware physically located in Berlin. The server problem affected the research work schedule, approach, and technique.

In the beginning, the project was established within the structure of MUDL. Therefore, the "IT Center" (ITC) Directorate was the first to deploy the data [ITC 2018]. There were distinct advantages at the ITC:

- The host and domain were free of charge, and there was no limitation to bandwidth and domain usage.
- Maintenance and management were easy because the server was physically close to the researchers and belonged to the ministry.

But at the same time there were some limitations:

- The necessary infrastructure in Kabul, such as electricity, was unreliable and sometimes caused server downtime, preventing users from getting access to the data.
- Afghanistan is still in a state of armed conflict, and political changes and institution transformations are rapid (since the start of the project in April 2018, the MUDL has experienced three ministers, and at the same time, two central institutions, the Land Administrations and the Ministry of Urban Development and Housing have been merged).
- The old structure of governmental ministries is too slow to cope with new technology, and they do not have much experience using the system.

To solve these problems, the server was changed from MUDL to a commercial host. The new host was acceptable in terms of speed and reliability and it provided backups and took over technical responsibility. But the host and domain were not free, and there was no viable process for payment by MUDL. Therefore, the fees were paid from personal accounts without the possibility of reimbursement. But the most important problem was that the partners who wanted to share data with the project did not trust a commercial host that was unknown to them.

In September 2018, after several negotiations, the DAI, a research institution which carries out archaeological excavations, expeditions and other archaeology-related work, was chosen as a technological project partner for DPHC [DAI 2018]. The advantages of this arrangement have been these:

- Host and domain are free for MUDL.
- Speed and reliability of the hosted site are good.
- Backups and other responsibilities are taken over by the DAI, in direct coordination with the AH-SDI project, until all such liabilities can be transferred to MUDL.

But there remain some limitations. The sustainability of the project in the frame of this cooperation remains the primary concern. The concern mainly stems from the context of Afghanistan, a country in which armed conflict has persisted for several decades. To address this challenge, having a third partner organisation can be an option. Such a partner should be able to take over long-term technical responsibility. DPHC is currently considering the UNESCO Kabul Office and Avicenna University in Kabul as the best candidates.

WIDE OPEN PROSPECT

The new government (National Unity Government since 2013) has been trying to centralise all digital information [GDCG 2010], providing a unique platform for cultural heritage managers to share data between stakeholders. By creating a new department dedicated to the historic urban fabric at the MUDL, the government has facilitated the documentation and registration of Afghan heritage. From a more global point of view, it is clear that IT has been expanding at high speed during the past decade, while Afghanistan has been beset by war. Therefore, the state has not been able to provide a platform for new technologies to enter the different fields of management. In the domain of IT, GIS-related software is among the most fertile areas to explore, and this SDI project can be a pioneer of its kind.

The biggest challenge regarding the implementation of the AH-SDI project concerns the sustainability and maintenance of this new data center, as was mentioned in the description of our negotiations with the DAI. Some international documents have emphasised this topic, such as the UNESCO Oman Recommendation that suggests "*that all the technical information produced by experts, agencies and UNESCO be centralised and shared as a single system by the Government of Afghanistan*" [UNESCO 2018]. A credible strategy needs to be formulated with the coordination of national and international organisations to allow the new data centre to become a stable component of Afghanistan's new digital infrastructure. It is vital that the Afghan authorities establish inter-ministries cooperation that can support its updating and maintenance.

ACKNOWLEDGEMENTS

The German Archaeological Institute generously provided the domain and host for this project. Special thanks to Benjamin Ducke and Toni Schönbuchner for their constant support at every step of this project. Without them, reaching this point would have been impossible.

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Imprint:
Proceedings of the 23rd International Conference on Cultural Heritage and New Technologies 2018. CHNT 23, 2018 (Vienna 2019). http://www.chnt.at/proceedings-chnt-23/
ISBN 978-3-200-06576-5

Editor/Publisher: Museen der Stadt Wien – Stadtarchäologie
Editorial Team: Wolfgang Börner, Susanne Uhlirz
The editor's office is not responsible for the linguistic correctness of the manuscripts.