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CULT-STRAT

Assessment of Air Pollution Effects on
Cultural Heritage – Management Strategies

Specific Targeted Research Project (STREP)
Priority 8.1 Policy-oriented Research

Deliverable *no 10*

Estimation of cost for conservation/renovation works for materials and elements considering regional diversities

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Contents

1 Introduction

The aim of this part of WP5 has been to perform analyses of costs of repair of historical objects damaged by material degradation based on costs of interventions on 1 square meter of typical architectural heritage envelopes – roofs, façades and of surface of sculptures.

1.1 Conditions and constraints for the study

For practical reasons of cost calculations it was necessary to set up technical boundary conditions and constraints which are the following: a square sample of the area of $1 m^2$ is located next to the roof cornice on objects with a saddle roof with the cornice at height of 7 m above the terrain or on a façade with the lower edge of the square 6 meters above the terrain. The object is in usual way reachable for transport means and located on a plane terrain in a city with about 100 000 inhabitants. All media and engineering facilities are available on the site. Waste deposit is located in a distance shorter than 20 km. The period of scaffolding renting is derived from an average time of repair, because for some technologies it might be very long, e.g. in case of repeated lime water consolidation.

1.2 Cost bases and procedures

Cost calculations are strongly dependent on diverse national approaches and habits as well as on bases which have been applied. Therefore, the Annex of this report is divided into sections according to individual national contributions.

2 Estimated conservation/renovation costs

2.1 Cost bases and procedures

Costs for repair, replacement or protection of selected building envelope structures and surface systems on historic objects have been estimated according to the following procedures:

A Catalogue of description and guiding prices of construction works URS Prague, stock comp., from the year 2006/1 served as a basic document and all calculated costs have been created using the same methodology. New cost calculations took into account conditions typical for work on historic objects.

Prices from UK are a combination of sources - they are either purely specialist prices if there is no other source, or a combination of prices with some specialist input. Valuable assistance has been received from David Ball Restoration, Cliveden Conservation and Cathedral Studios.

Recommended suitable and appropriate materials and technologies which are used at repair of historic objects have been used.

Necessary skills of individual professions have been considered by modification of qualification classes and standards of time consumption for individual operations.

The catalogue contains only basic costs without complementary costs which must be added. They are, e.g. scaffolding, protective covering of openings or sculptural elements at rendering works, cleaning and washing of windows and doors etc.

Costs of replacement involve not only new structure including the transportation costs but also removal of the old one and handling of demolished material. The fee for use of waste deposits is not included!

The guiding prices of construction works do not include costs related to the site as well as to regional influences, which must be added following a procedure described below. VAT is not included.

Further, costs of surveys, design or engineering work and specific assembly activities must be calculated individually.

Costs of specific restoration works, namely on decorative surfaces or sculptures are represented by items collected from real recent conservation interventions and provided by individual restorers. The average values are given in the tables.

The presented costs are only representatives of guiding costs with a quite high ratio of possible deviations in concrete and better specified conditions, especially taking into account i) contractual prices, ii) variability of building material costs (namely of the imported ones), iii) individual approach to a choice of technology applied which may affect the resulting cost substantially.

Scaffolding costs for items concerning works on façade are not included and must be calculated individually from a table of auxiliary costs because of problems with generalization of very individual conditions in practice.

Costs of site (with regional influences of 0%) can be estimated for a city with 100 000 inhabitants by an additional costs of 7%.

Relevant exchange rate from the CZK to EUR: 1 EUR = 29,005 CZK (January 2006), for UK it was 1 GBP = 1,4649 EUR.

2.2 Technical details of individual structures and systems

2.2.1 Details based on Czech practice

2.2.1.1 Masonry

Replacement of 1m^2 of non-plastered brick masonry is considered in thickness of 15 cm and bound into the remaining masonry wall, with hydraulic (lime-cement) mortar.

Replacement of 1m^2 of non-plastered sandstone masonry is considered in thickness of 20 cm and bound into the remaining masonry wall, with hydraulic (lime-cement) mortar.

