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Damage index for stone monuments

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ABSTRACT: Precise diagnosis is required for characterisation, interpretation, rating and prediction of the weathering damages at stone monuments and is vital for remedy of stone damages and sustainable monument preservation. Quantitative rating of damages represents an important scientific contribution to reliable damage diagnosis at stone monuments. Damage indices are introduced as new tool for scientific quantification and rating of stone damages. Application of damage indices improves stone damage diagnosis and is very suitable for evaluation and certification of preservation measures and for long-term survey and maintenance of stone monuments. Importance and use of damage indices are presented for monuments in Germany, Malta, Jordan, Egypt and Brazil.

RESUMEN: La caracterización, interpretación, valoración y predicción de los daños de alteración en monumentos de piedra requieren un diagnóstico preciso de los mismos. Este tipo de diagnóstico es fundamental para remediar los daños en la piedra y para una conservación adecuada de los monumentos. La valoración cuantitativa de los daños representa una contribución científica importante para un diagnóstico de alteración adecuado en monumentos pétreos. Los índices de daños se introducen como una nueva herramienta para la cuantificación y valoración científica de los daños en piedra. El uso de los índices de daños supone un paso hacia adelante en el diagnóstico de alteración de la piedra y es muy adecuado para la evaluación y control de las medidas de conservación, así como para estudios a largo plazo y el mantenimiento de monumentos hechos en piedra. La importancia y el uso de índices de daños se presentan para diferentes monumentos en Alemania, Malta, Jordania, Egipto y Brasil.

1 INTRODUCTION

All natural stone monuments are affected by weathering. At many historical monuments weathering damages are alarming. Scientific characterisation, evaluation, quantification and rating of stone damages are essential for effective and economic monument preservation measures. Determination of damage indices means an innovative step of damage evaluation derived from improvement of monument mapping. The monument mapping method is approved as well-experienced procedure contributing to reliable damage diagnosis at stone monuments. This internationally accepted non-destructive method guarantees precise classification, registration, documentation and evaluation of stone types and degradation phenomena at natural stone monuments (Fitzner, Heinrichs & Kownatzki 1995, Fitzner, Heinrichs & Kownatzki 1997, Fitzner, Heinrichs & Volker 1997a, Fitzner & Heinrichs 1998a, Fitzner & Kownatzki 1997, Kownatzki 1997, Kownatzki & Fitzner 1999). The method can be applied to all stone types and to all stone monuments. It provides detailed information for the entire stone surface of monuments. Special computer-programmes have been developed for processing, illustration and quantitative evaluation of mapping information.

Evaluation, quantification and rating of stone damages by means of monument mapping is based on objective description and registration of weathering forms according to type and intensity. By means of maps, all weathering forms get exactly located. Type, intensity and distribution of the weathering forms are evaluated as indicators for weathering processes and environmental impacts. Evaluation of weathering forms contributes to the assessment of weathering progression and to the calculation of weathering rates considering environmental situation, stone types as well as monument characteristics such as location, exposition, geometry and utilisation.

Damage categories have been established already as practical tool for subsequent rating of all individual damages. Based on defined schemes, all weathering forms – considering different intensities – are related to damage categories. Determination, illustration and quantitative evaluation of damage categories contribute to risk estimation and to risk management.

Damage indices are introduced now for conclusive quantification and rating of stone damages. Determination of damage indices is based on quantitative evaluation of damage categories. Damage indices complete a consistent and convincing approach to characterisation, evaluation, quantification and rating of stone damages. The application of the modular components "weathering forms", "damage categories" and "damage indices" allows detailed damage diagnosis of entire stone monuments or single structures (Fig. 1). The individual steps of monument mapping procedure, data processing and evaluation are presented in Figure 2.

WEATHERING FORMS	Detailed description of individual weathering phenomena with quantification of intensities.

↓

Definition of damage categories,
relating of weathering forms
to damage categories

↓

DAMAGE CATEGORIES	Rating of individual weathering damages.

↓

Definition of damage indices,
calculation of damage indices
from proportion of damage categories

↓

DAMAGE INDICES	Conclusive quantification and rating of damages.

Figure 1. Damage diagnosis.

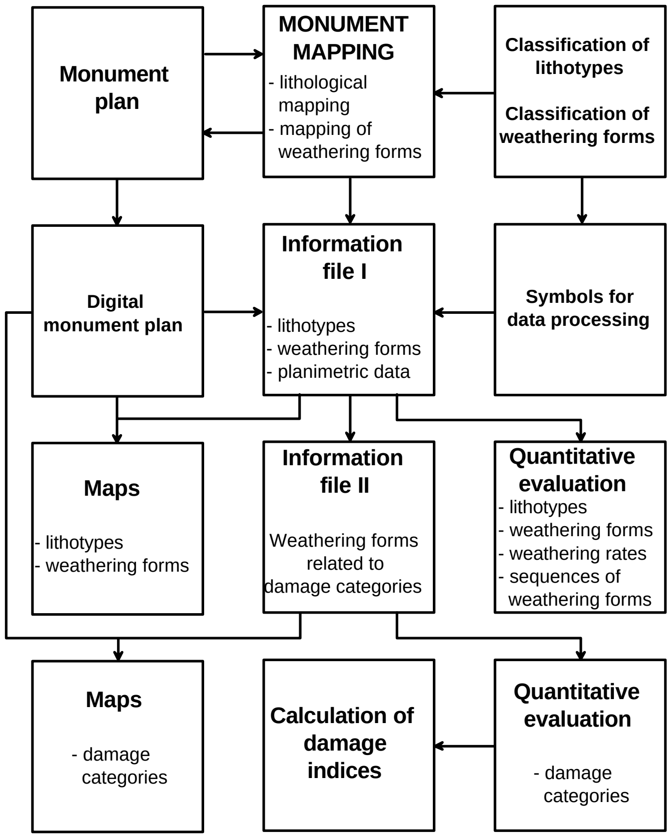

Figure 2. Monument mapping. Data processing and evaluation.

