Asterixe: Past, Present and Future – Expert Meeting Report 2024

Wilhelm, K.[1*], Gulotta, D.2, Viles, H.[1]

[1] School of Geography and the Environment, University of Oxford, South Parks Road, Oxford, OX1 3QY, UK. ORCID: 0000 000230395643

[2] Getty Conservation Institute, 1200 Getty Center Drive, Suite 700. Los Angeles, CA 90049, USA

Executive Summary

The 'Asterixe: Past, present and future' expert meeting in May 2023 involved a series of activities to plug gaps in the history of the project, review ongoing research initiatives, and inform future strategic directions for research on the Asterixe. This report captures the retrospective nature of the meeting, aiming to preserve the institutional memory of this pioneering project, document lessons learned, and outline its relevance as a case study for long-term exposure trials. The event highlighted the innovative aspects of the Asterixe project, such as its complex sample design, and explored how these approaches could inform future research methodologies.

The expert meeting evolved around a series of structured yet flexible activities, including individual interviews and collaborative discussions. It brought together some of the people involved in the original project with those working on the Asterixe now. The agenda included introductions, questions about the initial motivation and design of the project, and presentations on recent research activities by teams from the Fraunhofer Institute for Building Physics (IBP), Getty Conservation Institute, and the University of Oxford. Participants also went on a guided tour of the Asterixe test site and the IBP institute to discuss the remaining Asterixe specimens and the methods deployed to investigate them. The day concluded with a recollection and debriefing session, fostering reflections on the event and the project's broader legacy.

The key anticipated and planned outputs included the collection of additional historical data and photographs, recording and transcription of senior Asterixe experts' memories, and the production of this report. Crucially, the meeting also served as a starting point for the formation of a network of interested parties for an international research community focusing on long-term, large-scale exposure trials. By using the Asterixe project as a model, this network aims to draw from past successes and challenges to guide the design and governance of future trials.

Overall, the Expert Meeting served as a vital step in both preserving the Asterixe project's institutional knowledge and memory and providing insights for long-term, large-scale exposure trials. The Asterixe project offers a unique case study that underscores the need to balance innovative designs with practical implementation, making it a valuable reference point for future initiatives.

Key take home messages are:

- Persistent interest in stone exposure trials
- Need for a good balance between 'too simplified' and 'too complex' designs

- Strong collaborative interest in researching the effects of air pollution and microbiology on stone bioprotection
- Need to establish a global network for studying the environmental impact on natural stones and their conservation

1 Introduction

The Expert Meeting brought together scientists and conservators involved with the 'Stone deterioration and stone conservation' project funded by the German Ministry of Research and Technology (BMFT, now BMBF) between 1986 and 1996 with researchers from the Fraunhofer Institute for Building Physics (IBP), University of Oxford, and the Getty Conservation Institute.

Unlike other conservation efforts of the time, the Asterixe project stood out for its focus on combining scientific rigor with real-world applicability. By simulating architectural features typical of medieval cathedrals, the project aimed to provide insights into the long-term behaviour of stone under environmental stressors. The original project exposed two types of blocks of varying size and complexity (which, because of the shape of the larger ones became known as Asterixe and Idefixe) at two sites (Duisburg in the industrial NW of Germany, and Holzkirchen in the wetter, colder and more rural SW of the country; Figures 1, 2). The aim of the trial was to investigate the impact of different environmental conditions, set against the backdrop of 1980s concerns about air pollution and in particular acid rain. During the 1980s, acid rain was recognised as a major environmental threat, not only to forests (Waldsterben) but also to cultural heritage sites; particularly concerning for countries with historic stone-built architecture. Though collaboration between countries was limited at the time (pre-EU), parallel programs in countries like Germany and the UK (National Material Exposure Program, NMEP) demonstrate a growing awareness for the need of conservation efforts to tackle these challenges. The project also focused on trialling a number of conservation treatments and evaluating their performance. The main outputs of the project are a book series – Jahresberichte Steinzerfall – Steinkonservierung (1991 - 1996)– together with a bibliography (Quellennachweis zur Forschung fuer die Denkmalpflege BMFT-Foerderprojekte 1986-1994).

Although the project officially ended in the late 1990s, some of the exposure blocks remain in situ, others have been archived, and sporadic attempts have been made to investigate them further. Since 2019 scientists from the Fraunhofer IBP, University of Oxford and the Getty Conservation Institute have combined forces to rediscover the archived exposure samples, and carry out further measurements on them and those still in situ, as published in Wilhelm et al., 2020, 2022. There is ample opportunity for further research on the samples. We here use the shorthand term 'the Asterixe project' to refer to the combined past, present and potential future of this unique exposure trial.

Figure 1 Germany, Holzkirchen, test site with 'Asterixe' specimen (Snethlage 2005, p77).

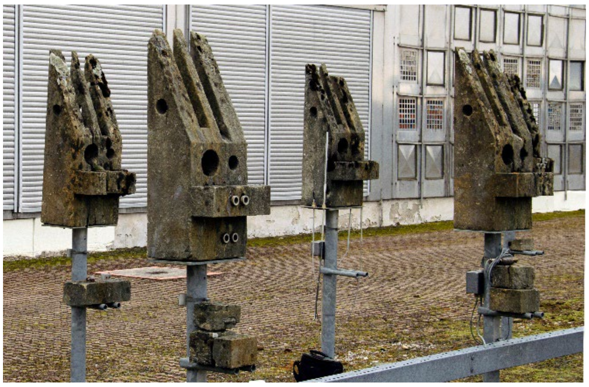

Figure 2 Germany, Holzkirchen, test site with 'Asterixe' specimen with (fragmented) Idefixe specimen below (Wilhelm 2019).

The aim of the expert meeting was to fill gaps in the records about the motivation, design and implementation of the original Asterixe project, as well as to share information about more recent investigations of the Asterixe samples, and develop ideas for future research. Furthermore, the meeting used the experience of the Asterixe exposure trial as a starting point for discussions of a research agenda for a future international network of long-term, large-scale exposure trials. The meeting was truly inter-generational, linking researchers at all stages of their careers from early career to retired. Several of the participants have worked for well over 35 years on stone deterioration and their combined expertise is enormous (Figure 3). A list of the participants, with information on their affiliation is reported in Appendix.

This report summarises the major discussion points and outcomes of the meeting, and is based on notes taken in individual interviews, and during the workshop, as well as an audio transcript.

Figure 3 Former Asterix project experts; from left to right Juergen Legrum, Thomas Warscheid, Stefan Brueggerhoff, Kurt Kiessl, Martin Krus (2023).

2 Discussion points

a) The past: Information which filled in gaps in knowledge about the original Asterixe exposure trial.

What was the original project design, and why did it change over time?

Eleven stone types were originally used to make the Asterixe, and they were chosen as all being commonly used in Germany, and showing a diversity of physical characteristics and environmental response (susceptibility) to weathering. Stefan Brueggerhoff was the original coordinator of the project. The Idefixe blocks (30 x 15 x 10 cm; derived from the lower part of the Asterixe specimen) were exposed alongside the Asterixe in order to allow invasive sampling (e.g. for microbiology) and avoid damage to the complex Asterixe (Figure 1, 2).

At the Duisburg site around this time there were also some of the 'carousels' of small stone samples as used in a parallel exposure trial (International Materials Exposure Programme or IMEP) which may have been archived at the German Mining Museum (Deutsche Bergbau-Musuem Bochum). There was also another exposure project at roughly the same time, called the IDEAS project, jointly run in Germany and Brazil (Minas Gerais, with some samples in Belo Horizonte; Figure 4). This project used simpler blocks than the Asterixe project, but with some architectural features. A further contemporaneous exposure trial involving large triangular prisms of 10 stone types exposed at 6 sites in North-Rhine-Westphalia and Bavaria, Germany which aimed to investigate the performance of waterproofing treatments and consolidants was also mentioned by Stefan Brueggerhoff (for further details and some recent additional research see Braun et al., 2020 and Kunz et al, 2022).

