CONCLUSION

The research presented and discussed in this dissertation aimed to gain a more precise picture about asymmetric tools from the Late Middle Palaeolithic by testing common interpretations concerning their tool design and function. As a case study, *Keilmesser* and *Prądnik scrapers* as well as their resharpening debris, *Prądnik spalls,* from three sites – Buhlen, Balver Höhle and Ramioul – have been studied. Based on a multidisciplinary approach, including a functional analysis combined with controlled experiments, new data could be collected. To summarise the main findings, the addressed aspects concerning tool design are given in combination with the obtained results. The following conclusions can be drawn based on the data gained through the application of interrelated methods and techniques.

To start with, the first aspect concerns the results achieved through the raw material characterisation, which indicates the importance of raw material analyses in functional studies. The significance of the raw material regarding tool performance and wear formation could be clearly observed based on the results of the conducted experiments and quantitative use-wear analysis. During the sequential experiments, the observation could be made that lydite standard samples performed better than flint standard samples. Performance is thereby measured based on tool efficiency and durability. Although the lydite samples experienced more material loss and changes in the edge angles during usage, this did not affect the tool function. With one exception, all samples performed 2000 strokes without any maintenance processes. The flint standard samples displayed less material loss, but material loss is visually more similar to retouch than edge damage. The efficiency was evaluated via the contact material displacement and recording the penetration depth when constant force was applied. Lydite could be documented as less hard, but with a higher surface roughness compared to flint. Moreover, lydite contains schistosity planes and natural cracks, leading altogether to a more fragile impression. These raw material properties likely explain the better performance of the lydite samples in the course of the experiments. The material loss documented on the flint samples can be described as microfracturing, which is likely leading to the promotion of continuous »refresh« during tool use. In contrast, the minimal material loss observed on the flint samples seemed to have caused a blunting of the tool's edge in early stages. To achieve the same penetration depth with a flint sample compared to a lydite sample, additional force would need to be applied.

During the quantitative use-wear analysis, a second aspect related to the raw material of the samples became evident: the raw material properties of lydite promote the formation of use-wear traces more than the properties of flint do. As previously mentioned, the surface roughness of the machine-cut lydite samples is higher than the one from the flint samples. In the course of the sequential experiments, it could be documented, that from a qualitative point of view, the surface begins to change earlier than the surface from the flint samples. The results from the quantitative use-wear analysis performed for the »artificial VS. natural« experiment support this observation. It could be demonstrated that samples with initially higher *Sq* values (surface texture roughness), experienced more abrasion during the use, which is visible on the samples' surface as use-wear. To generalise, some raw materials seem to be, due to their properties, more prone to surface abrasion and thus, develop use-wear more easily. At the same time, *Sq* as a parameter for the surface texture roughness, can be pointed out as an indicator for tool use duration or intensity as it reflects surface abrasion processes. Correlated with the initial surface roughness of the artefact, the measured parameters for the use-wear traces can be put into relation. The observation from the experiments and the quantitative use-wear analysis taken together, emphasise the need of raw material characterisation in functional studies to create a framework for reliable and meaningful interpretations (Lerner 2014). Moreover, the results raise