Replacement of 1m^2 of non-plastered marble masonry is considered in thickness of 10 cm and bound into the remaining masonry wall, with hydraulic (lime-cement) mortar – here the operation is rather cladding than traditional masonry work.

Replacement of 1m^2 of non-plastered granitoid masonry is considered in thickness of 20 cm and bound into the remaining masonry wall, with hydraulic (lime-cement) mortar.

The costs of cleaning depend on the method used. The power water cleaning is considered as representing one of the simplest techniques. The costs may depend on the stone finishing (polished, stugged, rockfaced, droved, boasted). For the simplicity only stugged finish is considered in the relevant tables.

2.2.1.2 Surfaces

The complexity of façade forms (walls and gables) is categorized into the following groups:

I. Flat plaster without jumps, with a simple main or cordon cornice.

II. Flat plaster with frames around windows and doors (with one jump), simple eaves and simple joints separating floors, with simple main and cordon cornice.

III. Flat plaster with frames around windows and doors (two or three jumps), simple eaves, simple joints between individual floors as well as around the windows, with simple main, floor and cordon cornices (III.1) or
Flat plaster without profiles but with an increased number of narrow surfaces and edges on façades with balconies or loggias associated with parapet walls and enlarged windows or surfaces with framing cladding (over 50% of the area), joints, simple cornices etc. (III.2)

IV. Flat plaster or partially rounded with openings´ framing with more than three jumps, simple eaves and window spandrels, simple joints between floors and around openings, simple main, floor, window and cordon cornices.

V. Flat or partially rounded plaster with openings´ framing with more than three jumps, segmented eaves and window spandrels, simple pilaster strips, simply rusticated, with framing for sgraffito, ceramic or stucco elements, plastic main, floor, window and cordon cornices (V.1) or

Flat plaster without profiles but with an increased number of narrow surfaces and edges on façades with balconies or loggias associated with parapet walls and enlarged windows, with enlarged number of drawn edges or flute in a distance of 80 to 150 mm on walls between windows, columns or parapet walls. (V.2)

VI. Flat and rounded plaster with openings´ framing with more than three jumps, complex eaves and window spandrels, complex pilaster strips, simply rusticated, with framing (even with several jumps) for sgraffito, ceramic or stucco elements, complex pilasters and columns, plastic main, floor, window and cordon cornices.

VII. Plaster of a more complex shape than the previous grades.

Minimum two layers plasters are considered in the tables.

2.2.1.3 Tinsmith works

The amount of material is given by the area to be covered given in a project plus a strip 100 mm wide for creation of eaves.

2.2.1.4 Roof tiles

Simple roofs are pent roofs and saddle roofs.

Complex roofs are hip roofs, mansard roofs and pyramidal roofs.

2.2.1.5 Sculptures

Costs of conservation and renovation are calculated for square meters or pieces of a life size figural sculpture. The damages are divided into two rather general groups – sculptures with light or severe damages. The light damage requires cleaning, local bulk repair and surface treatment (water repellent, antigrafitti). The severe damage is characterized by the necessity to consolidate the degraded parts, replace corroded fasteners, filling of lost material in a greater extent in addition to the above mentioned measures.

2.2.2 <u>Details based on Norwegian practice</u>

All reported costs are generally gathered as costs of maintenance and costs of replacement. Under the maintenance a very substantial conservation work is considered which includes cleaning, (in some cases even sand blasting) and minimum two layers of new coats. Some materials and systems are not specifically historic.

2.2.2.1 Masonry

Surface repair costs of brick and concrete masonry are reported including resealing and scaffolding in this case, too.

2.2.2.2 Surfaces

The complexity of façade forms is not demonstrated because only one item is reported which corresponds to category II.

2.2.2.3 Tinsmith works

All items reporting metal roof maintenance usually consider cleaning plus 2 coats of paint.

2.2.3 Details based on UK practice

2.2.3.1 Masonry

Replacement of 1m^2 of non-plastered brick masonry is considered in thickness of 22,5 cm and bound into the remaining masonry wall, with hydraulic (lime-cement) mortar.

