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INTEGRATIVE GIS-BASED INVESTIGATION OF THE MEDIEVAL FORTRESS ARCHITECTURE OF PFALZ, INCORPORATING PHOTOGRAMMETRY, GEOINFORMATICS AND LANDSCAPE ANALYSIS

1. Introduction

The region of the Pfalz in the vicinity of Kaiserslautern played an instrumental role in the defense of the Holy Roman Empire during the High Middle Ages. Located along the highway from Metz to Worms, the area surrounding Kaiserslautern was heavily fortified during the reign of the Hohenstaufen emperors (1155-1250 AD) with the reconstruction of the royal palace in Lautern (Hotz 1981), the construction of the four hill-top castles of Hohenecken (Keddigkeit 2002, 378), Beilstein (Kraft 1934, 67), Perlenberg (Eckrich 1960), and Wilenstein (Dolch 2004), and the foundation of a Teutonic Knight Commandry in Einsiedel[1] (Fendler 1986). All six sites were built within 90 years of one another and some even replaced previous sites built during the Salian dynasty. Curiously, three of the sites are located within an area of only 2.5 km in diameter. Furthermore, all six sites exhibit the characteristic style of the Hohenstaufen period incorporating *Buckelquarder* stones (rectangular stones with rounded, protruding sides) in addition to Romanesque arched-windows and vaults at the palace in Lautern and the commandry in Einsiedel.

The castles of Hohenecken and Perlenberg, and the Teutonic Knight Commandry were constructed along the western portion of the high way upon which Lautern was situated, castle Beilstein was built along the eastern side, and castle Wilenstein is located further to the S. Though their primary purpose was to protect the palace in Lautern, they also provided a key base of operations within the larger network of fortresses throughout the Pfalz (Holtz 1981). The palace in Lautern was the focal point of the defense network, controlled by servants that had been brought from the Hohenstaufen-held area of Alzey to Lautern to serve as Ministerialen – unfree nobles raised from serfdom (Werle 1970-1971, 55)[2]. These families left an extensive corpus of documents pertaining to their feudal operations and often worked closely with one another. They were inextricably linked to the structures in which they resided and to those with whom they were financially affiliated. The influence

[1] Currently known as Einsiedlerhof in the city of Kaiserslautern.

[2] The Ministerialen replaced the nobles in the region (Hess-Gotthold 1962, 39), filling the important bureaucratic roles of the regional government (Werle 1970-1971, 55). This hierarchical structure greatly diminished the threat of internal political opponents because the Ministerialen owed their entire existence to the Hohenstaufen rulers.

of the sites mirrored the authority of the unfree nobles residing within them, whose power waned following the election of King Rudolf of Habsburg in 1273 (Bilfinger 1904, 87). The collapse of the influence of the Ministerialen resulted in new ownerships and allegiances between the four hill-top castles. Over the following four centuries, five of the six sites were besieged and destroyed, and all of the structures were ruins by the end of the 17th century.

The existence of towering fortresses of red stone near the main roadways may have had a psychological effect upon travelers, as physical representations of the empire placed at key positions, optimizing their control of the land. The position of structures at the intersection of mountains, lakes, forests, and flatlands would have required a strategic placement at the cross-section of multiple roads, while remaining in sight. Therefore it is important to study the sites within the historical environment to effectively analyze their construction, their proximity to roadways, and their defensive positions. Visualizing 3D models of the sites in conjunction with the extracted information from the historical documents presents an opportunity to conduct digital geospatial analyses using state-of-the-art Geographical Information Systems (GIS), photogrammetric (SfM – Structure from Motion), and laserscan technologies.

2. Main questions

Can the medieval landscape be re-discovered based upon information from historical deeds and maps, archaeological reports, and 3D models? Furthermore, can these factors be combined to conduct digitally generated geospatial analyses in order to shed light upon the original designs, positions, and strategies of the six sites?