Figure 4 Examples for simpler blocks (compared to the Asterixe) exposed in Brazil as part of the IDEAS project (source: E. Wendler).

Sep and Nov 1995 in Duisburg and Holzkirchen respectively, two of the Asterixe stone types (Ihrlersteiner and Sander Sandstone) were treated with water repellents or consolidants. The project aimed to help innovate conservation treatments, and employed a consolidant on epoxy basis (SSS250) and a hydrophobic treatment based on Polyurethan basis (SSS219; Figure 5 shows an excerpt from the report IBAC Zwischenbericht F8454/1, p 5.

Schutzstoff-bezeichnung	Lösemittel	Filmbildende Komponente	Feststoff-gehalt M.-%
1	2	3	4
219	n-Butylacetat	Polyurethan-Prepolymer	25
250	Methylisobutylketon	Epoxidharz	21

Figure 5 Excerpt of historic archival material with explanation as to what SSS250 and SSS219 refer to. Schutzstoffbezeichung=name of the conservation agent; Loesemittel=solvent; Filmbildended Komponente=consolidating component; Feststoffgehalt=solid matter. Epoxidharz=epoxy resin.[1]

The Asterixe were cleaned with sand blasting before consolidation. The Holzkirchen ones proved particularly difficult to treat because of the growth of biofilms. At the Duisburg site, spray based application methods were used (including a prototype robot spraying system), whereas different methods were used at Holzkirchen (immersion). Some success was recorded with using a polyurethane monomeric water repellent on some of the Asterixe some of which are still at Holzkirchen.

Many different sets of measurements were taken on the Asterixe and Idefixe. For example, Michael Steiger carried out measurements of runoff water from some of the Asterixe using an elaborate gutter system, and his team also took many measurements of air pollution. When he took over from Stefan Brueggerhoff as coordinator of the project, there was a strong interest in the impacts of air pollution on building stones, and so more of a focus on the Duisburg rather than the Holzkirchen site, and particularly the accumulation of salts within the Asterixe at Duisburg. The biofilm growth on the Asterixe was also studied in detail, as an earlier trial on concrete had found that microbes were very important to deterioration. Thomas Warscheid (TW) noted that the methods used to quantify microbial growth in the 1980s and 1990s were no longer acceptable and so current growths could not be compared with those found during the earlier phase of the project. The assessment during the early phases of the program only targeted microbial counts and did not include any investigation of the biofilm community, in terms of diversity and structure. This was clearly linked to the methodologies available at the time. TW pointed out the limitations of such an approach which, for example, cannot provide any functional information.

The Duisburg site was hosted on Krupps industry land, and in 2008 they needed to close the site so the Asterixe were removed. Some of them were rescued by Gabrielle Grassegger, others have been looked after by Thomas Warscheid in his lab (or garden) in Bremen, Germany. Archiving samples may have 'stopped the clock' in terms of deterioration caused by external factors (air pollution, rain, biofilms, salt), but the samples today may have become altered since their participation in the exposure trial came to an end. Not all the Asterixe from Holzkirchen have remained in situ but have been moved elsewhere.

[1] In IBAC Zwischenbericht F8454/1, p 5.

Why was the size and shape of the Asterixe decided upon?

The design of the Asterixe was, in large part, aimed to mimic the variety of architectural features found on medieval cathedrals. The impact of air pollution on such cathedrals and, in general, on stone heritage, across Europe was a major concern in the mid 1980s, and so there was much interest in understanding the impact of geometry and orientation on the deterioration of some typical architectural features, including sloping surfaces, overhangs, and hollow areas. Kurt Kiessl was important in their design, and there were discussions with Pressbau and Arnold Wolf from the Cologne cathedral mason's team. D Dahmen, a technician at Pressbau also played a key role.

How were the Asterixe produced and how much did they cost?

Because of their size and complex design, the Asterixe required bespoke production methods, which led to their high cost of 3-5,000 Deutschmarks ($3400-5700 USD). The expense of creating the Asterixe may have been one reason why some specimens were used even though they had obvious defects at start of their exposure (e.g. one Ihrlesteiner presented a crack at the time of its installation).

How was change in the Asterixe specimens over time detected?

When the Asterixe project started in the mid 1980s many methods which are commonly used today were not available, and equipment and protocols used were sometimes different. For example, the UPV method used in the early stages of the project produced data which is hard to compare with data collected more recently (Wilhelm et al., 2022). Karsten tubes were used to investigate water penetration, but 5 cm diameter tubes were used (rather than the usual 2.5 cm diameter ones which are the standard today). Some datasets from the 1980s, such as those collected by colorimetry, have proven to be straightforward to compare with those obtained by more modern devices as calculations were based on a standard color space still in use (CIEl*a*b). The complex geometry of the Asterixe also made the application of some analytical methods to detect change challenging, limiting the array of methods that could be used. The high cost of the Asterixe meant that non destructive sampling methods were preferred. The smaller, simpler blocks of the same stone types (Idefix) were used for more invasive analyses, in order to preserve the high value Asterixe. For example, scraping of small areas of the surface was undertaken to sample the microbiological growths, which caused some slight disfigurement.
It was understood that the Idefixe weathered differently compared to the Asterixe and it was concluded that those could not be compared. The other issue with the Idefixe now is that they are more "mobile" than the Asterixe and thus, labelling and consequently knowing about their conservation history proves challenging.

Which treatments/ consolidants were trialled on the Asterixe?

The Asterixe project was used to test some innovative consolidants, some of which have not been properly documented. The Asterixe were left to weather until in November 1995 five Ihlersteiner Asterixe at Holzkirchen were treated with one of two consolidants (a hydrophobic silane modified polyurethane prepolymer – Co. Bayer Leverkusen; solvent n-

Butylacetat; solid matter 25w%) and a non-hydrophobic epoxy based resin (solvent Methylisobutylketon; solid matter 21w%) after almost 10 years of field exposure (Figure 6).

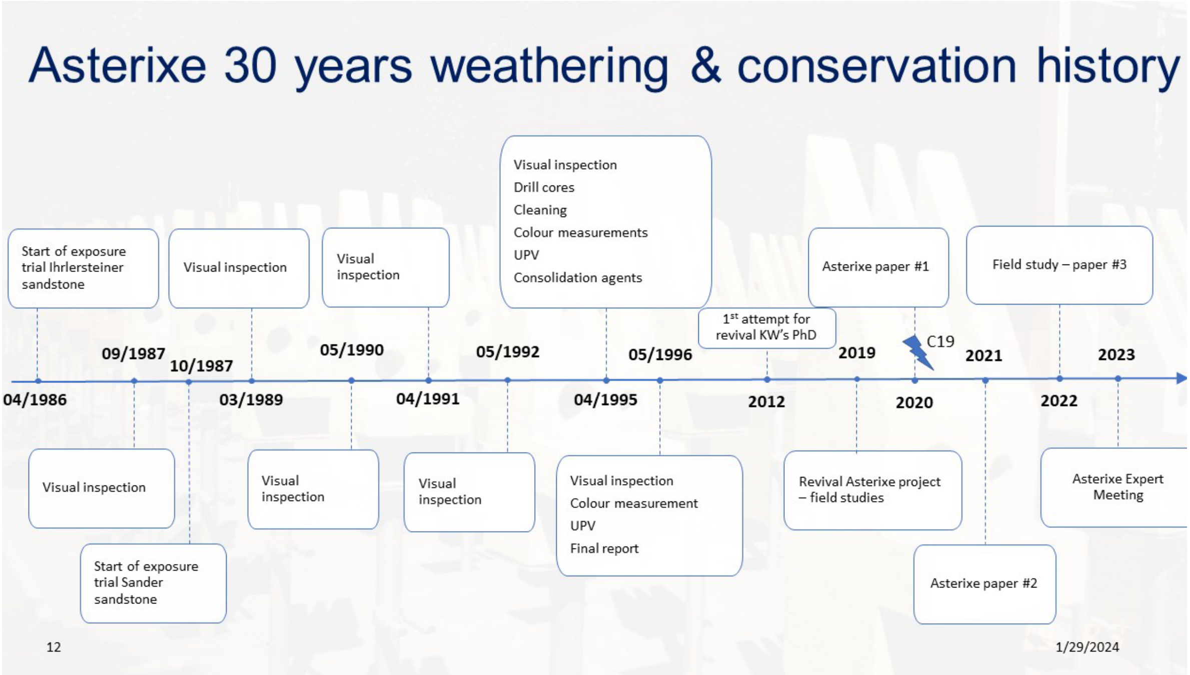

Figure 6 A timeline of the Asterixe history with key event such as consolidant application.

b) The present and future: Discussion of what is being done and could be done in future.