Replacement of 1m^2 of non-plastered stone masonry is considered in thickness of minimum 22,5 cm and bound into the remaining masonry wall, with hydraulic (lime-cement) mortar.

2.2.3.2 Surfaces

Cleaning costs are based on JOS rotational technique chemical free – gentle brushing after soaking. Lime, hydraulic lime and cement plaster costs are determined as specialist prices.

2.2.3.3 Roof tiles

The roofs are not exceeding 50 degree pitch. Clay pantiles are not made from two tiles compared to the Czech flap pantile systems. Paints on metal sheets and wood are composed from three coats.

2.2.3.4 Sculptures

The costs are based on specialist prices.

2.3 Average European conservation and renovation costs

Average European conservation and renovation costs are calculated from data supplied from Czech Republic, Italy, Norway and United Kingdom and presented in Table 1. This sample is not sufficiently large for any statistical evaluation and serves rather as a representation for very basic considerations of the pollution cost range and diversity conditions related to cultural heritage, (see below).

Table 1. Average European conservation and renovation costs

1.1 Roof envelope costs and typical experienced life times

No.	Surface layer or system	Unit	Guided cost EUR			Lifetime in years		
			Minimum	Maximum	Average	Min/Max/Average		
1	copper sheet – total replacement	m^2	55,65	85,00	**67,82**			
2	steel galvanized sheet – total replacement	m^2	16,04	52,00	**30,59**	5	45	**25**
3	plain tiles (double) – total replacement	m^2	30,23	43,32	**36,58**	40	100	**70**
4	flap pantile roofing – total replacement	m^2	24,23	45,39	**37,65**	30	70	**50**
5	wooden shingle split – total replacement	m^2	35,16	83,68	**58,04**	50	80	**65**
6	paint on steel sheet – renewal	m^2	3,75	5,48	**4,62**	3	9	**6**
7	paint on galvanized steel sheet – renewal	m^2	5,53	57,00	**26,02**	5	11	**8**
8	paint on wooden shingle roofing	m^2	5,32	43,32	**17,96**	5	8	**6,5**
9	regional variants – slate tiles	m^2	51,88	53,61	**52,74**			
10	flap pantile roofing – repair and making up till 10% of tiles	m^2	3,99	133,68	**49,30**			

1.2 Non-plastered masonry

No.	Surface layer or system	Unit	Guided cost EUR			Lifetime in years		
			Minimum	Maximum	Average	Min/Max/Average		
11	non-plastered brick masonry 150 mm – total replacement	m^2	51,39	454,12	**242,40**			
12	non-plastered brick masonry – pointing renewal	m^2	9,67	98,98	**52,40**			
13	non-plastered brick masonry – repair of degraded surface with replacement of bricks up to 10%	m^2	15,17	354,70	**166,75**			
14	non-plastered brick masonry – cleaning (power water)	m^2	1,90	208,14	**76,60**			
15	non-plastered brick masonry – luting of small defects and consolidation	m^2	7,58	172,13	**95,16**			
16	non-plastered brick masonry – paint renewal (water repellent – Porosil VV5)	m^2	2,85	13,04	**7,94**			
17	non-plastered ashlar masonry – sandstone – total replacement	m^2	111,21	897,25	**403,46**	80	80	**80**
18	non-plastered ashlar masonry – marble – total replacement	m^2	75,07	1464,90	**584,59**			
19	non-plastered ashlar masonry – granitoid – total replacement	m^2	127,63	1208,54	**516,66**	50	150	**100**
20	non-plastered irregular stone masonry 200 mm – total replacement	m^2	82,03	1552,79	**577,94**			
21	non-plastered stone masonry – pointing renewal	m^2	14,06	41,46	**27,76**			
22	non-plastered stone masonry – repair of degraded surface with replacement of stones up to 10%	m^2	22,58	439,47	**231,03**			
23	non-plastered stone ashlar masonry – cleaning (power water)	m^2	1,90	24,90	**13,40**			
24	non-plastered stone masonry – luting of small defects and consolidation	m^2	10,34	205,09	**107,71**			
25	non-plastered brick masonry – paint renewal (water repellent – Porosil ZV20 + VV5)	m^2	5,84	13,04	**9,44**	3	20	**11,5**
26	non-plastered irregular stone masonry – cleaning (power water)	m^2	1,90	208,14	**83,83**	15	30	**22,5**
27	concrete	m^2	99,00	99,00	**99,00**			