a question, which requires further investigation; to which degree do the properties of the raw materials influence for instance the active edge design and tool resharpening?
Regarding the tool design, information could be gained through a techno-typological analysis, the quantification of the edge angles and the use-wear analysis. The overall tool design is often seen as standardised, following an underlying concept for tool production and curation (Jöris 1994; Veil et al. 1994; Richter 1997; Jöris 2001; Pastoors 2001; Migal/Urbaowski 2006; Jöris 2012). The results of the techno-typological analysis of the studied artefacts confirm this perspective. The individual tools from each archaeological assemblage share many features regarding the selected blanks, dimensions (e. g. relative standardised back thickness) and edge retouch (in particular regarding the perimeter attributes). This is not only the case for the artefacts *per* site, but applies also to the inter-site comparison.
The perimeter sections are seen as functional units (Jöris 2001; Iovita 2010; Frick et al. 2017; Weiss et al. 2018; Weiss 2020). The base and the back serve as a prehensile area. The distal posterior part is the most variable perimeter section, serving in many specimens as a striking platform for thinning the distal end of the tool, which further allowed edge angle maintenance of the active edge. These aspects could not be disproven based on the techno-typological results. On the contrary, the results of the perimeter section analysis support the idea of *Keilmesser* as being shape variable while changes occur isometrically in relation to the perimeter sections. Additionally, the qualitative use-wear analysis verified that the active edge is the area, concentrating the highest number of traces, and therefore, is interpreted as the used part of the tool. The amount of documented use-wear traces along the back and the base is significantly lower, which could be due to function as a prehensile area. Clear traces indicating a hafting of the tools could not be found, supporting the idea of *Keilmesser* as handheld tools (Jöris 2001; Jöris/Uomini 2019).
Additionally, *Keilmesser* are described as tools with a distinct laterality (Jöris/Uomini 2019; Frick/Herkert 2019). Laterality is seen as a proxy for handedness. This means, *Keilmesser* are either made by and/ or for individuals with a certain hand preference. The lateralisation of the studied artefacts was recorded, leading to an overall majority of right-lateral artefacts in Buhlen, Balve and Ramioul. Although evidence or indications for handedness in the Palaeolithic exist, these are often individual cases, not leading to any percentage figures. Nevertheless, several research studies indicate a bias towards the right-handedness (Ruck/Broadfield/Brown 2015; Uomini/Ruck 2019), as still valid for our modern population worldwide. Hence, the data obtained from the three archaeological assemblages builds on existing evidence concerning the predominance of right-handedness starting in early hominin populations. The laterality of the studied artefacts was addressed within the project, to see if the tool laterality can be confirmed by the use-wear analysis. Unfortunately, the data obtained with the qualitative and quantitative use-wear analysis did not provide significant evidence that could add more information to this topic.
Part of the overall tool design is the design of the active edge. To analyse the design, edge angle values along the entire tool active edge have been calculated. In the distal part of the tool, edge angles are more acute and increase in value towards the proximal part of the tool. The change amounts to a shift of 10° on average. The data for the proximal tool area is often near or above 60°, which is seen as a threshold for cutting tasks (Veil et al. 1994). This observation applies for *Keilmesser* with and without the modification by the application of the *Prądnik method*. However, *Keilmesser* characterised by a scar of the *Prądnik spall* removal at the distal part tend to have slightly more acute edges in this specific tool area. The difference is only small though and ranges between a few and maximum ten degrees. All *Keilmesser* display the same trend of diverging edge angle values in the distal and proximal tool parts. Thus, the data is in line with the morphological interpretation and supports the idea of *Keilmesser* as tools with bipartite edge morphology, whereas the focus lies on the distal tool edge. Thereby, the application of the *Prądnik method* likely fulfilled the purpose of resharpening the edge by creating more acute angles.

The aforementioned observation could also be addressed based on the results of the use-wear analysis performed on the *Prądnik spalls*. The results indicate the use of the tools, before the *Prądnik spalls* were removed. At least, some of the analysed primary *Prądnik spalls* show use-wear traces along the former active edge of the *Keilmesser* or *Prądnik scrapers.* This contradicts the idea, that the spalls were removed before the tool was subjected to use. The numerous secondary *Prądnik spalls* attest repeated (re-) sharpening sequences. Here again, the use-wear analysis could confirm traces along the former active edge of the *Keilmesser* or *Prądnik scrapers* on some pieces.

The idea of primary *Prądnik spalls* as a result of the tool finishing to create a bipartite active edge has led to the common interpretation of *Keilmesser* as multifunctional tools (Jöris 2001; 2006; Frick/Herkert 2019; Jöris/Uomini 2019; Frick 2020). Next to the edge angle calculation, the conducted use-wear analysis could provide further information regarding the type (e. g. polish, striations), the intensity and the location of use-wear. The results indicate a more versatile use compared to the other studied artefact categories, *Prądnik scrapers* and scrapers. Versatile means thereby that some artefacts show identical use-wear traces along the entire tool edge, some display traces either only in the distal or in the proximal part of the tool and others again illustrate diverging use-wear traces in both sections of the active edge. In general, data suggests that *Keilmesser* were either used for more than one single activity or that at least the handling (in the sense of how to hold the tool and how to perform a task) was not static, resulting in different locations and intensities of use-wear along the active edge. However, this does not exclude the possibility of some *Keilmesser* only being used for a single task solely. The conducted *second generation* experiments could confirm the suitability of certain edge angle values (extrapolated from the archaeological assemblages) for the performance of cutting as well as carving movements.