2 DETERMINATION AND APPLICATION OF DAMAGE INDICES

Damage indices for monuments are determined consequently via weathering forms and damage categories. Weathering forms represent the visible result of weathering processes which are initiated and controlled by interacting weathering factors. Weathering forms are used for detailed description of individual weathering phenomena (Fig. 1). By means of monument mapping all weathering forms at stone monuments are registered in detail according to type, intensity and distribution. The objective and reproducible registration and documentation require a standardised classification scheme of weathering forms. Such a classification scheme has been established, based on investigation at monuments world-wide considering different stone types, monuments and environments (Fitzner, Heinrichs & Kownatzki 1995).

Parameters for classification of intensities of weathering forms have been proposed. A standard intensity classification for all weathering forms is not feasible. It should be adjusted to the monuments considering the whole range of intensities. The example presented in Table 1 reveals the necessity of individual intensity classification. It refers to studies at historical limestone monuments in Cairo/Egypt. Here, the different intensity range of weathering forms corresponds to different size of dimension stones used for the two monuments.

Table 1. Intensity classification of the weathering form “back weathering” for two monuments in Cairo / Egypt.

Monument	Intensity classification for the weathering form “back weathering (W)“ according to depth of back weathering in cm						
	Intensity 1	Intensity 2	Intensity 3	Intensity 4	Intensity 5	Intensity 6	Intensity 7
El-Merdani Mosque – composed of small dimension stones	< 0.2	0.2 – 0.5	0.5 – 1	1 – 3	3 – 5	5 – 10	> 10
Great Pyramid of Cheops – composed of huge dimension stones	< 5	5 – 15	15 – 25	25 – 50	50 – 75	75 – 100	> 100

Weathering forms serve for precise description of stone degradation phenomena. Damage categories have been established for comparative rating of individual damages. Six damage categories have been defined (Tab. 2). Based on defined schemes, all weathering forms with their different intensities are related to damage categories. The transition schemes “weathering forms – damage categories“ must consider the historical value and the function of dimension stones and the proportion “degradated stone parts / total dimension stone”. The schemes should be discussed with experts involved in monument preservation activities like monument owners, architects, engineers and restorers. Examples of schemes relating weathering forms to damage categories are presented in Fitzner, Heinrichs & Kownatzki (1995), Kownatzki & Fitzner (1999), Heinrichs & Fitzner (1999).

Tables 3 and 4 present two examples of transition schemes “weathering forms – damage categories”. For the Church of São Francisco de Assis in Ouro Preto/Brazil, Table 3 shows the proposed damage categories for the weathering form ”relief“ considering its different intensities. Same range of intensities has been stated for ashlar and architectonic decoration. For architectonic deco-ration and dimension stones of high historical and artistical value the intensity classes of ”relief“ have been attributed to higher damage categories than for ashlar. Table 4 shows the proposed damage categories for the weathering form “relief“ for a Minster in Germany and the Great Pyramid of Cheops in Egypt. A very different intensity range of this weathering form can be stated. The proportion “degradated stone parts / total dimension stone” has been considered in this case.

Table 2. Definition of damage categories.

Damage category 0 – no visible damages	Damage category 3 – moderate damages
Damage category 1 – very slight damages	Damage category 4 – severe damages
Damage category 2 – slight damages	Damage category 5 – very severe damages

Table 3. Weathering form “relief” related to damage categories. Consideration of different structures of a monument. Church of São Francisco de Assis in Ouro Preto / Brazil.

Church of São Francisco de Assis – Ouro Preto / Brazil		Weathering form: Relief (R) – *Morphological change of the stone surface due to partial or selective loss of stone material.*					
		Intensities - depth of relief in mm					
		< 2	*2 – 5*	*5 – 10*	*10 – 30*	*30 – 50*	*50 – 100*
DAMAGE CATEGORIES	Ashlar	1	2	3	4	4	5
	Architectonic decoration and other dimension stones of high value	2	3	4	5	5	5

Table 4. Weathering form “relief” related to damage categories for different monuments.

		Weathering form: Relief (R)				
Minster St. Quirin – Neuss / Germany, composed mainly of very small dimension stones	Intensities - depth of relief in cm	< 0.5	0.5 - 1	1 – 2	2 – 3	> 3
Great Pyramid of Cheops – Cairo / Egypt, composed of huge dimension stones		< 5	5 – 15	15 – 25	25 – 50	> 50
DAMAGE CATEGORIES		1	2	3	4	5

Damage indices are calculated from damage categories (area-%). Linear and progressive damage index have been defined (Tab. 5). The damage indices range from 0 to 5.0. According to the defined calculation modes, the linear damage index corresponds to average damage category, whereas the progressive damage index emphasises proportion of higher damage categories (Tab. 6). Differences between linear and progressive damage index increases as proportion of higher damage categories increases.

Following relation arises:

progressive damage index ≥ linear damage index.

The application of damage indices allows a reliable and reproducible quantification and rating of stone damages and contributes to monument preservation. It provides important information on need and urgency of interventions. In Figure 3 the aims and the different application modes of damage indices are presented.

Table 5. Calculation of damage indices.

LINEAR DAMAGE INDEX
DI_{lin}=

$$\frac{(A\cdot 0)+(B\cdot 1)+(C\cdot 2)+(D\cdot 3)+(E\cdot 4)+(F\cdot 5)}{100} = \frac{B+(C\cdot 2)+(D\cdot 3)+(E\cdot 4)+(F\cdot 5)}{100}$$

PROGRESSIVE DAMAGE INDEX
DI_{prog}=

$$\sqrt{\frac{(A\cdot 0^2)+(B\cdot 1^2)+(C\cdot 2^2)+(D\cdot 3^2)+(E\cdot 4^2)+(F\cdot 5^2)}{100}} = \sqrt{\frac{B+(C\cdot 4)+(D\cdot 9)+(E\cdot 16)+(F\cdot 25)}{100}}$$

A = Area (%) – damage category 0
B = Area (%) – damage category 1
C = Area (%) – damage category 2
D = Area (%) – damage category 3
E = Area (%) – damage category 4
F = Area (%) – damage category 5

$$\sum_{A}^{F} = 100$$

Table 6. Examples of linear and progressive damage indices.