What has been done since 2019 on the Asterixe samples and what methods could be used in future?

As well as the recently-collected colorimetry, UPV and Karsten tube data from the Asterixe specimens still exposed at Holzkirchen which has been compared with earlier datasets, data has also been collected on surface hardness (using an Equotip device), subsurface moisture contents (using a microwave moisture measurement system) and microbial functional activity (Wilhelm et al., 2020, 2022). Photogrammetry has also been deployed to produce a 3D model with sub-mm accuracy, with the complex geometry of selected Sander sandstone Asterixe with and without consolidation treatment, requiring c. 80 photos to capture all the topographical elements. Furthermore, a vast array of archival material has been collected and digitised by Katrin Wilhelm to form the basis of a technical report on the Asterixe project. A range of different methods have been used to capture 3D models of the Asterixe. Kristina Holl and Ralf Kilian have also led on trials of Terahertz imaging, in situ 3D microscopy (which proved problematical), CT scans, and established a field balance set-up to allow in situ measurement of weight changes of selected Asterixe at Holzkirchen. They have also developed a Fraunhofer own Wikipage dedicated to the Asterixe project.

The group suggested a range of other methods which could be used in the near future to investigate the Asterixe and Idefixe, such as DRMS, video microscopy, multispectral imaging, thermal IR and functional profiling of the microbiome using modern methods.

Possible future research projects on the Asterixe

There is clearly huge scope for carrying out more studies on the remaining in situ Asterixe at Holzkirchen, as well as the Asterixe which were rescued from Duisburg and have been in storage since then. The group identified several potential future directions as listed below, which might be particularly suitable for doctoral students.

- Investigating the responses of the 11 stone types to prolonged natural exposure. Have the trends in deterioration that were identified on untreated Asterixe after 10 years of exposure continued? How do they relate to trends in key climate and air quality variables?
- Evaluating the performance of the past conservation treatments and the retreatability of the stones after 20+ years. How might new consolidation treatments perform?
- Understanding the long term bioreceptivity of sandstone. What is growing there and what is it doing on some contrasting stone types? Thomas Warscheid noted that clays in Sander sandstone encourage biogrowths, and that some biofilms have considerable impact on water-transport properties (this is also evident in our Karsten tube measurements). Ihlersteiner sandstone has also been shown to be particularly sensitive to microbial growths. Could one or more Asterixe at Holzkichen be cleaned and monitored in comparison with Asterixe of the same stone types with biofilm growth? Could the microbial biofilms on the Holzkirchen Asterixe be compared with those found on the archived Duisburg samples? Can we identify the impact of the consolidation treatments on the bio-susceptibility of treated vs. untreated Asterixe made of the same stone?
- The complex geometry of the Asterixe specimens provides an excellent opportunity to investigate the spatial patterning of microbial biofilms and their impacts on the underlying stone.
- The Asterixe from Holzkirchen and Duisburg could also be investigated for soluble salt contamination (with the caveat that the Duisburg ones have more complex histories of exposure and storage). Michael Steiger expressed interest in running analyses on the salts to investigate the long-term influence of air quality.
- Evaluating the response of samples aged naturally over the long term to new treatments, and comparing the characteristics of the naturally-weathered Asterixe with artificially weathered stone samples in order to improve artificial weathering methods based on observations of long term field behaviour.

(see Appendix III for further details)

c) Lessons learnt from the Asterixe project which could inform a future network of long-term exposure trials.

The challenges and successes of the Asterixe project provide a very useful bank of evidence for future exposure trials, and the group gave many useful suggestions and ideas based on their experience of working on this 30+ year project.

Project funding, management and governance

One key consideration for a larger scale future network of exposure trials based on the experience of the Asterixe and other allied projects (e.g. ICP materials) is the difficulty of securing long term funding. Most funding schemes work on <10 year timeframes, whereas one lesson of the Asterixe project is the huge value of stewarding and maintaining exposure trials over much longer periods. In the case of the Asterixe project this required passion and commitment from a few individuals who have worked hard to revitalise the project at various stages (including all the participants in this expert meeting). Any long-term project (>10 years) also faces a number of challenges in terms of changing personnel and support from the organisations involved as demonstrated by the Asterixe project as people retired, moved on, and one site had to close after the official end of the project. This can result in gaps in information, which can sometimes be filled by consulting the original people involved (as happened with this expert meeting).

Strong governance and clear decision-making are needed to ensure that a large scale, long term project can deliver on short, medium and long-term objectives. While a significant amount of data from the early parts of the Asterixe project have been published (mainly in German which adds a barrier), and much more has been archived safely, some remains unanalysed and the Asterixe project demonstrates how much work needs to go into making the results available.

The closure of the Duisburg site in 2008 illustrates the logistical vulnerabilities of long-term research projects. The subsequent removal of specimens, leading to challenges in preserving their condition and ensuring consistent data interpretation. Future projects should prioritise securing long-term agreements for site access to mitigate risks of site closure. Establishing contingency plans for specimen storage and data continuity can ensure the longevity of research, even in the face of unforeseen disruptions.

Additionally, it is crucial to identify key drivers that will not only make a compelling case for supporting the research in the long term but also sustain it. Initially, the Asterixe project concentrated on acid rain and air pollution, reflecting concerns prevalent in the 1980s. However, as these issues were considered less critical due to regulatory changes (and partial reduction in air pollution), research priorities now have shifted toward the impacts of climate change, such as increased thermal stress, severe weather events such as flooding and wind-driven rain, and microbial activity. This evolution underscores the need for flexible research frameworks capable of addressing emerging threats.

Coping with change

The Asterixe project exemplifies clearly the issues facing long term exposure trials as external conditions change, and methods for data collection and storage change. When the project started, the main threat to German stone-built heritage was seen to be air pollution and acid rain. Today, it is clear that climate change provides a new and as yet unquantified stimulus to stone deterioration. Further threats may come from hydrocarbons, and the interactions between air pollution, climate change and microbial biofilms. How should long term projects be designed to facilitate clear evaluation of current threats, and also remain relevant for the assessment of unknown future threats? Long term exposure trials in future need to strike a balance between being hypothesis-testing driven and designed for more 'blue-skies' observations because of the likely changes in conditions.

Obsolescence of methods used to collect data was also raised as a problem during our discussion of the Asterixe project. High quality time series of change are hard to establish as a result. Equipment is superseded by new designs which can produce incompatible datasets (e.g. the UPV methods used in the 1980s and 2020s). One approach to mitigating this risk is to ensure that older equipment involved in the early stages of a long-term project is kept in working order and archived, to allow cross-checking against newer equipment. Choosing the right sample size and shape for a long-term exposure trial can be complicated when current equipment requirements differ from those of future equipment. Such considerations of obsolescence and change also relate to data storage methods, as today's external hard drives may turn into the floppy discs of the future.