Since the Middle Ages, the regional landscape has been significantly altered, suffering intense periods of scorched-earth war tactics, depopulation, deforestation, industrialization and subsequent pollution. Many of the former major medieval road ways have since disappeared or have evolved into occasionally traveled forest paths, and the major lakes from the medieval period have been drained. The vestiges of the Teutonic Knight Commandry and the ruins of castle Perlenberg, castle Beilstein, and the royal palace in Lautern offer little insight as to how the medieval structures may have looked. Although the designs of castles Hohenecken and Wilenstein can be fairly well assumed based upon their current states, castle Hohenecken was routinely renovated over the 360 years following its completion in 1200 AD, and castle Wilenstein was recently repurposed as a youth center in the 1960s (Orth 1963), veiling much of the original design. Information regarding construction phases and correspondences among the Ministerialen exist in medieval deeds and letters, though accurate maps of the area do not appear until after 1600 AD – nearly 350 years after the end of the reign of the Hohenstaufen dynasty – and almost

no depictions of the sites prior to these maps exist. Essentially, information regarding the depiction of the landscape has been hidden over the past 800 years by the destruction of the sites, the extreme alteration of the landscape, and the absence of archival material.

3. Hypothesis and objectives

Historically, the area was laden with lakes and transected by rivers making the region difficult to traverse, requiring efficient and well-protected roadways adjusting for the topographical limitations of the terrain. This would have mandated defensive structures to have been built upon more solid ground, or cliff-rock in the case of the four hill-top castles, unperturbed by flood zones. Visibility was a function of power in which rulers sought to see and to be seen. Thus, designing these sites to optimize the view of the neighboring areas, roadways, and contemporaneous fortresses would have been paramount[3]. The thick walls of the four hill-top castles, particularly the imposing 30 meter shield-wall at castle Hohenecken, and the sloped southern wall of the royal palace of Lautern provide evidence that the sites were constructed to withstand sieges and assaults based upon battery techniques of the time. Despite the rapid change in weaponry from the end of the 13th to the beginning of the 18th century, castle Hohenecken was still able to withstand a 50 day barrage from heavy cannons in 1665 (Lehmann, 1857). In essence, the sites were built to last, necessitating robust designs and more importantly, well-evaluated strategic positions to buttress such expenditures.

In order to reveal the medieval landscape and postulate the strategic positioning of the case study sites, integrative methods must be applied. The extracted information from the historical sources and the recording of the 3D models will be used in conjunction to one another to generate geospatial analyses of the sites in relation to their environment. To accomplish this task, the project is divided into two main components: the textual component and the visual component. The textual component of the project consists of the historical documents related to all six sites. These documents are composed of medieval deeds/letters (both copies of the originals and transcriptions), previous archaeological excavation reports, historical maps (Fig. 1), drawing/etchings, and histories of the case studies. The documents contextualize the project within the framework of the medieval culture, offering key details regarding the area surrounding the six sites, information specifying funding for structures, correspondences among the Ministerialen and nobles, the extent of fiefdoms, and the construction of the sites themselves. The objectives of

[3] The windows from castle Hohenecken are all located on the western, southern, and northern sides where they can view the valley. Whereas the eastern side faces the hill upon which the castle is located.

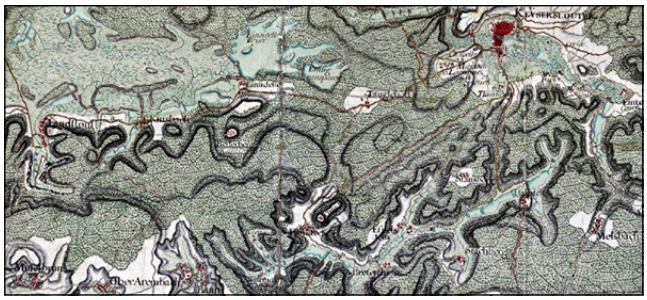

Fig. 1 – Excerpt of the map of the Palatinate Forest, from Jean-Jaques Nadin, 1736/1737.

the visual component are to merge SfM and laserscan models of each of the ruins of the six sites, in order to combine the high resolution imagery of SfM and measuring strength of Terrestrial LaserScan (TLS) data. Once digitized as merged 3D-models, the sites will be digitally examined, and placed atop the Aerial LaserScan (ALS) data of the terrain.