Proportion of damage categories - area-% Damage category 0	Damage category 1	Damage category 2	Damage category 3	Damage category 4	Damage category 5	Linear damage index DI_{lin}	Progressive damage index DI_{prog}
0	0	0	100	0	0	3.00	3.00
0	0	30	40	30	0	3.00	3.10
0	20	20	20	20	20	3.00	3.32
40	0	0	0	0	60	3.00	3.87

AIMS	
1	*GENERAL AIM* *Conclusive quantification and rating of stone damages for entire monuments or single structures*
2	*Comparison and ranking of different monuments with respect to state of damage*
3	*Comparison and ranking of different structures of a monument with respect to state of damage considering e.g. different age, orientation or other exposition characteristics, zonations of damages etc.*
4	*Comparison and rating of stone materials concerning their susceptibility to degradation*
5	*Risk estimation*
6	*Contribution to risk management, judgement of need and urgency of intervention*
7	*Certification / long-term control of preservation measures*
8	*Long-term survey of monuments with identification / quantification of damage progression*
9	*Contribution to maintenance of stone monuments*

APPLICATION	AIMS (No.)
Determination of damage indices for an entire monument	1, 5, 6
Determination of damage indices for single structures	1, 3, 5, 6
Determination of damage indices for different monuments, assemblies of monuments	1, 2, 5, 6
Determination of damage indices for individual stone types	1, 3, 4, 5, 6
Determination of damage indices before and after preservation measures	1, 5, 6, 7, 9
Determination of damage indices in the frame of regular reevaluation activities	1, 3, 4, 5, 6, 7, 8, 9

Figure 3. Damage indices. Aims and application modes.

3 EXAMPLES

Application and importance of damage indices are presented at five examples:

1) Monuments carved from bedrocks in Petra / Jordan – damage indices for entire monuments, ranking of monuments,
2) Church of Sta. Marija Ta´ Cwerra in Siggiewi / Malta - damage indices for an entire monument and single structures, characterisation of damage zonation,
3) El-Merdani Mosque in Cairo / Egypt – damage indices for characterisation of damage zonation,
4) Church of São Francisco de Assis in Ouro Preto / Brazil – damage indices for a single structure, rating of stone susceptibility to degradation,
5) Minster St. Quirin in Neuss / Germany – damage indices for certification of restoration measures and long-term survey / maintenance of a monument.

3.1. *Monuments carved from bedrocks in Petra / Jordan*

The monuments of ancient Nabataean Petra in south west Jordan rank among the most important historical monuments in the world. In 1985 Petra has been inscribed into the UNESCO-list of world cultural heritage. Almost one thousand monuments like tombs and sanctuaries were carved from bedrocks about 2000 years ago. Most of these monuments appear as facade with chambers behind (Fig. 4). At all monuments damages can be stated. In 1998 the World Monument Fund has inscribed Petra on the list of the one hundred most endangered monument assemblies of the world.

Within the frame of the research project ”Systematic registration and evaluation of damages at monuments in Petra“ – funded by Deutsche Forschungsgemeinschaft (DFG) – studies have been executed at Petra monuments. Damage diagnosis has been focussed on material properties and on weathering state of the twenty-five distinguished lithotypes.

Figure 4. Tomb No. 676 – Petra / Jordan.

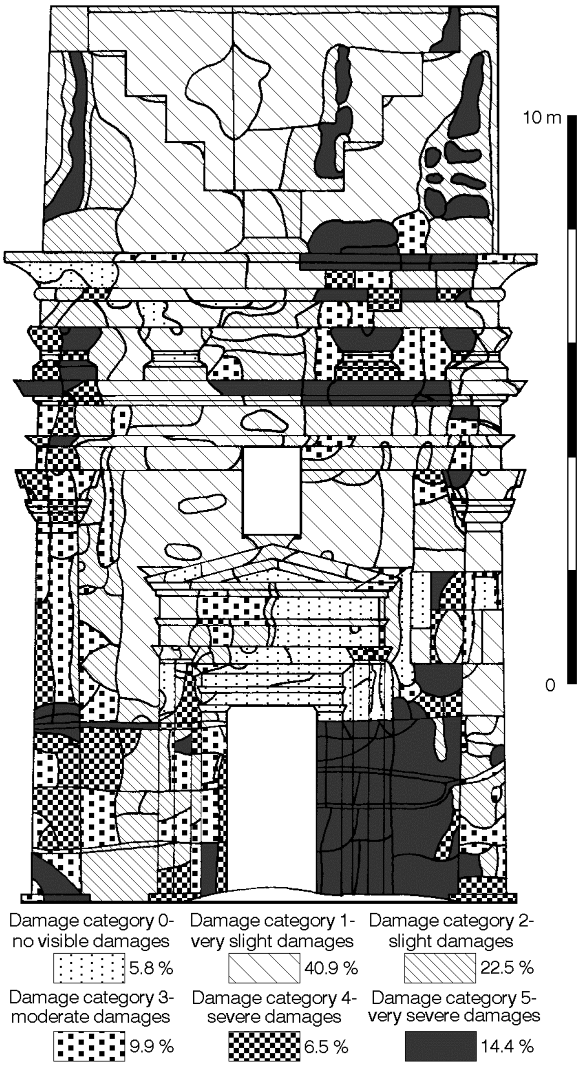

Figure 5. Map of damage categories with quantitative evaluation. Tomb No. 676 – Petra / Jordan.

Environmental influences as well as the different monument characteristics like location, geometry and exposition have been considered (Fitzner & Heinrichs 1998b, Fitzner & Heinrichs 1999, Heinrichs & Fitzner 1999, 2000). One aim of these studies is the quantification of the state of damage and a ranking of monuments regarding urgency of preservation measures. For this purpose damage indices have been established and used for the first time. Weathering forms at the monuments have been registered by monument mapping. This information has been related to damage categories according to a scheme adjusted to the Petra monuments (Fig. 5).

Damage indices have been determined for conclusive quantification and rating of damages (Fig. 6). The results line out the wide range of damages at the monuments. The ranking of the monuments corresponds to increasing need and urgency of preservation measures.