Project design

The Asterixe project and other similar projects started in the 1980s, such as the UK's NMEP, illustrate the difficulties of designing a long-term exposure trial to balance complexity of sample design (to replicate reality) and replication of samples (to ensure meaningful results). Using very large, expensive and complex samples of 11 stone types at 2 sites as in the Asterixe project, may be compared with using small, cheap and simple samples of 2 stone types at 29 sites as in the NMEP (Butlin et al., 1992). There are pros and cons of both approaches. The size and complexity of the Asterixe samples is much more representative of real historic stonework than the 50 x 50 x 8 mm tablets used in the NMEP. The NMEP samples were also prone to loss and the carousels on which they were mounted did not always rotate freely as designed. However, the small size and easily movable nature of the NMEP samples meant that repeat measurements of weight could be taken easily, providing a simple metric of change. Discussion amongst the group suggested that samples roughly the size of the Asterixe, but with a simpler design, might be a sensible option for a future project.

Particular lessons learnt in terms of project design from the Asterixe project include:

- **Choice of stone types** – in particular whether to focus on commonly used stones (and if so, where should they be commonly used?) or whether to focus on problem stones which suffer particularly from deterioration. Experience of the Asterixe project suggests that inhomogeneous stones, such as Ihrlersteiner sandstone, can be challenging (and perhaps Bamberg sandstone which is similar mineralogically and weathers quickly, but is more homogeneous might be a better alternative in future).
- **Choice of sample size and shape** – balancing simplicity and cost against mimicking conditions found on historic stone buildings. The use of both complex and simple samples (as with Asterixe and Idefixe) could be a good way forward, although several members of the group suggested that the Asterixe design could usefully be simplified (in particular having the same features on both/all sides). From looking at the remaining Asterixe in situ at Holzkirchen another suggestion from the group was that holes for monitoring could be built in to the design to enable better data collection on change in subsurface conditions.

- **Choice of exposure methods** – the deficiencies of complex systems to mount samples, like the NMEP carousels, can be contrasted with the simple mounting system of the Asterixe. However, during group discussions it became obvious that mounting the Asterixe directly on metal plates had initially led to unnaturally saturated conditions towards the base of the samples and was subsequently rectified. So, care needs to be taken in testing and evaluating the exposure methods before a large-scale, long-term project gets under way.
- **Importance of controls** – it is unclear whether the Asterixe project had parallel samples of each stone type kept in controlled conditions (and assumed to not suffer from any deterioration over the course of the project). Such controls are a highly important part of any experimental design and maintaining them can be difficult over the course of a long project given changes in personnel and organisations involved. Stefan Brueggerhoff also suggested that a set of short-term exposure blocks would be helpful, with exposure periods of 1-5 years followed by storage under controlled conditions.
- **Data accessibility and collaboration** – Creating centralised digital repositories for archival materials and datasets can facilitate collaboration and ensure broader accessibility for international research networks. The International Co-operative Programme on Effects on Materials including Historic and Cultural Monuments (ICP Materials) serves as a good example (https://www.ri.se/en/icp-materials?refid=18).

3 Meeting outcomes – take home messages

There are some very clear take aways:

- There is a sustained scientific interest in conducting stone exposure trials, which are crucial for advancing our understanding of stone weathering processes and conservation strategies. (See Appendix II and III for Brueggerhoff's and BHRI's concepts respectively)
- A critical need exists to achieve an optimal balance in experimental design, navigating between overly simplistic and excessively complex models, to effectively simulate real-world stone deterioration conditions.
- The establishment of a comprehensive global network of natural stone exposure sites is recognized as invaluable. Such a network would facilitate a more profound understanding of the environmental responses of different stone types and the efficacy of various conservation interventions, particularly in the context of evolving environmental stressors
- There is a strong consensus on the importance of collaborative research efforts, especially focusing on the effects of air pollution and the role of microbiology in stone bioprotection. Investigating these areas is expected to yield significant insights. The interplay between air pollution and microbial activity in the context of stone deterioration and preservation is an under-researched area, yet it is anticipated to become increasingly relevant due to climate change impacts. In this context, Mike Steiger's observations on sulphur dioxide (SO2) concentrations are noteworthy. He suggests that despite a decrease in SO2 levels, its reactivity with stone surfaces may not necessarily diminish; rather, the efficiency of its uptake might have increased. This highlights the need for further research in this area. Additionally, there is a

consensus on the types of stones to be prioritized in future trials, with Portland limestone being a specific example.

On an ethnographic note, the expert meeting successfully brought together multiple generations of international stone weathering scientists, fostering a strong sense of community and shared purpose. This format could serve as a valuable template for future exposure trial networks, prompting reflection on the community's social dynamics, norms, and practices. Are these dynamics consistent over time, or do they evolve with the shifting priorities and methodologies of the field? This collaborative approach not only strengthens the scientific foundation of long-term projects but also ensures the continuity and evolution of knowledge across generations, paving the way for innovative and resilient research communities.

4 References

Braun, F., Orlowsky, J. and Brüggerhoff, S., 2020. Analyzing near-surface regions of hydrophobic and long-term weathered natural stones at microscopic scale. *Heritage*, *3*(2), pp.457-473.

Butlin, R.N., Coote, A.T., Devenish, M., Hughes, I.S.C., Hutchens, C.M., Irwin, J.G., Lloyd, G.O., Massey, S.W., Webb, A.H. and Yates, T.J.S., 1992. Preliminary results from the analysis of metal samples from the National Materials Exposure Programme (NMEP). *Atmospheric Environment. Part B. Urban Atmosphere*, *26*(2), pp.199-206.

Kunz, A., Groh, M., Braun, F., Brüggerhoff, S. and Orlowsky, J., 2022. Durability assessment of differently orientated surfaces of treated long-term weathered natural stones. *Journal of Cultural Heritage*, *53*, pp.176-183.

Snethlage, R. (2005). 30 Jahre Steinkonservierung. Stein: Zerfall und Konservierung. S. A. Siegesmund, M.; Snethlage, R., Edition Leipzig.

Wilhelm, K., Gulotta, D., Leslie, A., Krus, M., Thome, V., Kilian, R and Viles, H. 2020 Reviving 'Asterixe': a unique long-term archive for built heritage research. In: Siegesmund, S and Middendorf, B. (eds) *Monument Future: Decay and Conservation of Stone*, pp. 351-356. Halle/Saale: Mitteldeutscher Verlag.

Wilhelm, K., Gulotta, D., Krus, M., Kilian, R and Viles, H. 2022 Complexities in comparing UPV data over a >30-year exposure trial of consolidated sandstone. In: Delgado Rodrigues, J and Menezes, M. (eds) *International Symposium Stone Consolidation in Cultural Heritage*, pp.103-113.

Appendix

Appendix I
List of participants and interviewees of the expert workshop

#	Country	First name	Last name	Affiliation
1	GER	Stefan	Bichlmair	IBP
2	GER	Stefan	Brueggerhoff	Deutsches Bergbau – Museum Bochum
3	US	Davide	Gulotta	Getty Conservation Institute
4	GER	Timo	Hevesi-Toth	IBP
5	GER	Kristina	Holl	IBP
6	GER	Kurt	Kiessl	NA
7	GER	Ralf	Kilian	Fraunhofer IBP

8	GER	Martin	Krus	Fraunhofer IBP
9	GER	Helmut	Kuenzel	IBP
10	GER	Hartwig	Künzel	IBP
11	US	Tom	Learner	Getty Conservation Institute
12	GER	Juergen	Legrum	
13	GER	Hans	Leonhard	NA
14	US	Nicole	Onishi	Getty Conservation Institute
15	GER	Gehard	Riedel	IBP
16	GER	Michael	Steiger	Universität Hamburg, Faculty of Mathematics, Informatics and Natural Sciences, Fachbereich Chemie
17	UK	Heather	Viles	University of Oxford
18	GER	Thomas	Warscheid	Head at LBW-Bioconsult
19	GER	Eberhard	Wendler	Fachlabor für Konservierungsfragen in der Denkmalpfege
20	UK	Katrin	Wilhelm	University of Oxford

Appendix II

Freilandexposition mit Naturstein
S. Brueggerhoff
Gedanken zu einer Projektkonzeption (erstellt im Jahr 2004)

Welche Basis steht zur Verfügung

Asterix-Exponate in Duisburg und Holzkirchen
Blockprüfkörper in Duisburg und (Holzkirchen?)
Kleinprüfkörper in Duisburg und (Holzkirchen?)
Alle Prüfkörper überwiegend unbehandelt (?)
Steinsorten, Stückzahlen??
Aufstellung= Bewitterungszeitraum: ab 1987?? (alle??)

