INTRODUCTION

Lithic artefacts represent a crucial source of information in the archaeological record, serving as a window into the study of the evolution of human technological and ecological adaptations (Bar-Yosef/Kuhn 1999; Klein 2000; Ambrose 2001; Eerkens/Lipo 2007; Whiten/Schick/Toth 2009; Iovita 2010; Goodale/Andrefsky 2015; Lycett 2015). In the Middle Palaeolithic record, samples for lithic analyses are provided by categories such as blank production, retouched tools or debris presented within archaeological lithic assemblages. In this context, Middle Palaeolithic retouched tools are found intentionally worked unifacially as well as bifacially. Both cases commonly result in characteristic sharp active edges (Iovita 2010; Iovita/McPherron 2011; Retzek et al. 2019). Asymmetric tools as bifacial backed knives (hereafter *Keilmesser*) or »*Prądnik scrapers*« (hereafter *Prądnik scraper*) illustrate no exception in this technological characterisation. These asymmetric tools characterise the so-called »*Keilmessergruppen*« (KMG) (Mania 1990; Veil et al. 1994; Jöris 2004; 2006; 2012) and are known from Central and Eastern European archaeological sites dating from late OIS 5 until mid OIS 3 (Jöris 2004; 2006). In KMG assemblages, *Keilmesser* usually occur together with a spectrum of tools, for example hand axes, foliate pieces, scrapers and points of different shapes (Bosinski 1967; Jöris 2004). Within this spectrum, *Keilmesser* as well as *Prądnik scrapers* offer a unique opportunity to study several aspects, for instance tool standardisation and design, tool function and curation. Furthermore, *Keilmesser* represent an archive for tracing certain behavioural phenomena of Neanderthals such as learning strategies, the formation of tool making tradition and knowledge transfer across generations. One reason for that is their morphology.

Keilmesser can be described as tools with a sophisticated morphology and design, which is reflected by a combination of a single active edge opposed by a natural or roughly worked back (Krukowski 1939; Bosinski 1967; Jöris 2001; 2012). Numerous technological studies demonstrate that the manufacturing of the tools seems to follow an underlying concept, highlighting a high degree of tool standardisation (Jöris 1994; Veil et al. 1994; Richter 1997; Jöris 2001; 2012). Long reduction sequences have repeatedly been documented, allowing for detailed morpho-technological reconstructions of their use-life histories, including repeated phases of production, resharpening and reworking (in the sense of shape transformation) (Jöris 1994; Richter 1997; Pastoors 2001; Migal/Urbanowski 2006; Iovita 2014; Jöris 2001; 2006; Jöris/Uomini 2019). This has been argued as a technological strategy requiring the application of comparable production concepts and elaborated resharpening strategies. While these aspects concern tool standardisation, they also account for tool design. Tool design includes a multitude of aspects and goes beyond the overall tool shape. Design also involves the producer's anticipation of the envisaged tool function and its interaction with the user. Thereby, design can be reflected by more obvious aspects such as tool morphology and handling but also includes details like a specific edge retouch.

Within asymmetric tools, such as *Keilmesser* and *Prądnik scraper*, the active edge is seen as being the most characteristic part of the tool. *Keilmesser* mostly display a bifacially worked, acute active edge. Frequently, this edge is altered by the application of the so-called »*Prądnik method*« (hereafter *Prądnik method*) (Jöris 1992; 2006; Frick et al. 2017; Frick/Herkert 2019; Frick 2020a). Here, the *Prądnik method* describes a special type of lateral edge removal from the distal part of the tool (Bosinski 1969; Jöris 2001; Jöris/Uomini 2019). This modification detaches an elongated spall running from the tool's tip along the active lateral edge. This method is used to produce a stable and straight active edge (Jöris 2006; Frick et al. 2017; Frick/Herkert 2019). At the same time, it divides the active edge into two parts. Compared to the proximal part of the tool, the distal part seems frequently sharper due to a more acute edge angle. Given this observation, the

interpretation of *Keilmesser* as a tool with a multifunctional morphology arose (Jöris 2001; Rots 2009; Jöris 2006; 2012; Golovanova et al. 2017). However, this assumption has not been experimentally tested yet. Some tools testify a sequential application of the *Prądnik method*, leading researchers to the conclusion that this strategy is embedded within »resharpening cycles« on tool production, use and maintenance (Jöris 2001; Frick/Herkert 2019; Jöris/Uomini 2019). The implications of the *Prądnik method* are not conclusively clear. For instance, improvement of the edge angle in the sense of increasing sharpness has not been investigated in detail. A further question is also, which influence(s) the modification of the active edge has on tool efficiency and durability during a performed task.

Moreover, the possible influence(s) of the raw material has rarely been discussed. Although *Keilmesser* seem to be standardised in several aspects, the raw material used for the production of these tools has not always been the same (e. g. flint, silicified schist). This variability likely reflects intentional choices based on the availability and the characteristics of the individual raw materials. Raw material properties are known to have a significant impact on tool production and use (Odell 1981; Eren et al. 2016; Dogandžić et al. 2020; Key/Proffitt/de la Torre 2020). The effects of the raw material properties on the *Keilmesser* production, use and maintenance still need to be tested experimentally.