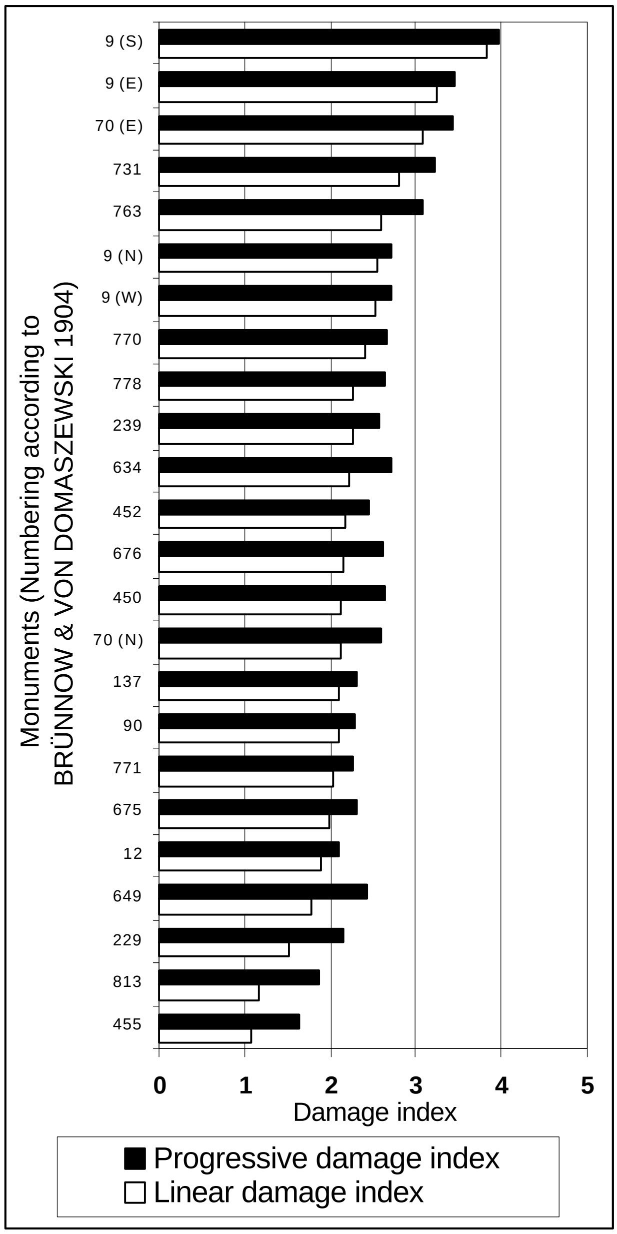

Figure 6. Ranking of monuments by damage indices, Petra / Jordan.

3.2. *Church of Sta. Marija Ta´ Cwerra in Siggiewi / Malta*

Studies at the Church of Sta. Marija Ta´ Cwerra in Siggiewi in the Southwest of Malta have been carried out in the framework of the E.C.-Research project "Marine spray and polluted atmosphere as factors of damage to monuments in the Mediterranean coastal environment“ (Fitzner, Heinrichs & Volker 1997b). The church was built in the 16th century and rebuilt in the 18th century (Fig. 7). Tertiary Globigerina limestone was used for construction. This soft stone material has been used for Maltese monuments from antiquity until today. The lowermost parts of the church are covered with plaster.

According to interdisciplinary studies, salt weathering due to marine environment is the essential weathering process causing degradation of the very porous limestone. High deposition of salt from the atmosphere has been stated for the monument. The lower parts of the monuments are also affected by highly salt-loaded rising humidity resulting in salt accumulation and intensification of salt weathering processes. Halite is the predominant salt mineral. Seasonal and diurnal variations of relative humidity create high frequencies of salt mobilisation and salt crystallisation - cycles.

Damage indices have been determined via weathering forms and damage categories for the entire monument and for the four facades of the free-standing monument. Vertical zonation of damages at the facades has been characterised by means of damage indices (Figs 8, 9). For the entire monument high damage indices have been stated. The linear damage index DI_{lin} = 2.73 and the progressive damage index DI_{prog} = 3.07 indicate the need of intervention. Considering the age of the monument, the damage indices show a high susceptibility of the Globigerina limestone to salt weathering.

Comparing the damage indices of the four facades, the south facade shows the most severe state of damage (DI_{lin} = 3.38, DI_{prog} = 3.64). This is due to extreme microclimatic variations at this facade causing intense salt weathering processes. At all four facades two zones of damages can be distinguished: an upper zone with mainly slight damages and a lower zone with mainly severe or even very severe damages (Fig. 8). The lower zone corresponds to parts of the church affected by salt-loaded rising damp. Salt load in these lower part is remarkably higher than in the upper part. The damage indices for these two zones – presented as example for the south facade (Fig. 9) - reflect the different state of damage as consequence of different salt load (south facade - lower part: DI_{lin} = 4.64, DI_{prog} = 4.69; upper part: DI_{lin} = 2.40, DI_{prog} = 2.54). Prospective interventions have to be addressed to the lower parts of the church.

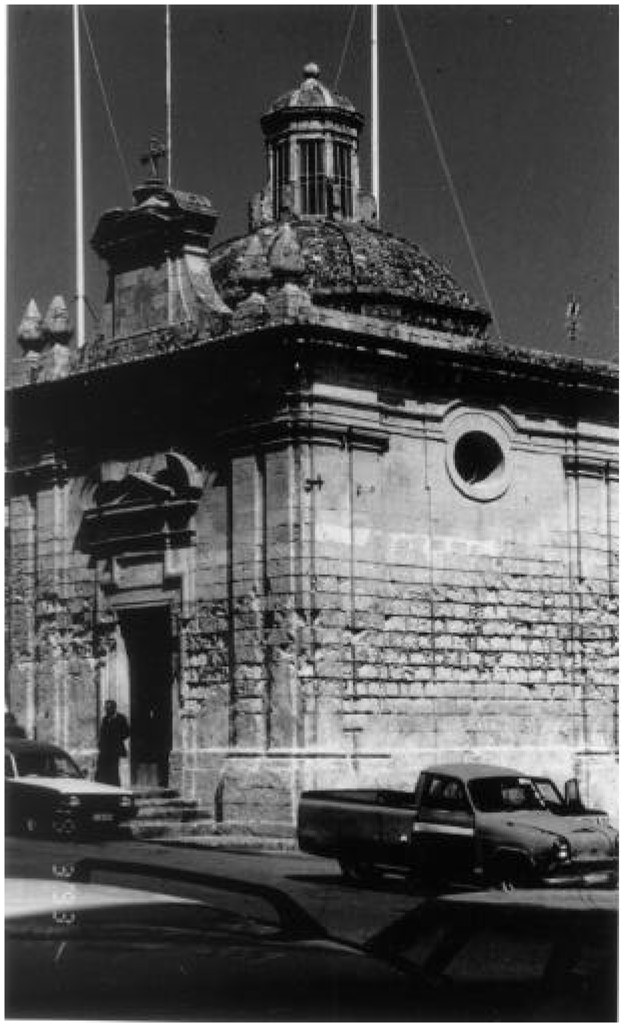

Figure 7. Church of Sta. Marija Ta´ Cwerra. Siggiewi / Malta.