Prismenprüfkörper an sechs Standorten (Dortmund, Duisburg, Eifel, Nürnberg, München, Kempten)
10 Steinsorten (in Bayern nur acht) mit je zwei unbehandelten und 14 behandelten Exponaten)

Welche Ziele könnten angestrebt werden

1. Beschreibung der Verwitterungsrate in einem Zeitraum, der von stark zurückgehender und geänderter Immissionsbelastung geprägt ist. Aussagen zur Bedeutung der aktuellen Schadstoffsituation bei der Bewertung von Schadensfaktoren für den Denkmalschutz

1a. Untersuchung der Schadstoffeinträge unter den geänderten Bedingungen (Vergleich mit Objekt wäre sinnvoll um den Fortschritt in einem anderen Schadensausmaß (anderer Startzeitpunkt) zu erhalten. Hier liegengut untersuchte Ausgangsbedingungen vor)

1b Untersuchung der Schadensentwicklung (siehe 1a)

2. Beschreibung der Bedeutung biologischen Einflüsse bei den heutigen Einflußbedingungen
2a Welche Bedeutung haben diese in der derzeitigen Belastungssituation (Klima, Schadstoffe)
(Da hier mit frischem Material begonnen wurde, kann die Bedeutung besser abgeschätzt werden, als wenn wir eine Momentaufnahme an einem Objekt betrachten)
2b Kann eine Beseitigung durch „Biozide“ eine Verbesserung bringen?

3. Welchen Einfluss haben die Schutzmittel auf den Verwitterungsprozess?

4. Welche Dauerhaftigkeit besitzen die Schutzmittel und über welche Mechanismen werden sie abgebaut?

5. Aufbau eines langfristigen„nationalen Expositionsfeld-Programms“ für die Beurteilung der Natursteinverwitterung

Auf welches Datenmaterial können wir uns stützen?

Wo liegen, welche Daten in welchem Zustand vor:
- Aufstellungsdaten
- Behandlungsdaten (Konservierungsmittel, Biozide)
- Klimaeinflüsse
- Schadstoffeinflüsse
- Zustand des Ausgangsmaterials in:

mineralogischer Hinsicht, im Hinblick auf Schadstoffe, im Hinblick auf (bau)physikalische Parameter
- Zustand bei Zwischenphasen in:

mineralogischer Hinsicht, im Hinblick auf Schadstoffe, im Hinblick auf (bau)physikalische Parameter, in Bezug biogenen Bewuchs
- Beprobungsergebnisse

Welche Schritte unternehmen wir im Hinblick auf eine Antragserstellung?

- Wollen wir nach der ersten Sichtung und Klärung der Ziele einen Antrag stellen?
- Was sind die Projektziele?
- Wer soll sich beteiligen?
- Mit welchen Teilaufgaben?
- Wie formulieren wir einen Antrag?
    - Abklären bei welchem Förderer bestehen Aussichten?
        - in Frage kommende Organisationen
        - Wer klärt dies bei den Organisationen ab?
        - Wie wird abgeklärt? (vorab nur telef.? oder sofort kleine Skizze erstellen?)
        - Wie entsteht die Skizze (Initiator, Beteiligung)?
        - Bis wann muss sie vorliegen?
- Welche Dauer soll das Projekt haben?
- Welchen finanziellen Umfang kann man heute durchsetzen?
- Wie soll die Zusammenarbeit aussehen?
- Wie gehen wir mit der Fa. Thyssen-Krupp um?
    - Ist eine langfristige Initiative („Nationales Expositionsprogramm“) realistisch?
    - Welche Formen müssten für so einen Zusammenschluss gewählt werden?

Appendix III
Wilhelm, K., et al. (2020). Reviving 'Asterixe': a unique long-term archive for built heritage research. Monument Future: Decay and Conservation of Stone. S. Siegesmund and B. Middendorf. Halle/Saale, Mitteldeutscher Verlag**:** 351–356.

Appendix IV
Selected outputs

Publikationsliste Brüggerhoff (zum Thema Freilandexposition von Natursteinmaterial)

1. BRÜGGERHOFF, S. (1989):
Gesteinsverwitterung in Freilandversuchsfeldern - Erfahrungen ihrer Errichtung und Nutzung.
Bautenschutz und Bausanierung, Sonderh. Bausubstanzerhaltung in der Denkmalpflege
Verlagsgesellschaft R. Müller, Köln, S. 76-80

2. BRÜGGERHOFF, S., MIRWALD, P.W. (1991):
Expositionsversuche mit Naturstein zum Studium vonVerwitterungsvorgängen an Denkmälern.
Beitrag: 20. Jahrestagung der Gesellschaft für Umweltsimulation (GUS), Pfinztal, 7.-8. März 1991

3. BRÜGGERHOFF,S., MIRWALD, P.W. (1991):
Expositionsversuche mit Naturstein - Studium von Verwitterungsvorgängen an Denkmälern.
Berichte der Deutschen Mineralogischen Gesellschaft, Beihefte zum European Journal of Mineralogy,Vol.3, No.1, E. Schweizerbart´sche Verlagsbuchhandlung Stuttgart, S. 46

4. BRÜGGERHOFF, S., MIRWALD, P.W. (1992):
Examination of complex weathering processes on different stone materials by field exposure studies.
Proceedings: VIIth International Congress on Deterioration and Conservation of stone, 15.-18.6.92, Lissabon, S. 715-724

5. BRÜGGERHOFF, S., MIRWALD, P.W. (1993):
Dosis-Depositionsstudien an ausgewählten Natursteinmaterialien.
in: Materialien in ihrer Umwelt; Kommission Reinhaltung der Luft im VDI und DIN, VDI-Verlag, Düsseldorf, 1993, Band 1060, S. 269-280

6. BRÜGGERHOFF, S. (1993):
Freilandexpositionsstudien zur Erforschung des Natursteinzerfalls -
Eine Zusammenfassung der nationalen und internationalen Aktivitäten.
in: Materialien in ihrer Umwelt. Kommission Reinhaltung der Luft im VDI und DIN, VDI-Verlag, Düsseldorf, 1993, Band 1060, S. 85-97

7. BRÜGGERHOFF, S., LAIDIG, G., SCHNEIDER, J. (1993):
Exposition von Naturstein in Rheinland-Pfalz.
in: Materialien in ihrer Umwelt. Kommission Reinhaltung der Luft im VDI und DIN, VDI-Verlag, Düsseldorf, 1993, Band 1060, S. 345-357

8. BRÜGGERHOFF, S., LAIDIG, G., SCHNEIDER, J. (1993):
Untersuchungen zur Wirkung saurer Immissionskomponenten auf Baumberger Kalksandstein als Indikatormaterial.
Herausgegeben vom Landesamt für Umweltschutz und Gewerbeaufsicht Rheinland-Pfalz, Mainz im Juni 1993, 112 Seiten

9. MIRWALD, P.W. BRÜGGERHOFF, S. (1995):
Verwitterungsvorgänge an Kalkstein unter mitteleuropäischen Klima- und Immissionsbedingungen - Ergebnisse aus Freiland-Expositionsversuchen
Geol. Paläont. Mitt. Innsbruck, Bd. 20, S. 207-220

10. BRUCHERTSEIFER, Chr., BRÜGGERHOFF, S., GROBE, J., STOPPEK- LANGNER, K. (1995): Long-term exposure of treated natural stone - development and first results of a testing concept. Proceedings: 1st International Symposium on Surface Treatment of Building Materials with Water Repellant Agents, 9.-10.11.1995, Delft, Niederlande, Beitrag: 27, 1- 11.