1.3 Glass walls

No.	Surface layer or system	Unit	Guided cost EUR			Lifetime in years
			Minimum	Maximum	Average	Min/Max/Average
28	flat glass surface – cleaning by hand washing	m^2	0,69	7,32	**4,01**	
29	flat glass surface – cleaning by power water	m^2	1,03	1,03	**1,03**	
30	glass historical – staggered protection sheets including structure	m^2	878,94	878,94	**878,94**	

1.4 Plastered façades

No.	Surface layer or system	Unit	Guided cost EUR			Lifetime in years		
			Minimum	Maximum	Average	Min/Max/Average		
31	lime plaster (rendering) simple (gothic) I-II – cleaning	m^2	1,74	65,92	**26,19**			
32	lime plaster (rendering) simple I-II – colour paint lime based (Porokalk PB)	m^2	2,68	47,00	**19,76**			
33	lime plaster (rendering) simple I-II – colour paint silicate based KEIM Soldalit	m^2	6,39	15,38	**11,92**			
34	lime plaster (rendering) simple I-II – consolidation with lime water (60 applications)	m^2	19,98	117,19	**68,58**			
35	lime plaster (rendering) simple I-II – consolidation „chemical" (e.g. SiO_2) – Porosil ZTS	m^2	2,60	28,78	**15,10**			
36	lime plaster (rendering) simple I-II – consolidation „chemical" (e.g. organo silicates) – Porosil Z40	m^2	4,80	36,62	**23,40**			
37	lime plaster (rendering) simple I-II – protected or aesthetic paint (hydrophobic, lime wash..)	m^2	1,12	28,78	**15,34**	3	6	**4,5**
38	lime plaster (rendering) simple I-II – repair up to 10% of the surface (fine mortar + VAPO)	m^2	4,84	54,19	**28,47**			
39	lime plaster (rendering) simple I-II – total replacement	m^2	16,74	112,80	**53,74**	25	25	**25**
40	lime plaster (rendering) type III-V – cleaning	m^2	1,84	62,96	**32,40**			
41	lime plaster (rendering) type III-V – total replacement	m^2	27,84	27,84	**27,84**			
42	lime plaster (rendering) III-V – consolidation with lime water (60 applications)	m^2	23,25	23,25	**23,25**			
43	lime plaster (rendering) III-V – consolidation „chemical" (e.g. SiO_2) – Porosil ZTS	m^2	3,07	3,07	**3,07**			
44	lime plaster (rendering) III-V – consolidation „chemical" (e.g. organo silicates) – Porosil Z40	m^2	5,65	5,65	**5,65**			
45	lime plaster (rendering) IIIVI – protected or aesthetic paint (hydrophobic, lime wash..)	m^2	1,33	1,33	**1,33**			
46	lime plaster (rendering) III-V – repair up to 10% of the surface (fine mortar + VAPO)	m^2	5,67	5,67	**5,67**			
47	lime plaster (rendering) III-V – colour paint lime based (Porokalk P+B)	m^2	3,02	3,02	**3,02**			
48	lime plaster (rendering) III-V – colour paint silicate based KEIM Soldalit	m^2	8,19	8,19	**8,19**			
49	lime plaster (rendering) type VI-VII – cleaning	m^2	2,45	39,55	**21,00**	3	6	**4,5**
50	lime plaster (rendering) type VI-VII – total replacement	m^2	45,62	136,24	**90,93**			
51	lime plaster (rendering) simple VI-VII – consolidation with lime water (60 applications)	m^2	25,78	25,78	**25,78**			