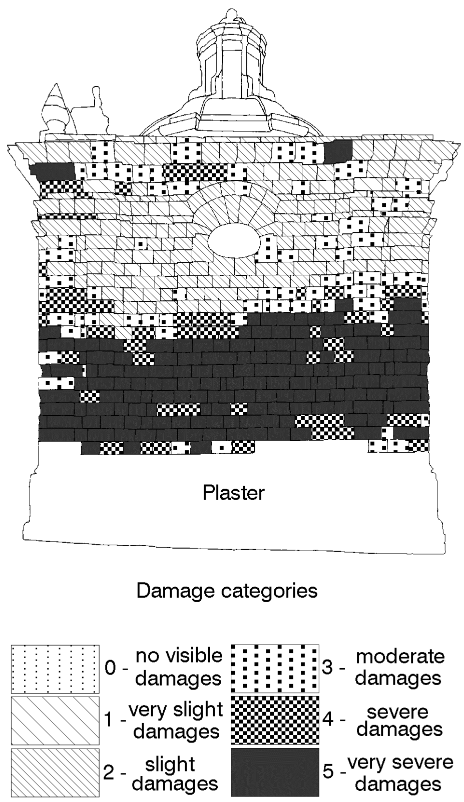

Figure 8. Map of damage categories. Church of Sta. Marija Ta´ Cwerra. South facade.

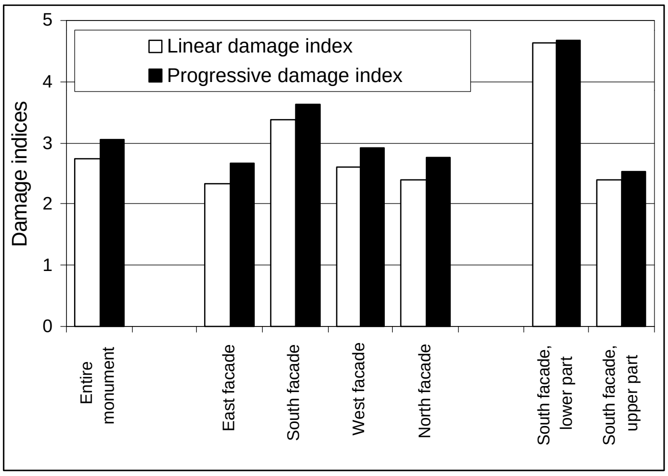

Figure 9. Damage indices. Church of Sta. Marija Ta´ Cwerra.

3.3. *El-Merdani Mosque in Cairo / Egypt*

El-Merdani Mosque is located in the historic center of Cairo. The Islamic Cairo has been declared by UNESCO as "World cultural heritage". The mosque was built in the 14th century as one of the finest examples of Islamic architecture in Cairo. Porous limestones from the Mokattam mountains east of Cairo were used for construction. The mosque was restored a century ago, but it needs again intervention. Especially damages in the lower parts of the monument are striking (Figs 10, 11).

Within the framework of the EC-Concerted Action "Study, characterisation and analysis of degradation phenomena of ancient, traditional and improved building materials of geologic origin used in construction of historical monuments in the Mediterranean area" studies have been carried out at pilot areas of the mosque. The results have revealed an extreme example of salt weathering damages, mainly induced by salt-loaded rising humidity. This situation can be observed at many historical monuments in Cairo. Defect water and sewage systems causes rising of the ground water table and pollution of the ground water.

The study of El-Merdani Mosque demonstrates the use of damage indices for quantitative evaluation of damage zonation. In order to quantify damages in vertical profile, damage indices have been calculated for each row of dimension stones (Figs 10, 12). The profile illustrates increase of damage indices from the lowermost part of the investigation area to maximum in the middle to upper part, followed by decrease of damage indices towards the uppermost part of the investigation area.

The part with highest damage indices represents the main zone of salt precipitation resulting in most intense salt weathering processes and stone degradation. Presented damage indices contribute to risk estimation and to identification of risk areas at El-Merdani Mosque.

Figure 10. El-Merdani Mosque – Cairo/Egypt. Lower part of the SE-facade with numbering of rows of dimension stones.

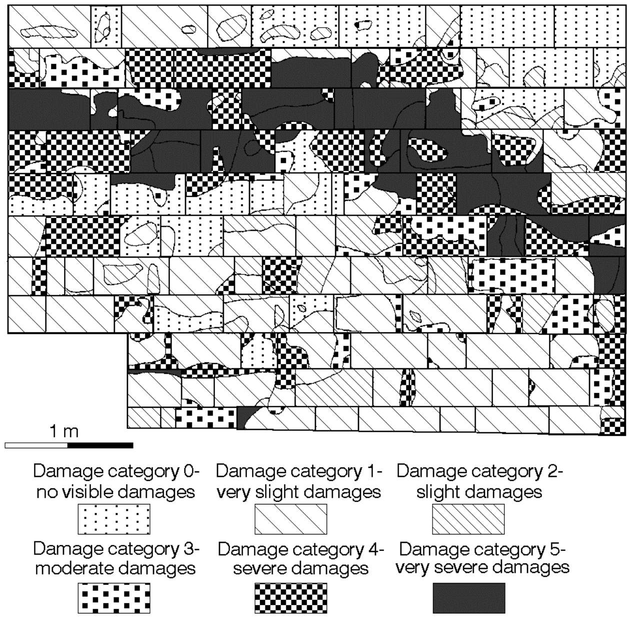

Figure 11. Map of damage categories. El-Merdani Mosque. Lower part of the SE-facade.