Keilmesser are not always the only asymmetric tools in Late Middle Palaeolithic assemblages. Some, as the three studied assemblages, also yield similar tools, here called *Prądnik scrapers.* One interpretation of *Prądnik scrapers* refers to them as simple, spontaneous and therefore less carefully produced versions of *Keilmesser* (Jöris 2001; 2004; Jöris/Uomini 2019; see also Weiss et al. 2018); another interpretation argues that *Prądnik scrapers* could have been produced by less experienced knappers, who imitate or copy more experienced knappers (Jöris/Uomini 2019). *Prądnik scrapers* do resemble *Keilmesser* in many ways. While the underlying tool concept as explained for *Keilmesser*, can also be in parts retrieved in *Prądnik scrapers*, other aspects differ. Both have the asymmetric shape in common, which is derived from the morphological components. In addition, *Prądnik scrapers* are modified by the application of the *Prądnik method*. Contrary to *Keilmesser*, the vast majority of *Prądnik scrapers* are produced from flakes and only unifacially or semi-bifacially retouched along the active edge. Moreover, (re-)sharpening processes, which go beyond the application of a primary *Prądnick spall* removal, and reworking are rarely documented for *Prądnik scrapers*. In summation, these results support the idea of *Prądnik scraper* as an »*ad hoc*« version of *Keilmesser*. However, the use-wear analysis does not support the idea of *Prądnik scrapers* mimicking, concerning their function. Based on these results, *Prądnik scrapers* do not display a versatile use in the sense of diverging use-wear types such as polish and striations, or the combination of those in different locations. However, the use-wear traces reflect a long-term or intense usage of the *Prądnik scrapers*. Additionally, the calculated edge angle values indicate a considerably more acute active edge with fewer differences in the values along the entire edge. Thus, due to their tool design, the data taken together supports the idea of *Prądnik scrapers* as a simplistic version of *Keilmesser*. At the same time, the results also suggest that *Prądnik scrapers* show less versatility in their handling and function than *Keilmesser*. Based on these findings, an alternative interpretation, which sees *Prądnik scrapers* as morphologically simplistic versions of *Keilmesser* with only a single function, will be proposed.

Additionally, new information about *Prądnik spalls* could be gained through the conducted qualitative use-wear analysis. Next to use-wear traces along the former active edge of the *Keilmesser* or *Prądnik scrapers*,

several use-wear traces could be documented in other locations on the dorsal as well as the ventral surface. The results of this analysis indicate that *Prądnik spalls* likely have been used as a tool after being removed from *Keilmesser* or *Prądnik scraper*. The edge angle calculation for the *Prądnik spalls* resulted in low values around 20° to 25° on average. Perhaps, these acute edge angles made them more suitable for certain tasks than other tools.

To summarise, asymmetric tools from the Late Middle Palaeolithic seem to be designed as standardised tools following a specific concept, which creates the typical morphology and allows for maintaining this morphology throughout the life-history of each individual tool. This observation is strengthened by the fact that these alleged standards are not only visible within the temporal resolution of one archaeological assemblage, but also across sites. Thus, these aspects taken together with the documented tool laterality, which, when seen as proxy for human handedness can be linked with social learning, knowledge transmission and the existence of certain rules and regulations, point towards the emerge of regional traditions. The *Keilmesser* tool concept would thereby be passed on as a skill from generation to generation.

In *Keilmesser*, the active edge design offers the possibility to perform different tasks. Based on the edge angle calculations and the results of the use-wear analysis, it seems as if these traits assign a unique role to *Keilmesser* within the studied artefact categories, but maybe also in *Keilmesser* assemblages in general.

As mentioned earlier, *Keilmesser* are well studied from a techno-typological point of view. However, use-wear on *Keilmesser* has rarely been addressed (Rots 2009); and, as a consequence, experiments focusing on tool use and function have not yet been conducted. This is precisely why a multidisciplinary approach promised the greatest chance of achieving new insights. As demonstrated, the results from the techno-typological approach only, could confirm the existing interpretations about *Keilmesser*. Interestingly, the data also showed that the three studied assemblages – Buhlen, Balve and Ramioul – share many similarities. However, the raw material analysis, the use-wear analysis and the conducted *second generation experiments* could enhance the data relating to this research topic. The calculation of the edge angle values made it possible to first quantify edge geometry and second, to verify assumptions about this design. From this point of view, the experiments fulfilled a similar goal. By conducting the experiments, the interpretations of the *Keilmesser* functionality could be tested. It could be demonstrated that the various tested edge angles (35°, 40°, 45° and 60°) can be used to perform unidirectional cutting as well as carving movements. At the same time, these sequential experiments made it possible to gain information about the mechanics behind tool abrasion and the formation of use-wear. To current knowledge, this project is the first one to illustrate this, applying qualitative and quantitative use-wear analysis to a lithic assemblage of this size. In particular the combination of both use-wear disciplines is new for lithic studies. Together, these two analyses led to new data concerning the use of *Keilmesser*, *Prądnik scrapers* and *Prądnik spalls*, especially to their use intensity.