52	lime plaster (rendering) simple VI-VII – consolidation „chemical“ (e.g. SiO_2) – Porosil ZTS	m^2	4,06	4,06	**4,06**	
53	lime plaster (rendering) simple VI-VII – consolidation „chemical“ (e.g. organo silicates) – Porosil Z40	m^2	7,49	7,49	**7,49**	
54	lime plaster (rendering) simple VI-VII – protected or aesthetic paint (hydrophobic, lime wash..)	m^2	1,60	1,60	**1,60**	
55	lime plaster (rendering) simple VI-VII – repair up to 10% of the surface (fine mortar + VAPO)	m^2	8,71	8,71	**8,71**	
56	lime plaster (rendering) simple VI-VII – colour paint lime based (Porokalk P+B)	m^2	3,97	3,97	**3,97**	
57	lime plaster (rendering) simple VI-VII – colour paint silicate based KEIM Soldalit	m^2	9,95	9,95	**9,95**	
58	artificial stone rendering – cleaning	m^2	1,71	1,71	**1,71**	
59	artificial stone rendering – total replacement (Petra C)	m^2	72,33	72,33	**72,33**	
60	artificial stone rendering - repair up to 10% of the surface (Petra C)	m^2	9,94	9,94	**9,94**	
61	artificial stone rendering - consolidation „chemical“ (e.g. organo silicates) – Porosil Z40	m^2	2,69	2,69	**2,69**	
62	Sand cement rendering simple – colour paint lime based	m^2	15,38	15,38	**15,38**	
63	Sand cement rendering simple – colour paint silicate based	m^2	15,38	15,38	**15,38**	
64	Sand cement rendering simple – consolidation with lime water (60 applications)	m^2	117,19	117,19	**117,19**	
65	Sand cement rendering simple – consolidation „chemical“ (e.g. SiO_2)	m^2	13,92	13,92	**13,92**	
66	Sand cement rendering simple – consolidation „chemical“ (e.g. organo silicates)	m^2	36,62	36,62	**36,62**	
67	Sand cement rendering simple – protected or aesthetic paint (hydrop, lime wash)	m^2	16,11	16,11	**16,11**	
68	Sand cement rendering simple – repair up to 10% of the surface	m^2	33,69	33,69	**33,69**	
69	Sand cement rendering simple – total replacement	m^2	139,17	139,17	**139,17**	
70	Sand, hydraulic lime rendering simple – colour paint lime based	m^2	15,38	15,38	**15,38**	
71	Sand, hydraulic lime rendering simple – colour paint silicate based	m^2	15,38	15,38	**15,38**	
72	Sand, hydraulic lime rendering simple – consolidation with lime water (60 applications)	m^2	117,19	117,19	**117,19**	
73	Sand, hydraulic lime rendering simple – consolidation „chemical“ (e.g. SiO_2)	m^2	13,92	13,92	**13,92**	
74	Sand, hydraulic lime rendering simple – consolidation „chemical“ (e.g. organo silicates)	m^2	36,62	36,62	**36,62**	
75	Sand, hydraulic lime rendering simple – protected or aesthetic paint	m^2	16,11	16,11	**16,11**	

	(hydrophobic, lime wash..)					
76	Sand, hydraulic lime rendering simple – repair up to 10% of the surface	m^2	38,09	38,09	**38,09**	
77	Sand, hydraulic lime rendering simple – total replacement	m^2	152,35	152,35	**152,35**	

1.5 Painted wood

No.	Surface layer or system	Unit	Guided cost EUR			Lifetime in years
			Minimum	Maximum	Average	Min/Max/Average
78	new paint on wood	m^2	8,78	8,78	**8,78**	
79	paint on wood – total replacement	m^2	8,21	21,97	**15,06**	

1.6 Supporting works

No.	Surface layer or system	Unit	Guided cost EUR			Lifetime in years
			Minimum	Maximum	Average	Min/Max/Average
80	scaffolding for rendering works up to 10 m of height, 1 m wide	m^2	4,59	4,59	**4,59**	
81	heavy scaffolding for masonry works up to 10 m of height, 2,5 m wide	m^2	9,93	9,93	**9,93**	
82	cleaning of windows and doors	m^2	0,72	0,72	**0,72**	
83	covering of windows and doors	m^2	1,02	1,02	**1,02**	