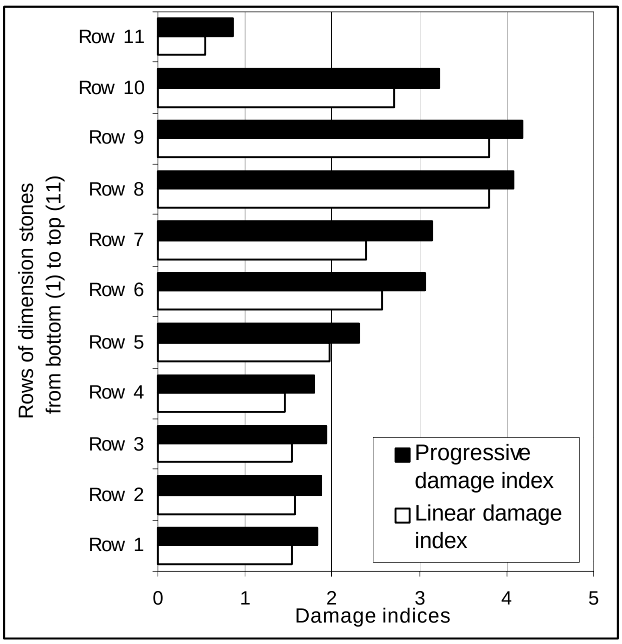

Figure 12. Damage indices - vertical profile. El-Merdani Mosque. Lower part of the SE-facade.

3.4 *Church of São Francisco de Assis in Ouro Preto / Brazil*

Ouro Preto can be considered as masterpiece of colonial architecture in Brazil. UNESCO has declared this town as ”World cultural heritage“. The church of São Francisco de Assis was built and decorated in the second half of the 18th century by the famous Brazilian artist Antonio Francisco Lisboa, known as Aleijadinho. Local quartzites were used for the ashlar parts of the church, soapstones for the decoration parts of the facades.

Studies have been carried out at the church in the framework of the German-Brazilian project ”IDEAS – Investigation into devices against environmental attack on stones“. Use and significance of damage indices are presented for the soapstone decoration of the main portal (Fig. 13). Soapstone represents a soft stone material that can be worked easily. Two different soapstone varieties were used for construction of the decoration part of the main portal. Few degradated stone pieces were replaced in the frame of previous restoration. Damage indices have been determined for the entire decoration part in order to estimate need of intervention. Additionally, damage indices have been calculated individually for the different soapstone types in order to rate and compare their susceptibility to weathering. This information contributes to selection of appropriate soapstone varieties in case of stone replacement measures.

Figure 13. Church of São Francisco de Assis, Ouro Preto / Brazil. Soapstone decoration of the main portal.

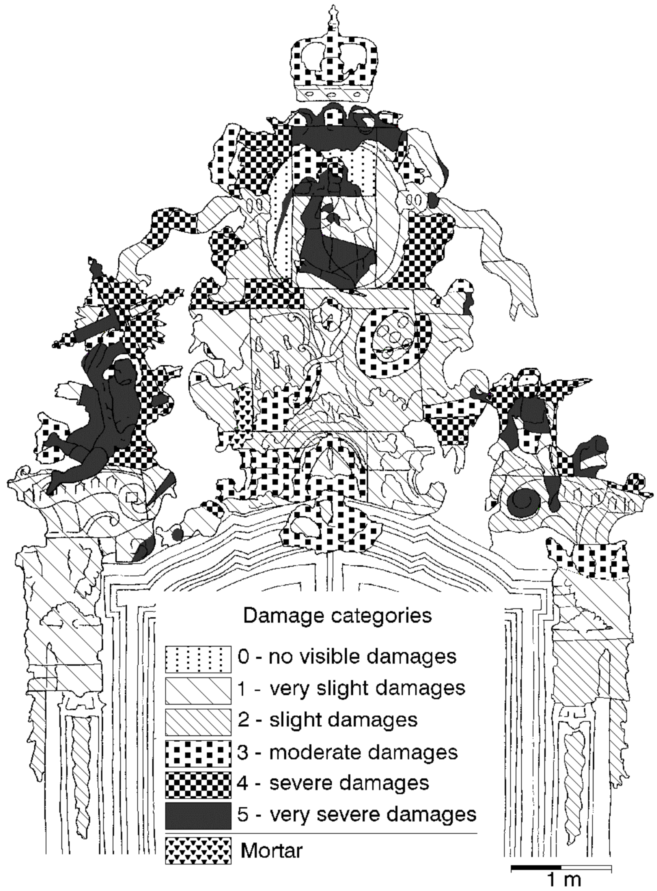

Figure 14. Map of damage categories. Church of São Francisco de Assis, Ouro Preto / Brazil. Soapstone decoration of the main portal.

Table 7. Damage indices. Church of São Francisco de Assis. Soapstone decoration of the main portal.

	Damage index	
	linear DI_{lin}	progressive DI_{prog}
Entire soapstone decoration	2.42	2.78
Soapstone – type 1	1.99	2.25
Soapstone – type 2	3.49	3.82
Soapstone – type 3	1.40	1.74

Figure 14 shows the map of damage categories for the soapstone decoration part. Damage indices are presented in Table 7. The damage indices for the entire soapstone decoration indicate the need of intervention (DI_{lin} = 2.42, DI_{prog} = 2.78). Severe and very severe damages predominantly occur at soapstone – type 2, very slight and slight damages mainly at soapstone – type 1. Comparing the damage indices for the two soapstone types, the higher susceptibility of soapstone – type 2 to degradation is obvious. Intervention at those parts made from soapstone – type 2 is urgent. Soapstone – type 3, used for stone replacement, has suffered damages, too. Low number and small size of the soapstone pieces do not allow the reliable rating of their weathering susceptibility.

3.5. *Minster St. Quirin in Neuss / Germany*

The use of damage indices for The judgement of restoration measures is presented for the Minster St. Quirin in Neuss/Germany (Fig. 15). The late Romanic basilica dates back to the beginning of the 13th century. Several times parts of the monument were destroyed by war or fire. Due to restoration activities in the past, many stone types like different varieties of volcanic tuff, trachyte, basalt, limestone, sandstone and slate occur.