As previously mentioned, tool design also includes aspects such as tool handling and function. Since the back of a *Keilmesser* normally forms the thickest part of the tool and the lower surface is usually flatter compared to the more strongly curved upper surface (Jöris 2012; Weiss 2018; Wiśniewski et al. 2020), the morphological design supports the idea of a *Keilmesser* as a handheld tool (Jöris 2001; Frick et al. 2017; Jöris/Uomini 2019). Moreover, the tools can be distinguished into left-lateral and right-lateral specimens (Jöris/Uomini 2019). This distinction is based on the length-axial tool asymmetry. It has been argued that tool lateralisation reflects hand preferences and thus can serve as a proxy for human handedness. While techno-typological analyses have been conducted extensively (e. g. Krukowski 1939; Richter 1997; Jöris 2001; Pastoors 2001; Frick 2016a; 2016b; Weiss 2015; Weiss/Otcherednoy/Wiśniewski 2017), the same does not apply to other types of analysis, for instance use-wear studies (Rots 2009) or experimental approaches (Migal/Urbanowski 2006). This PhD thesis targets at filling this gap. Asymmetric tools such as *Keilmesser* and *Prądnik scraper* are highly suitable for this endeavour due to their special morphology. Already the fact that *Keilmesser* as well as *Prądnik scrapers* have only one active edge compared to other tools, such as hand axes, simplifies the analysis. It does not reduce the work, but leads instead to less complex and more reliable results when the spacial assignment (active edge VS back etc.) of the use-wear traces is given.

The aim of this study is to obtain a more precise picture about Late Middle Palaeolithic *Keilmesser* and *Prądnik scrapers*. Thus, the overarching research question is to gain a better understanding of the tools by combining data concerning the techno-typology as well as data regarding functionality and tool use. To test generally accepted models about *Keilmesser*, the approach chosen for this research moves beyond conventional technological and typological studies. The multidisciplinary approach also includes the analysis of 3D data, qualitative and quantitative use-wear analysis and controlled experiments. To capture tool design in more detail, high resolution 3D data, next to quantitative metric measurements and qualitative attributes, offer the possibility for testing these models. Within these analyses, a special focus lies on the detailed morphology of the tool's edge. To address tool use directly, use-wear analysis aims to combine qualitative and quantitative data. Additionally, controlled experiments add data to aspects such as tool use, performance, efficiency and durability. At the same time, the experiments are designed to test the possible functionality of *Keilmesser* by executing different movements such as cutting and carving. The influencing factor of the different raw materials involved – silicified schist and flint – and their properties, will be tested throughout the experiments.

Taken together, the proposed approach has two main goals. The first goal is to gain new data about *Keilmesser* focussing on tool design, function and use. This data aims to be predominantly quantitative over qualitative and thus, also statistically evaluable. The second goal of this study is to test given interpretations or accepted models about *Keilmesser*. The only way to do so is by applying a multidisciplinary approach. The combination of the different scales of analysis and methods as techno-typological and material properties studies, use-wear analysis and controlled experiments can lead to a more holistic view on *Keilmesser*. Investigating and understanding aspects as the underlying tool concept and design, as well as tool function and use is conditional upon tracing certain behavioural phenomena of Neanderthals such as learning strategies, knowledge transmission and the formation of rules and regulations that can be approached from such a perspective. The study of these asymmetric tools may contribute to answering such questions and may allow us to gain new insights into Late Middle Palaeolithic technological choices.

Three selected Middle Palaeolithic assemblages from Central Europe, namely Buhlen (Bosinski 1969; Bosinski/Kulick 1973; Jöris 2001), Balver Höhle (Andree 1928; Bahnschulte 1940; Günther 1964; 1988) and Ramioul (Vandebosch 1921; 1929; Ulrix-Closset 1975) serve as a case study. The Upper Site of Buhlen is a collapsed rock-shelter in northern Hesse, while Balver Höhle is a large cave in North Rhine-Westphalia, both are in Germany. Ramioul represents a cave located in Belgium. All three sites have been excavated mainly in the beginning of the twentieth century or in the case of Buhlen in the beginning of the second half of the twentieth century.