11. KRAUSE, G., SPECOVIUS, J., GARUS, G., BRÜGGERHOFF, S. (1995):
Exposure of materials in areas with different pollution climates.
Posterbeitrag: International Conference on Acidic Deposition - Acid Rain `95, 26. - 30.6.1995, Göteborg, Schweden

12. FIMMEL, R, MIRWALD, P.W. &. BRÜGGERHOFF, S. (1996):
Baumberg calcareous sandstone - a sensor material for various environmental influences - comparative results of a field exposure study. Proceedings: European commission research workshop „Origin, mechanism and effects of salts on degradation of monuments in marine and continental environments“ vom 25.-27.3.1996 in Bari/Italien, S. 323-329

13. BRÜGGERHOFF, S., MIRWALD, P.W. (1996):
Dosis-Depositionsstudien an ausgewählten Natursteinmaterialien.
Berichte: Tagung „Materialien in ihrer Umwelt“ vom 24. bis 25.9.1996 in Halle
Hrsg.: Gesellschaft für Umweltsimulation e.V. Pfinztal/Berghausen, Beitrag C2, 1-14

14. BRÜGGERHOFF, S., LAIDIG, G., SCHNEIDER, J. (1996):
Environmental monitoring with natural stone sensors.
Proceedings: 8th Int. Congr. on Deterioration and Conservation of Stone, Berlin, 30.9.-4.10.1996, Volume 2, S. 861-870

15. MIRWALD, P.W., BRÜGGERHOFF, S., FIMMEL, R. (1996):
Baumberg calcareous sandstone and Obernkirchener Sandstone, natural sensor materials for environmental monitoring - results of a field exposure study.
Proceedings: 8th Int. Congr. on Deterioration and Conservation of Stone, Berlin, 30.9.-4.10.1996, Volume 2, S. 871-877

16. MIRWALD, P.W., BRÜGGERHOFF, S. (1996):
Requirements for and interpretation of accelerated and field testing.
in: „Saving Our Architectural Heritage: The Conservation of Historic Stone Structures“, Hrsg.: N.S. Baer & R. Snethlage, Dahlem workshop reports, Environmental sciences research report No.20, John Wiley&Sons Ltd., S. 255-268

17. MIRWALD, P.W., BRÜGGERHOFF, S., FIMMEL, R., LAIDIG, G. (1997):
Stone Materials as Sensors for Environmental Monitoring - Results of Field Exposure Studies.
To be published in a special issue of „Folia Facultatis Scientarium Naturalium“, Universitas Masarykianae Brunensis, Fol.97

18. MIRWALD, P.W., BRÜGGERHOFF, S. (1997):
Erfassung von Umweltbedingungen an Denkmälern mittels einfacher Messverfahren.
Restauratorenblätter, Band 17, (20 Jahre Steinkonservierung 1976 - 1996),
Mayer & Comp, Klosterneuburg - Wien, S. 61-65

19. BRÜGGERHOFF, S., MIRWALD, P.W. (1998):
Baumberger Kalksandstein als Schadstoffsammler.
in: Die Steinskulpturen am Zentralbau des Jagdschlosses Clemenswerth/Emsland,
Arbeitshefte zur Denkmalpflege in Niedersachsen 15, 62-68

20. KURSAWE, P., ZINN, P., BRÜGGERHOFF, S., LAIDIG, G. (1999):
Multivariate Ansätze zur Auswertung einer Freilandexpositionsstudie mit Natursteinmaterial.
Gefahrstoffe – Reinhaltung der Luft 59 Nr. 4, S. 135-141

21. BRÜGGERHOFF, S., KURSAWE, P., ZINN, P., LAIDIG, G. (1999):
Effects monitoring with stone sensors. Results of exposure studies with Baumberg Calcareous Sandstone in Germany.
in: „Quantification of Effects of Air Pollutants on Materials“, Proceedings of the UN/ECE Workshop, May 1998, Umweltbundesamt, Berlin, Texte 24/99, S. 113-127
In: Archäologischer Anzeiger 1999, Walter de Gruyter, Berlin, New York, S. 99-108

22. KRAUSE, H.M., GARUS, G., KÖLLNER, B., BRÜGGERHOFF, S. (2002):
Untersuchung zur Wirkung von Luftverunreinigungen auf Materialien an sechs Standorten mit unterschiedlicher Immissionsbelastung.
Immissionsschutz 3 (2002), S. 80-86

23. BECKER, KARL-HEINZ., BRÜGGERHOFF, STEFAN, STEIGER, MICHAEL, WARSCHEID, THOMAS (2005):
Luftschadstoffe und Natursteinschäden.
In: SIEGESMUND, SIEGFRIED, AURAS, MICHAEL, SNETHLAGE, ROLF (Hrsg.): Stein - Zerfall und Konservierung, Edition Leipzig 2005, S. 36-45

24 BRÜGGERHOFF, STEFFAN (2007):
Schädigung von Kulturgütern durch Umwelteinflüsse – Wie steht es heute mit dem „Sauren Regen“?
In: Diekamp, Anja (Hrsg.)
Naturwissenschaft & Denkmalpflege, innsbruck university press, Innsbruck 2007, S. 111-119

25. TIDBLAD, J., KUCERA, V., FERM, M., KREISLOVA, K., BRÜGGERHOFF, S., DOYTCHINOV, S., SCREPANTI, A., GRØNTOFT, T., YATES, T., de la FUENTE, D., ROOTS, O., LOMBARDO, T., SIMON, S., FALLER, M., KWIATKOWSKI, L., KOBUS, J., VAROTSOS, C., TZANIS, C., KRAGE, L., SCHREINER, M., MELCHER, M., GRANCHAROV, I., KARMANOVA, N. (2012):
Effects of Air Pollution on Materials and Cultural Heritage: ICP Materials Celebrates 25 Years of Research.
International Journal of Corrosion, Vol. 2012, published online, Article ID 496321, DOI: 10.1155/2012/496321

26. BRAUN, F., ORLOWSKY, J., BRÜGGERHOFF, S. (2020):

Analyzing Near-Surface Regions of Hydrophobic and Long-Term Weathered Natural Stones at Microscopic Scale.
Heritage, 2020, 3, S. 457-473
Link: https://www.mdpi.com/2571-9408/3/2/27/pdf

27. GROH, M., BRAUN, F., BRÜGGERHOFF, S., ORLOWSKY. J. (2022):
Durability assessment of differently orientated surfaces of treated long-term weathered natural stones
Journal of Cultural Heritage,Volume 53, January–February 2022, Pages 176-183

28. BRAUN, F., ORLOWSKY, J., BRÜGGERHOFF, S. (2022):
Zerstörungsfreie Untersuchungen an hydrophobierten und langzeitbewitterten Natursteinen mittels mobiler NMR.
In: Gabriele Patitz, Karin Schinken (Hrsg.). Natursteinsanierung 2022. Fraunhofer IRB Verlag

<u>Literaturdokumentation Kiessl</u>

Aus dem Logistik- und Stützprojekt L514 sowie aus dem Logistik / Modellhandwerk-Unterauftrag im Vorhaben L714 sind aufgabenbedingt keine wissenschaftlichen Publikationen hervorgegangen. Die wesentlichen Aussagen dazu sind daher in diesem zusammenfassenden Schluss- und Erfolgskontrollbericht gemacht.