Extensive studies have been carried out at the monument in order of damage diagnosis and appropriate restoration. The interdisciplinary cooperation of scientists, curator, representatives of monument authorities, architect, engineers and restorers has comprised precise damage diagnosis, development of a restoration concept based on the damage diagnosis, execution and documentation of restoration measures, reevaluation after restoration and judgement of restoration measures (Fig. 16). Results of the reevaluation after restoration are necessary for future restoration activities and maintenance of the monument. With this step the approach to effective and economic monument preservation is completed.

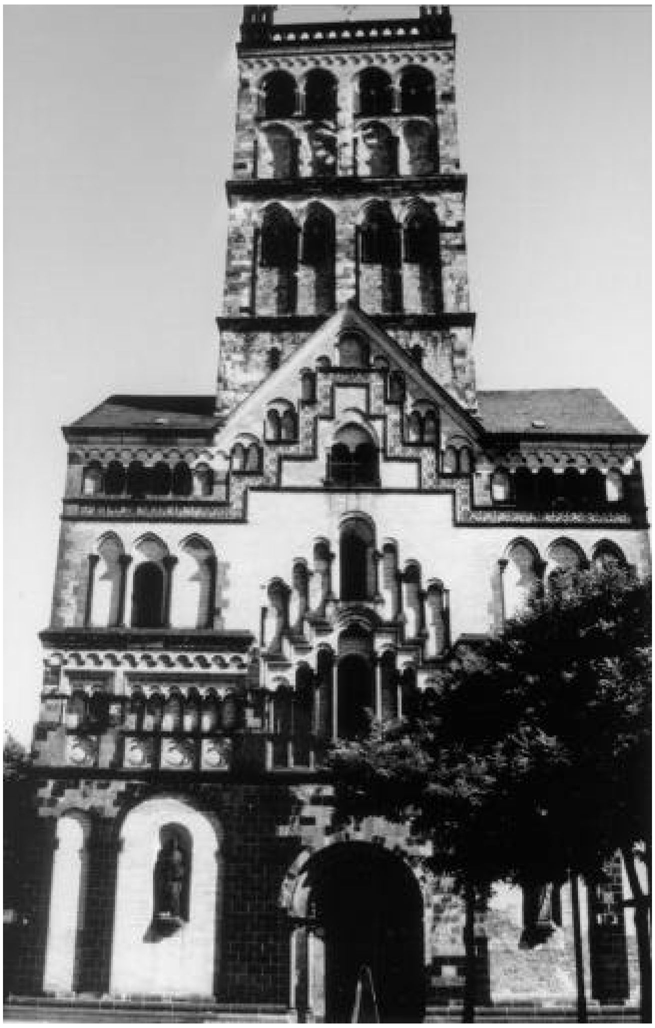

Figure 15. Minster St. Quirin. Neuss / Germany.

DAMAGE DIAGNOSIS BEFORE RESTORATION (D 1)
Stone material, weathering forms, damage categories, damage indices

↓

RESTORATION CONCEPT
(Co-operation of scientists, monument owner, monument authorities, architect, restorers)
↓
RESTORATION MEASURES
↓
DOCUMENTATION OF RESTORATION MEASURES

↓

REEVALUATION AFTER RESTORATION (D 2)
Stone material, weathering forms, damage categories, damage indices

↓

JUDGEMENT / CERTIFICATION OF RESTORATION MEASURES
(Based on comparison of D 1 and D 2)

Figure 16. Damage diagnosis for monument restoration.

In order to judge resp. certificate restoration measures, the state of damage before and after restoration has been compared. In a first step of evaluation, damage categories before and after restoration have been considered. In the Figures 17 and 18 maps of damage categories before and after restoration are presented for a part at the south facade of the tower. The quantitative evaluation of damage categories for this investigation area is shown in Figure 19. The very severe and the severe damages (damage categories 4, 5) and most of the moderate damages (damage category 3) have been remedied or reduced in the course of restoration. After restoration about two third of the stone surface is without visible damages. Damage indices have been calculated from proportion of damages categories before and after restoration for conclusive judgement/certification of the restoration measures.

In Figure 20 damage indices before and after restoration are compared. The linear damage index is taken as example. Compared to damage indices before restoration, a reduction of damage indices up to 80 % can be stated after restoration. Restoration never will achieve an absolutely damage-free situation. The comparison of damage indices before and after restoration proves great success of the executed restoration measures. In a further step of evaluation by means of damage indices it is possible to judge success of restoration measures individually for each stone type. This is of special importance for all monuments constructed from stone types with different degradation behaviour.

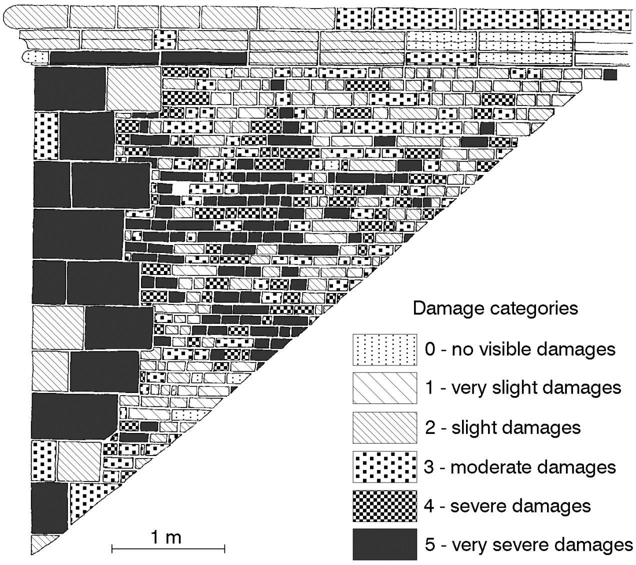

Figure 17. Map of damage categories before restoration. Minster St. Quirin – Neuss / Germany. Tower – part of the south facade.