To address the research question, this study is structured as follows: »State-of-the-art« for the topics: 1) Middle Palaeolithic asymmetric tools and 2) Tool design. These are the topics building the foundation for this research. Based on this, a discussion of the research questions including all objectives and aim will follow. The chapter »Materials« refers to the archaeological sites, which serve as case studies. The chapter provides basic information about the archaeological sites selected for this research, including short excavation histories and the samples used in this study. The applied methods are outlined in the chapter »Methods«. Here, the methodological workflow of this study can be summarised in its main approaches: 1) Raw material characterisation, 2) Techno-typological analysis 3) Quantification of edge design, 4) Qualitative and quantitative use-wear analysis and lastly 6) Controlled experiments. The results of all these methods are presented in the subsequent chapter. The »Discussion« chapter refers to the major interpretations and implications resulting from the newly presented data. Aspects such as tool standardisation and design, the influence of the raw material properties in terms of tool modification, performance and efficiency and the edge design are part of the discussion. Also addressed are topics such as the tool lateralisation and the lateralisation as a proxy for human handedness, tool function and use. The following chapter »Conclusion« combines the aforementioned topics and aims to provide a more distinct and holistic view on *Keilmesser*. The chapter also addresses the role of *Keilmesser* in Late Middle Palaeolithic assemblages and the interpretations and inferences on Neanderthal behaviour, which can be made. Additionally, it also points out the limitations experienced within this research and elaborates further on existing unclear aspects. Finally, this PhD project highlights the necessary work, which could enhance specific future research.

Furthermore, images of all the use-wear traces documented on the archaeological artefacts as well as on the experimental samples can be found in the **appendix** (**I-II**).

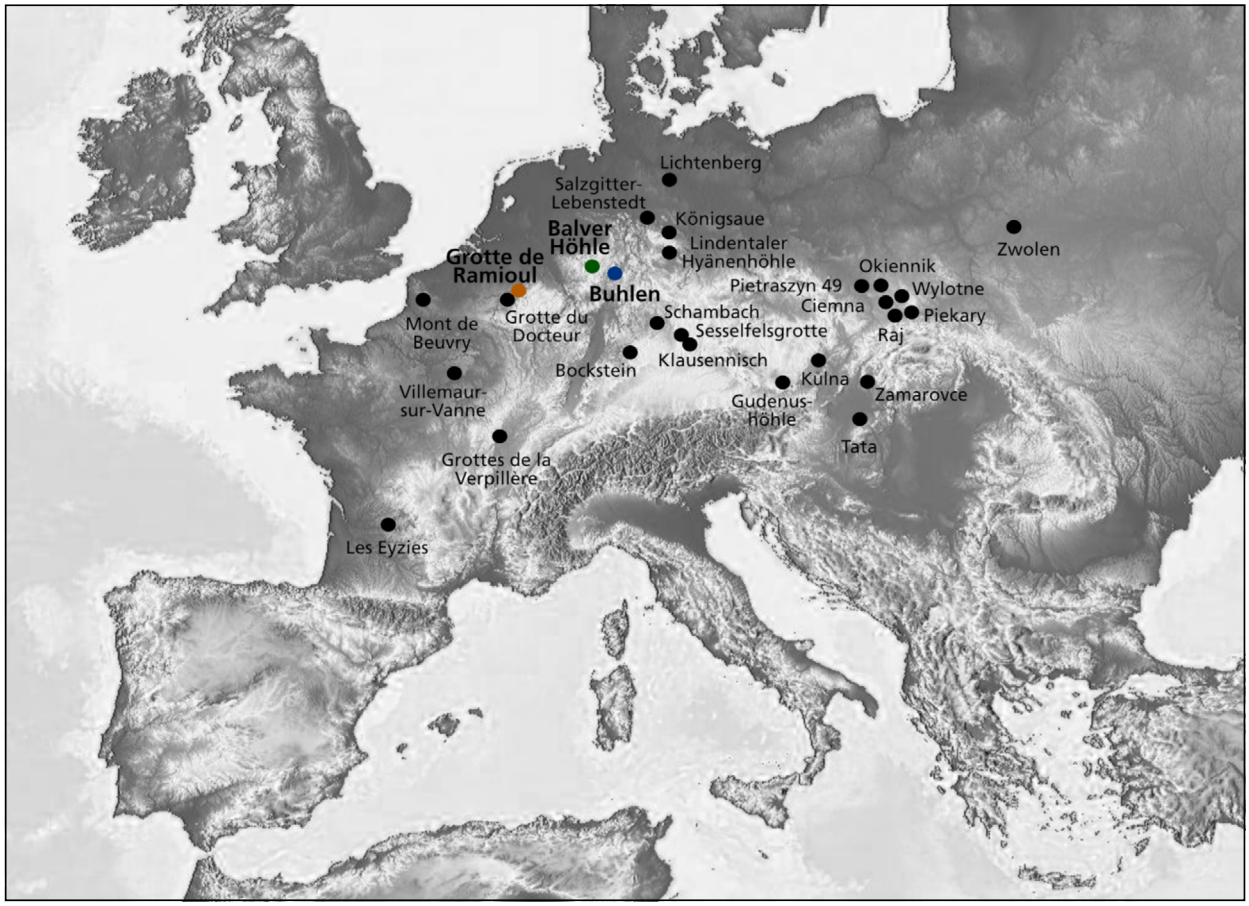

Fig. 1 Distribution of the major *Keilmessergruppen* sites in Central Europe. The sites of Buhlen (blue point), Balver Höhle (green dot), both in Germany and La Grotte de Ramioul, in Belgium (orange dot) are highlighted. – (The map is adapted from Jöris/Uomini 2019).