Both components, conducted in parallel, will be combined in a GIS in which a series of geospatial analyses will be conducted to determine what could be seen from all six sites, to discover areas hidden from the sight of the castles, the most energy efficient paths between the sites, and where water would have naturally drained and accumulated. Integrating these technologies is essential in combining as much information as is known about the area of the six sites. This process works backwards to complete a depiction of the landscape during the High Middle Ages to determine how the positions and efficiency of the designs of the sites were affected by the landscape.

4. Literature and research review

A complete landscape analysis of the region of the six sites has not yet been produced. The *Pfälzisches Burgenlexikon* series offers excellent historical synopses of each of the sites and what is known about them including – if applicable – their location, years of construction, histories, and previous excavations. The references from the *Pfälzisches Burgenlexikon* series compose the majority of the historical documents for this project. However, the neglect of historical inspection for sites such as castle Perlenberg over the past centuries regarding its construction and purpose has rendered it a sylvan mystery atop a lonely mountain. Nothing but brief histories and tales of hidden treasure exist for it since its destruction, though curiously, it is often misrepresented in 18th century maps for an early medieval site upon the mountain directly to the N. The *Pfälzisches Klosterlexikon* has the most complete accumulation of

information for the Teutonic Knight Commandry in the Einsiedel, including a new survey of its remnants. A highly detailed text from 1986 provides a thorough history of the Commandry even including agricultural holdings and trade amongst its neighbors (Fendler 1986).

Archaeological investigations of the sites have been limited, with the exception of the royal palace of Lautern and castle Beilstein, though the royal palace in Lautern and the castles of Hohenecken and Wilenstein have been periodically documented throughout the past 150 years. The latter two were surveyed as part of an 1887 publication on medieval defensive architecture of the Palatinate (Fallot-Burghardt 2001). Lautern was even thoroughly excavated in the 1930s in which Frankish graves from the 6th and 7th centuries were found in addition to some of the original walls and foundations of the structure built in the 12th century (Keddigkeit 1995). Unfortunately, the site of the royal palace fell victim to the bombings of WWII and many of the remnants found during the 1930s excavation were destroyed by the construction of the city hall of Kaiserslautern in the 1960s. In 1957, an excavation was conducted at castle Beilstein resulting in a report of the findings including ornate stonework and ceramics (Eckrich 1958). No other sites, besides the aforementioned excavations of Beilstein and the royal place, have been excavated.

Recently, the palace of Lautern was again excavated and rehabilitation measures in the form of a steel scaffolding atop the foundations of the southwestern chambers were implemented[4]. The deterioration of castle Hohenecken has been well-documented over the past 100 years offering a sobering account of poor preservation. Although it has been deteriorating since its destruction by the forces of Louis XIV in 1689, more damage has occurred in the last 90 years than in the centuries after its destruction. Photos from the 1920s show entire levels of the castle that currently no longer exist. Fortunately, a local organization, formed in 2007, has taken to protecting the site. Since 2014, over 60,000 euros have been invested in castle Hohenecken[5], repairing the remaining walls of the citadel and preserving its foundations[6].

The use of digital techniques to record, survey, and preserve cultural heritage has been steadily growing over the past 20 years, including studies combining SfM and laserscanning. A study from 2008 discussed the combination

[4] See *Vorbereitung für das Aufmauern laufen – Kaiserpfalz Kaiserslautern*, «Die Rheinpfalz», 9 July 2013.

[5] See J. Luttenberger, *Eine Krone für die Mauer – Deutsche Stiftung Denkmalschutz, Förderverein und Stadt investieren rund 56 000 in Nordpalas der Burg Hohenecken*, «Die Rheinpfalz», 21 May 2014.