Die folgende Literaturauflistung stellt Veröffentlichungen des Fraunhofer-Instituts für Bauphysik beruhend auf wissenschaftlichen Ergebnissen aus dem Vorhaben K514 und dem bauphysikalischen Teil des Vorhabens L714 zusammen.

Einzelne Artikel bzw. Berichte/Daten sind, soweit nicht allgemein zugänglich publiziert, verfügbar über:

Fraunhofer-Institut für Bauphysik, Postfach 1152, 83601 Holzkirchen

Eine Vielzahl von Vorträgen, Präsentationen etc. auf nationalen und internationalen Veranstaltungen ist hier nicht extra aufgeführt, da sie dieselbe Thematik wie auch die Publikationen beinhalten. Sie sind z.B. in den Jahresberichten des Fraunhofer-Instituts für Bauphysik dokumentiert.

<u>Aus 1992 :</u>

[1] Kießl, K.: Feuchtetechnische Untersuchungsbeiträge im Bereich der Bauwerkserhaltung. Neue Ansätze, Beispiele, Ergebnisse. WTA-Berichte (1992), H. 8, S. 107-128.

[2] Krus, M.: Einfluß der Stoffeuchte von Natursandstein auf die Applikation von Schutzmitteln. Tagungsband: Werkstoffwissenschaften und Bausanierung, Teil 3, 1992, S. 1674-1680, Expert-Verlag Ehningen.

[3] Möller, U.: Vergleichende Untersuchungen temperatur- und feuchtebedingter Verformungen von bruchfrischen, verwitterten und schutzmittelbehandelten Natursteinen. Kongreß-Dokumentation 1. Internationaler Kongreß zur Bauwerkserhaltung anläßlich der BAUTEC Berlin. Bausubstanz 8 (1992), Sonderausgabe S. 3-4.

[4] Möller, U.; Wendler, E.; Schuh, H.: Thermisches und hygrisches Längenänderungsverhalten hydrophobierter Sandsteine. Tagungsband: Werkstoffwissenschaften und Bausanierung, Teil 3, 1992, S. 1796-1807. Expert-Verlag Ehningen.

[5] Möller, U.; Schuh, H.; Wendler, E.: Längenänderungsverhalten hydrophobierter Sandsteine. Bautenschutz + Bausanierung 15(1992), H. 4, S. 46-49.

Aus 1993 :

[6] Kießl, K.; Krus, M.; Künzel, H.M.: Weiterentwickelte Meß- und Rechenansätze zur Feuchtebeurteilung von Bauteilen. Praktische Anwendungsbeispiele. Sonderdruck Bauphysik 15 (1993), H. 2, S. 61-67.

[7] Kießl, K.: Bauphysikalische Qualitätssicherung - Erfordernisse bei der Bauwerkserhaltung. WTA-Schriftenreihe (1993), H. 2. Aedificatio Verlag, Zürich.

[8] Kießl, K.; Krus, M.; Künzel, H.M.: Advanced measuring and calculative procedures for moisture assessment of building elements. CIB W40 meeting, Sopron, 7. Sept. 1993.

[9] Krus,M.; Kießl, K.: Influences of moisture in natural sandstone on the application of protective agents. CIB W40 meeting, Sopron, 7. Sept. 1993.

[10] Krus, M.; Künzel, H.M.: Determination of D_w from the A-value. IEA-Annex 24 meeting, Glasgow, 28.-30. April 1993.

[11] Krus, M.: Does vapour diffusion really depend on moisture content? SCIENCE meeting, Porto, 14.-15. Juni 1993.

[12] Künzel, H.M.; Krus, M.: Beurteilung des Feuchteverhaltens von Natursteinfassaden durch Kombination von rechnerischen und experimentellen Untersuchungsmethoden. Jahresberichte aus dem Forschungsprogramm Steinzerfall - Steinkonservierung, Band 5 (1993), S. 19-25.

[13] Künzel, H.M.; Kießl, K.: Berechnung des gekoppelten Wärme- und Feuchtetransports in Bauteilen unter natürlichen Klimabedingungen. Feuchtetag, Berlin, 21. Sept. 1993.

[14] Künzel, H.M.: Appropriate potentials for the calculation of heat, air and moisture flow in building elements. IEA-Annex 24 meeting, Glasgow, 28.-30. April 1993.

Aus 1994 :

[15] Krus, M.: Ist der Diffusionswiderstand von Baustoffen wirklich feuchteabhängig? 9. Bauklimatisches Symposium TU Dresden, 14.-16. Sept. 1994.

[16] Krus, M.: The Sensitivity of the Diffusivity Function. Science-meeting Holzkirchen, 17.-18. Jan. 1994.

[17] Künzel, H.M.: Einfluß der Mittelwertbildung von Klimadaten auf die Ergebnisse von Feuchtetransportberechnungen. 9. Bauklimatisches Symposium TU Dresden, 14.-16. Sept. 1994.

[18] Künzel, H.M.: Bestimmung der Schlagregenbelastung von Fassadenflächen. IBP-Mitteilung 21 (1994), Nr. 263.

[19] Künzel, H.M.: Regendaten für die Berechnung des Feuchtetransports. IBP-Mitteilung 21 (1994), Nr. 265.

[20] Künzel, H.M. Verfahren zur ein- und zweidimensionalen Berechnung des gekoppelten Wärme- und Feuchtetransports in Bauteilen mit einfachen Kennwerten. Dissertation Universität Stuttgart, Lehrstuhl für Konstruktive Bauphysik, 1994.

Aus 1995 :

[21] Kießl, K., Krus, M.: Experimental determination of building material properties for moisture calculation. Proceedings CSTB-Tagung Paris, 9.-11. Januar 1995. Paris Cedex: Centre Scientifique et Technique du Bâtiment, (1995), S. 322-342.

[22] Krus, M., Künzel, H.M.: Flüssigtransport im Übersättigungsbereich. IPB-Mitteilung 22 (1995), Nr. 270.

[23] Künzel, H.M., Krus, M.: Beurteilung des Feuchteverhaltens von Natursteinfassaden durch Kombination von rechnerischen und experimentellen Untersuchungsmethoden. Internationale Zeitschrift für Bauinstandsetzen 1 (1995), H. 1, S. 5-19.

[24] Künzel, H.M., Kießl, K., Krus, M.: Feuchtemigration und langfristige Feuchteverteilung in exponierten Natursteinmauern. Internationale Zeitschrift für Bauinstandsetzen 1 (1995), H. 4, S. 267-279. Jahresberichte aus dem Forschungsprogramm Steinzerfall - Steinkonservierung 1994 - 1996, IRB-Verlag Stuttgart, 1998, S. 149-156.

[25] Künzel, H.M., Kießl, K., Krus, M.: Moisture in Exposed Building Components. International Symposium on Moisture Problems in Building Walls. Porto, 11.-13. Sept. 1995, Proceedings, S. 258-266.

[26] Künzel, H.M., Kießl, K.; Krus, M.: Feuchteverhalten bewitterter Fassadenbauteile. IBP-Mitteilung 22 (1995) Nr. 274.

[27] de Freitas, V.P., Krus, M., Künzel, H.M., Quenard, D.: Determination of the Water Diffusivity of Porous Materials by Gamma-ray Attenuation and NMR. International Symposium on Moisture Problems in Building Walls. Porto, 11.-13. Sept. 1995, Proceedings, S. 445-460.

[28] Künzel, H.M., Kießl, K.: Hydrophobing historical facades for rain protection and thermal quality purposes. International Symposium on Moisture Problems in Building Walls. Porto, 11.-13. Sept. 1995, Last papers, S. 1-14.

[29] Künzel, H.M., Kießl, K.: Feuchte- und Wärmeschutz im Altbau durch Fassadenhydrophobierung. Bauphysik 17 (1995), H. 6, S. 165-169.