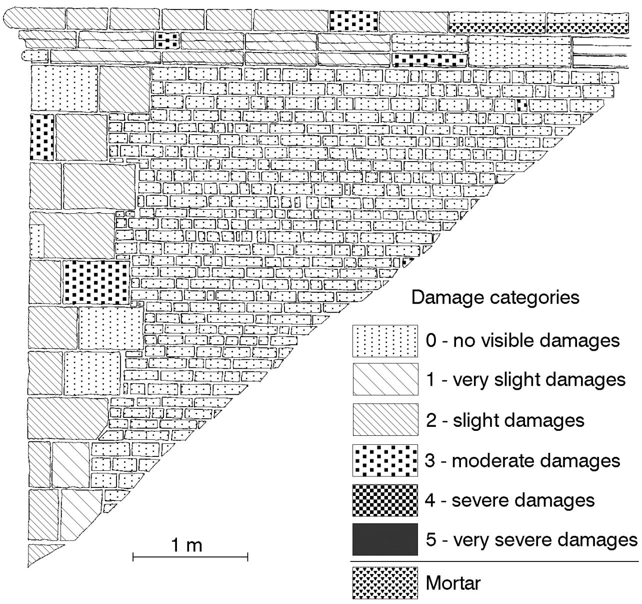

Figure 18. Map of damage categories after restoration. Minster St. Quirin – Neuss / Germany. Tower – part of the south facade.

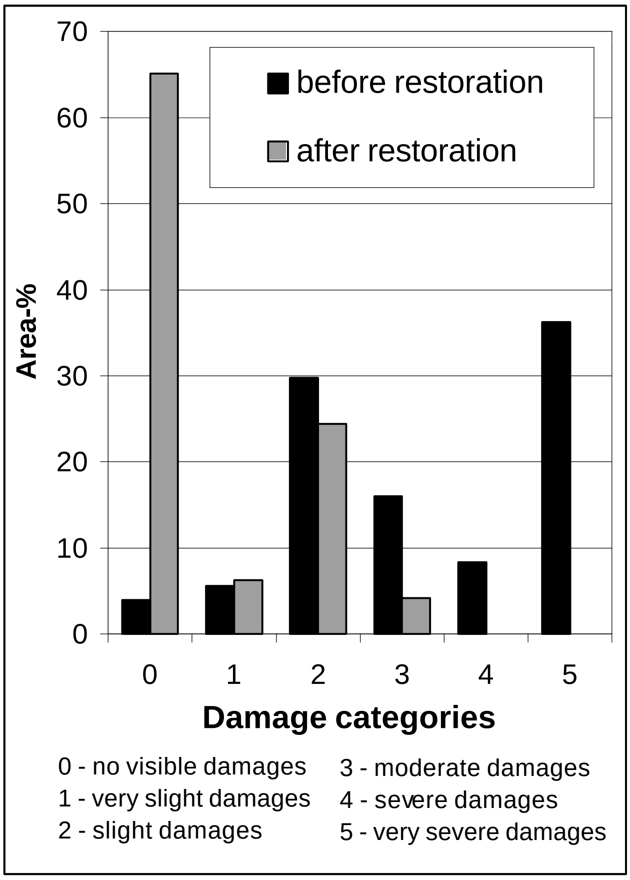

Figure 19. Damage categories before and after restoration. Part of Minster St. Quirin.

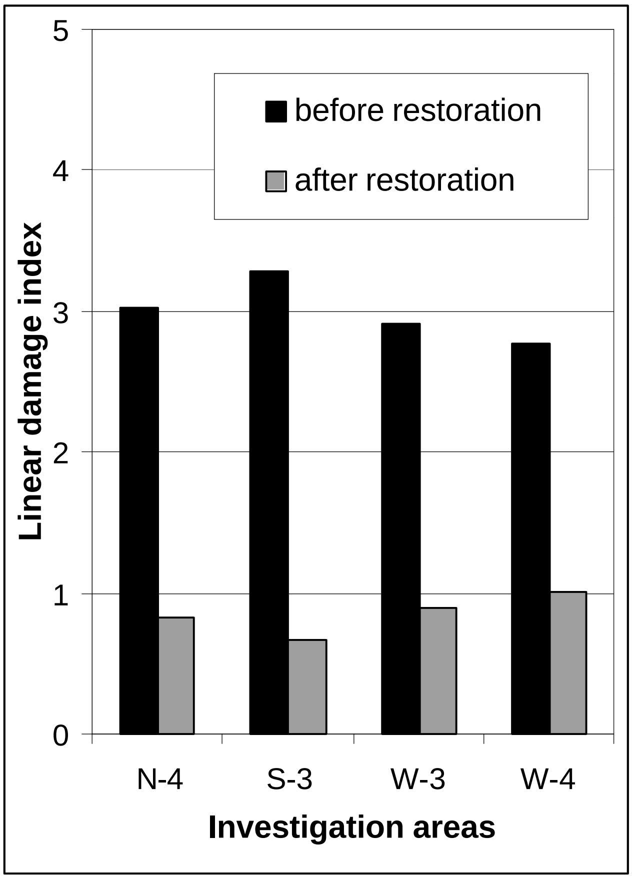

Figure 20. Linear damage index before and after restoration. Minster St. Quirin. Parts of the tower.

4 SUMMARY AND CONCLUSIONS

The monument mapping method has proved to be a reliable and efficient phenomenological procedure for characterisation, documentation, evaluation and rating of stone degradation at monuments. In addition to weathering forms, used for objective and reproducible description of degradation phenomena, and damage categories, used for rating of individual stone damages, damage indices have been established as very suitable tool for conclusive quantitative rating of damages. The consequent use of weathering forms, damage categories and damage indices can be considered as an advanced approach and essential contribution to well-founded damage diagnosis at stone monuments and to sustainable monument preservation. The consistent strategy of linking weathering forms with damage categories and damage indices is addressed and recommended to end-users like:

- organisations, monument authorities or monument owners involved in planning and decision of monument preservation policies and strategies,

- contractors involved in damage diagnosis and monument preservation activities like architects, engineers, restorers, conservators, consultants, project managers, construction com-panies etc.

Use of damage indices ensures scientific quantification and rating of stone damages for entire monuments or single structures. Damage indices allow comparison and ranking of different monuments or parts of monuments. Use of damage indices contributes essentially to rating and comparison of stone materials regarding their susceptibility to degradation. It enhances risk estimation and it contributes to risk management. Suitable use of damage indices have been presented by means of examples.

Damage indices point out need and urgency of intervention. Damage categories locate those parts of a monument which intervention has to focus on. Weathering forms have to be considered for deduction of appropriate types of preservation measures. Damage categories and especially damage indices represent very practical tools for reliable judgement of preservation measures. For regular reevaluation of monuments in the frame of long-term survey and maintenance the consequent application of weathering forms, damage categories and damage indices is advisable.

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