[6] See H. Kruse, *„Jetzt läuft das Wasser wieder" – Förderverein der Burg hat allein 2014 fast 1000 Arbeitsstunden ehrenamtlich geleistet – Mitte Juni soll Fahne gehisst werden*, «Die Rheinpfalz», 7 May 2015.

and limitations of SfM and TLS at a medieval French castle. The authors noted that despite having placed the laser-scanner in 19 positions at castle Haut-Andlau, there were still many gaps in the data. They then combined the TLS point cloud with the SfM point cloud, which resulted in a complete model of the castle. The TLS data were particularly important because it could penetrate much of the vegetation. The authors noted that one technique cannot be preferred over the other because both SfM and TLS scans retrieve different data that are essential in analyzing medieval castles (Grussenmeyer *et al.* 2008). A study from 2012 discussed the adaptation of ALS data to reveal hidden sites within the landscape. They discovered the foundations of a tower from a neighboring castle using viewshed analyses in GIS. The discovery of the position of the tower using ALS data strengthens the argument for implementing laserscan technology in archaeology (Hoefle, Wagener 2012). This 2012 study provided a method in which nearby castles can be analyzed in order to evaluate their geographical relation to other sites, and to discover lost structures including towers and wall positions. Although these new and developing recording techniques are being widely implemented all across the world, the question of archaeological integrity, accuracy, and precision must be taken into account. A publication from 2016 addressed the issue regarding accuracy and precision in SfM methods, using the Temple of Hera at Olympia as the case study. The author noted that for SfM studies, calibrated markers should be used on-site whenever possible, because they significantly increase the accuracy of the orientation of the photos and reduce the time necessary for the generation of the 3D models (Sapirstein 2016). The methodology from this paper provides the basis for the SfM technique for all six sites in this project.

5. Methods

Most of the historical documents for the project have been collected from the Institut für Pfälzische Geschichte in Kaiserslautern and the University Library in Heidelberg. However, the original maps at the archives in Koblenz, Metz, and Speyer still have to be retrieved in the forms of digital scans to allow the maps to be analyzed outside the archive and to be implemented into the digital landscape model in GIS.

The corpus of documents composing the textual component consists of slightly more than 150 deeds/letters from the 12th to the 17th century including information regarding brickyards, agricultural fields, tolls, road signs, forest properties, logging rights, and even guesthouses. Though only the approximate areas are provided in the texts, all of the locations fall within the region where the structures are situated, and many are represented in the maps after 1500. The historical maps will be layered atop one another in a process known as non-rigid registration in which the maps are spread across the modern digitally

recorded landscape using certain landmarks as focal points. The more locations that are plotted, the more accurate the overlay of the map. Recurring sites such as the six sites under investigation and the aforementioned locations extracted from the historical documents will all be plotted. This procedure creates a digital depiction of the landscape based entirely upon historical sources and maps, upon which the 3D models can be fixed.

The SfM and laserscan models have been recorded at four of the six sites and are providing high-resolution images and incredibly precise measurements of the structures. Once one SfM and one laserscan model has been generated for each site, they will be merged into six models incorporating the advantages of both techniques for each site. The models allow for the rapid and precise calculation of chamber volumes, wall widths, heights, and surface areas. The widths of the walls will then be compared to one another, between structures as well, to assist in empirically determining which portions of the structures were most heavily fortified. These scans and cross-sections of the structures will also be compared with the historical surveys and cross-sections, particularly those that were produced for castle Hohenecken and the palace of Lautern over the past 130 years.

Once the models are combined into the digital landscape provided by the combination of the modern topography with the historical maps, the geospatial analyses of the sites in relation to the medieval environment will be generated. Viewshed Analyses from the structures will provide a depiction of what the inhabitants of the structures could have seen from the vantage points of each site. The calculated Viewshed Analyses will take into account uncertain vegetation patterns and will draw upon historical forestry data to determine the extent and volume of the forests at the time of the construction of the sites. Buffer Analyses surrounding the known medieval roadways will assist in demonstrating where the areas of least protection were located, regarding both topography and vegetation. The most efficient paths and roadways will then be determined using the Least Cost Path Analysis, heavily reliant upon the historical maps, in which the most direct and energy efficient paths will be calculated from the topographical ALS data based upon both distance and elevation. Conducting Watershed and Local Drainage Direction (LDD) Analyses of the area will help determine where the lakes were to be found and where water would have naturally drained and accumulated.