[30] Künzel, H.M., Kießl, K.: Performance of silane impregnation for exposed brick masonry. 1st International Symposium on Surface Treatment of Building Materials with Water Repellent Agents, Delft, 9.-10. Nov. 1995, Proceedings S. 1/1-1/11.

Aus 1996 :

[31] Holm, A., Krus, M., Künzel, H.M.: Feuchtetransport über Materialgrenzen im Mauerwerk. Internationale Zeitschrift für Bauinstandsetzen 2 (1996), H. 5, S. 375-396.

[32] Krus, M.: Veränderung der feuchtetechnischen Kennwerte nach Schutzmittelbehandlung der Asterixe in den Freilandversuchsstellen Duisburg und Holzkirchen.
IBP-Bericht, Sitzung AG-Prüffelder, Oberhausen, 28. August 1996.

[33] Krus, M.: Simulation des Feuchteverhaltens eines Asterix-Prüfkörpers.
IBP-Bericht, Sitzung AG-Prüffelder, Oberhausen, 17. April 1996.

[34] Krus, M: Bestimmung der Feuchtespeicherfunktion, IBP-Mitteilung 23 (1996) Nr. 292.

[35] Krus, M.; Klier, M.: Flüssigtransport über die Schichtgrenzen zweier miteinander verbundener kapillar-poröser Materialien. IBP-Mitteilung 23 (1996) Nr. 291.

[36] Krus, M.: Flüssigtransport über die Schichtgrenze zwischen kapillaraktiven Materialien. Teil 1: Idealer hygrischer Kontakt. 4. Internationales Kolloquium Werkstoffwissenschaften und Bauinstandsetzen. Band 1, S. 57-67.IRB-Verlag Stuttgart (1996).

[37] Krus, M.: Moisture Transport and Storage Coefficients of Porous Mineral Building Materials. Theoretical Principles and New Test Methods. IRB-Verlag Stuttgart (1996).

[38] Krus, M., Künzel, H.M.: Vergleich experimenteller und rechnerischer Ergebnisse anhand des Austrocknungsverhaltens von Ziegelwänden. International Symposium of CIB W67 Energy and Mass Flow in the Life Cycle of Buildings. Wien, 4.-10. August 1996, Proceedings, S. 493-498.

[39] Krus, M., Künzel, H.M., Kießl, K.: Feuchtetransportvorgänge in Stein und Mauerwerk. Bauforschung für die Praxis, Band 25. IRB-Verlag Stuttgart (1996).

Aus 1997 :

[40] Winter, K., Krus, M., Künzel, H.M.: Feuchtetransport in feinporigen Materialien. Intern. Zeitschrift für Bauinstandsetzen 3 (1997), H. 1, S. 1-14.

[41] Krus, M.: Messung von Feuchteverteilungen mit dem Kernresonanzverfahren. In: Kupfer, K. et al.: Materialfeuchtemessung. Fachbuchreihe Kontakt & Studium, Band 513, S. 173-191. Expert-Verlag, Renningen-Malmsheim (1997). (ISBN 3-8169-1359-8)

[42] Neue, J., Krus, M., Kupfer, K.: Hygrometrische Verfahren. In: Kupfer, K. et al.: Materialfeuchtemessung. Fachbuchreihe Kontakt & Studium, Band 513, S. 235-245. Expert-Verlag, Renningen-Malmsheim (1997). (ISBN 3-8169-1359-8)

[43] Krus, M., Holm, A., Schmidt, Th: Ermittlung der Kapillartransportkoeffizienten mineralischer Baustoffe aus dem w-Wert. Internationale Zeitschrift für Bauinstandsetzen 3 (1997), H. 3, S. 1-16.

[44] Krus, M., Holm, A., Wardzikowski, P.: Bestimmung der Wasser- und Salzgehaltsverteilungen durch Kombination von NMR- und γ - Durchstrahlungsmessungen. 9. Feuchtetag Weimar, 17.-18. Sept. 1997, Proceedings, S. 203-217.

[45] M. Krus: Das Austrocknungsverhalten hydrophobierter Natursteinwände unter natürlichen Klimabedingungen. IBP-Mitteilung 24 (1997) Nr. 313.

[46] Hansen, H.H., Houvenaghel, G., Janz, M., Krus, M., Stromdahl, K.: Interlaboratory comparison of the measurement of retention curves. Proceedings CIB W40-Meeting, Kyoto, Oct. 1997.

[47] Künzel, H.M.: Raumluftfeuchteverhältnisse in Wohnräumen. IBP-Mitteilung 24 (1997) Nr. 314.

Aus 1998 :

[48] Krus, M., Rapp, K., Wendler, E.: Einsatz von Steintränkungsstoffen zur Verbesserung des Haftverbundes zwischen Naturstein und Restauriermörtel. Jahresberichte aus dem Forschungsprogramm Steinzerfall - Steinkonservierung 1994 – 1996, S. 291-305. IRB-Verlag, Stuttgart (1998).

[49] Krus, M., Kießl, K.: Determination of the moisture storage characteristics of porous capillary active materials. Materials and Structures, Vol. 31 (1998), H. 212, pp 522-529.

[50] Krus, M., Künzel, H.M., Kießl, K.: Feuchtemessung und Feuchteverteilung in Stein und Mauerwerk. Jahresberichte aus dem Forschungsprogramm Steinzerfall - Steinkonservierung, Band II, S. 93-118. IRB-Verlag, Stuttgart (1998).

[51] Holm, A., Krus, M.: Bestimmung des Transportkoeffizienten für die Feuchte-Weiterverteilung aus einfachen Trocknungsversuchen und rechnerischer Anpassung. Bauinstandsetzen 4 (1998), H. 1, S. 33-52.

[52] Holm, A., Krus, M.: Zerstörungsfreie Bestimmung der Salzgehaltsverteilung durch Kombination zweier Meßmethoden. IBP-Mitteilung 25 (1998) Nr. 340.

[53] Krus, M.: Hygrothermal calculations applied to water-repellent surfaces - validation and application. Proceedings Second International Conference on Surface Technology with Water Repellent Agents, ETH Zürich, 10.-11. Sept. 1998, S. 169-176.

[54] Künzel, H.M.: Innendämmung von Natursteinmauern. IBP-Mitteilung 25 (1998), Nr. 336.

Aus 1999 bis 2000

[55] Krus, M., Holm, A.: Simple methods to approximate the liquid transport coefficients describing the absorption and drying process. Proceedings of the 5th Symposium 'Building Physics in the Nordic Countries', Göteborg, August 24-26, 1999, S. 241-248.

[56] Krus, M., Holm, A.: Approximationsverfahren für die Bestimmung feuchtetechnischer Materialkennwerte. Proceedings 10. Bauklimatisches Symposium TU Dresden, 27.-29. September 1999, S. 423-432.

[57] Krus, M., Künzel, H.M., Kießl, K.: Use of advanced measuring and calculative procedures for moisture assessment of building elements. Trends in Heat, Mass & Momentum Transfer, Vol. 5 (1999), S. 1-17.

[58] Holm, A., Krus, M.: Zweidimensionale WUFI-Berechnungen zur aufsteigenden Feuchtigkeit. FAS-Schriftenreihe, Heft 10, Entsalzung / Entfeuchtung, 10. Hanseatischen Sanierungstage, Kühlungsborn 1999, S. 107-116.

[59] Künzel, H.M. und Schmidt, Th.: Auswahl und Aufbereitung von meteorologischen Datensätzen für Feuchtetransportberechnungen. Tagungsband 2 des 10. Bauklimatischen Symposiums, TU Dresden 1999, S. 637-647.

[60] Holm, A. und Künzel, H.M.: Bestimmung der Wasser- und Salzgehaltsverteilung durch Kombination von NMR- und γ- Durchstrahlungsmessungen. Bauinstandsetzen 6 (2000), H. 4, S. 401-414.

Appendix V

Quellennachweis zur Forschung fuer die Denkmalpflege BMFT-Foerderprojekte 1986-1994