While the application of the mentioned methods and techniques could provide a more distinct picture about asymmetric tools from the Late Middle Palaeolithic, they also have their limitations. The first limitation relates to the experiments. *Second generation experiments*, such as the conducted ones, focus on basic fundamental mechanics by testing the effect of individual variables. This means at the same time, the obtained results are only valid within the exact same experimental framework. The results cannot directly be transferred to the archaeological record. Certainly, the results can be extrapolated, but still, they need to be tested again within another experimental setup. Thus, a *second generation experiment* in itself is limited. To overcome this limitation, a subsequent *third generation experiment* should be conducted (Marreiros et al. 2020), incorporating the human variability and testing the models detected during the previous generation of experiments. The second limitation could be experienced regarding the quantitative use-wear analysis. Quantitative use-wear analysis is a relatively new approach in archaeology. This means, reference collections or interpretations of the data are rarely existing. Most quantitative use-wear studies have been applied on

experimental samples (Stemp/Stemp 2001; 2003; Lerner et al. 2007; Evans/Donahue 2008; Evans/Macdonald 2011; Stemp/Chung 2011; Giusca et al. 2012; Ibáñez/Lazuen/González-Urquijo 2018; Galland et al. 2019; Stemp/Macdonald/Gleason 2019; Álvarez-Fernández et al. 2020; Pedergnana et al. 2020b), some on archaeological bone samples (d'Errico/Backwell 2009; Martisius et al. 2018; Bradfield 2020; Martisius et al. 2020). Quantitative use-wear studies on lithic artefacts are not published yet and especially a raw material such as silicified schist has not been the focus of such studies yet. Unfortunately, that makes the interpretation of the data insecure and complicated, in particular when trying to infer on the contact material. Although, following international standards (ISO 25178-2) for data analysis offers a secure way, it does not explain the data itself. The relevance of the individual parameters for lithic studies is not conclusively known yet.

Based on these conclusions, the following recommendations for future research can be made. Firstly, the importance of raw material characterisation should again be stressed. The raw material properties play an important role concerning various aspects such as tool production, curation and performance as well as material abrasion, and therefore, the formation of use-wear traces. To obtain reliable results throughout quantitative use-wear analyses, besides the use-wear traces, the original surface should also be measured. The identification of properties such as the surface texture roughness will provide information necessary to understand how the use-wear formed. Since the development of use-wear is the result of surface abrasion (Schmidt et al. 2020), these processes are highly dependent on the raw material of the used sample. Without analysing these properties, the mechanics behind the use-wear formation cannot be incorporated in the overall interpretation. As demonstrated, within the experimental frame, the raw material properties likely play a more important role than the contact material. Further research is needed to determine the effects of the contact material in the process of use-wear formation. However, since the mechanics, which affect the sample during use, are not entirely understood, functional interpretations of diagnostic use-wear traces should be made with caution. Without this important background information, a judgment regarding the performed task or the contact material can only result in speculation. These observations lead to a second aspect. Use-wear studies would benefit from the incorporation of tribology. An interdisciplinary research approach including tribology would help to understand principles such as friction and lubrication and the cause-effect relation of wear formation. To better understand the implications of these observations, future studies could address these tribological principles, in order to build a framework to transfer theoretical and experimental results to the archaeological record.

Lithic artefacts provide key insights into early hominin behaviour. The study of stone tools such as Late Middle Palaeolithic artefacts helps to contextualise technological adaptability, innovations and dynamics in Neanderthal behavioural choices. By analysing the three *Keilmesser* assemblages from Buhlen, Balver Höhle and la Grotte de Ramioul new data concerning tool design, usage and functionality could be gathered. *Keilmesser* represent thereby such a complex and sophisticated artefact category, offering the potential to address numerous fundamental aspects. These aspects cover nearly the entire range of features that are possible to study on lithics. This includes raw material selection, tool production, maintenance and reworking, tool handling, functionality and use. In *Keilmesser*, all these features are combined in one specific tool design. Moreover, this tool design illustrates a technology, which has been kept and transmitted over long periods of time, giving clear indications on Neanderthal behaviour. Together, this makes it likely, that this tool design fulfilled a specific purpose. The data could be achieved through the employment of different methods and scales of analysis. For the first time, *Keilmesser* have been studied by combining techno-typological analyses with controlled experiments as well as qualitative and quantitative use-wear analysis. Consequently, the research presented herein provides a more holistic view on *Keilmesser.* Thus, this study adds a significant piece to the puzzle of our understanding of the evolutionary trajectory of past human behaviour.