6. Current State and Future Work

Thus far, nearly all of the textual documents have been gathered and the main recurring sites have been identified. However, the historical maps have not yet been scanned from the archives in Koblenz, Metz, and Speyer. Additionally, high resolution photogrammetric and laserscan models of the

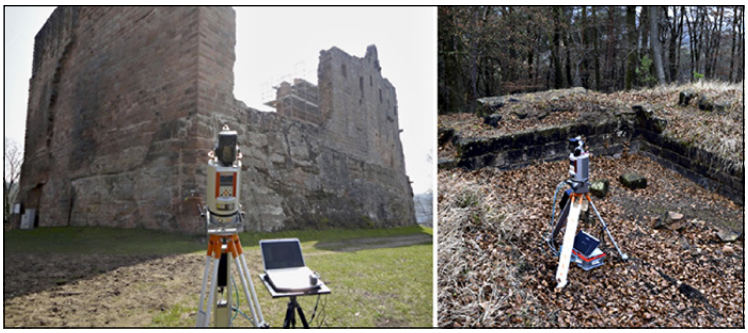

Fig. 2 – Riegl Laserscanner at castle Hohenecken (left) and castle Perlenberg (right).

Fig. 3 – Screenshot of the photogrammetric model of castle Hohenecken in CloudCompare.

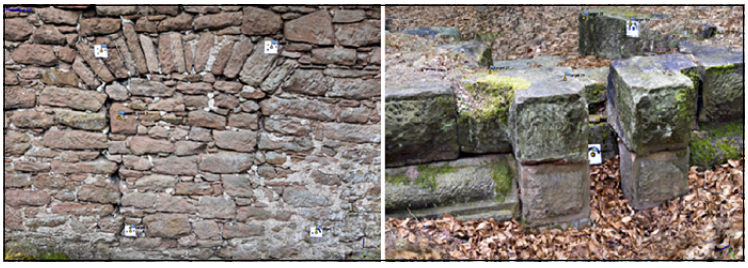

Fig. 4 – Photogrammetric screenshots of a portion of the wall at the Commandry in Einsiedel (left), and a portion of the wall at castle Perlenberg (right).

castles Hohenecken, Beilstein, and Perlenberg, as well as the remnants of the Teutonic Knight Commandry at Einsiedel (Figs. 2-4) have been generated, though the palace at Lautern and castle Wilenstein have not yet been recorded. Once they are recorded, they will be modeled using the same techniques.

Unifying the textual and visual components into an integrated digital landscape, model will open a portal into the past. The project essentially deduces the depiction of the landscape of the High Middle Ages by working backwards in time. Combining as many known sources as possible regarding the six sites allows for the most accurate analysis of the design, position, and strategy of the sites within the environment of their construction. The case study sites were expensive and took many years to construct, expand, and even reconstruct. The GIS-based geospatial analyses will bring into focus the importance of architectural design relative to the environment. This integrative approach incorporating traditional historical and archaeological research with state-of-the-art technologies will determine the historical environment and efficacy of the buildings, potentially shining light on the original designs that have been lost throughout the centuries.

Aaron Pattee
Heidelberg University
Institute for European Art History
acpattee30@gmail.com

Armin Volkmann
Heidelberg University
Cluster of Excellence – Asia and Europe in a Global Context
armin.volkmann@asia-europe.uni-heidelberg.de

Matthias Untermann
Heidelberg University
Institute for European Art History
m.untermann@zegk.uni-heidelberg.de

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ABSTRACT

This study explores the integration of photogrammetry, laser-scanning, GIS (Geographical Information Systems), and textual analysis to create a more holistic understanding of the effect of the landscape on medieval fortress design, position, and strategy in the area of Kaiserslautern, Germany, during the Middle Ages. The case study is composed of six defensive structures that served as key components to a larger network of fortresses built throughout the region of the Pfalz from 1050-1300 AD during the period of the High Middle Ages. All six structures will be modelled and linked into the digital landscape in GIS, with contextual information derived from historical documents creating a more complete depiction of the medieval territory once controlled by these prominent structures. The interdisciplinary nature of the project spanning art history, archaeology, anthropology, and computer science makes it both innovative and experimental. Access to high resolution models of the structures without having to be physically present at the sites is a significant advantage both for researching the architecture of the structures and for digital preservation efforts. The integrative technological approach will help determine the historical environment and efficacy of the buildings, potentially shedding light on the original designs that have been lost throughout the centuries.