1.7 Sculptures or sculptural items

No.	Surface layer or system	Unit	Guided cost EUR			Lifetime in years		
			Minimum	Maximum	Average	Min/Max/Average		
84	stone – cleaning I – light damage	m^2	17,93	219,74	127,51			
85	stone – pre-restoration works (removal of damaging parts, mechanical fasteners, …)	m^2	13,10	85,82	**46,40**			
86	stone – consolidation of damaged parts (organo silicate)	m^2	12,76	222,78	**93,16**			
87	stone – new fasteners, filling with cement etc.	m^2	34,55	46,88	**40,76**			
88	colour retouch of surface	m^2	18,62	53,78	**40,00**	10	20	**15**
89	protective coating (hydrophobic paint, ..)	m^2	5,52	77,64	**39,04**	3	20	**11,5**
90	alternative surface protection (lime wash, micro mortars, …)	m^2	87,89	87,89	**87,89**			
91	balustrade cleaning	m^2	14,65	14,65	**14,65**	15	30	**22,5**
92	pre-consolidation	m^2	8,96	40,30	**29,85**			
93	stone – cleaning II – severe damage (incl. desalination)	m^2	68,95	234,38	**166,45**	15	30	**22,5**
94	stone – consolidation II – severe damage	m^2	21,38	47,61	**34,49**	15	30	**22,5**
95	stone – overall consolidation (vacuum impregnation) – sculpture up to 2 m height	piece	90,75	275,81	**195,43**			
96	stone – new fasteners, filling with cement etc. II	m^2	46,88	60,16	**52,74**			

97	metal work – repair, new guild (average estimate)	m^2	13,79	131,84	**72,82**			
98	replacement by an artificial stone replica (cast sculpture in a mould) up to 2 m height	piece	11902,31	17238,41	**14570,36**	30	60	45
99	replacement by a cut replica – soft sandstone, baroque, up to 2 m height	piece	17212,58	20686,09	**18949,33**	100	100	**100**
100	replacement by a cut replica – hard sandstone, baroque, up to 2 m height	piece	29305,29	29305,29	**29305,29**	150	250	**200**
101	baluster soft sandstone – cut replica replacement	piece	275,81	275,81	**275,81**	80	100	**90**
102	artificial stone replica – mould column up to 3 m with a capital	piece	4137,22	4137,22	**4137,22**	30	60	**45**
103	lime plaster sgrafitto – cleaning and hydrophobization	m^2	18,55	29,30	**23,92**	4	9	**6,5**
104	lime plaster sgrafitto – substantial restoration	m^2	108,60	262,22	**185,41**	15	30	**22,5**
105	polychrome sandstone element (cornice) – conservation	m^2	40,68	40,68	**40,68**	15	20	**17,5**
106	lime plaster decorated (fresco) – cleaning	m^2	152,35	152,35	**152,35**			
107	lime plaster decorated (fresco) – substantial restoration	m^2	215,48	569,85	**392,66**	7	16	**11,5**
108	bronze – cleaning with lutting	m^2	103,43	337,80	**188,58**			
109	bronze – protection coat	m^2	11,80	87,89	**42,43**			
110	iron gate of a complex shape – substantial restoration	m^2	3016,72	3016,72	**3016,72**			

3 Calculation of general pollution costs

3.1 Lifetime estimates for general pollution costs

The time between maintenance or restoration actions for given materials and systems are dependent on the climate conditions and ambient environmental quality. This time can be calculated using dose response functions and agreed tolerable corrosion before action or it can be estimated from evaluation of practical experience.

3.1.1 Tolerable corrosion before maintenance action

Typical tolerable corrosion before maintenance action for selected building materials and stages of ageing / degradation were given in the final report from the EU project Multi Assess ((EVK4-CT-2001-00044) (Table 2).

Table 2. Tolerable values for corrosion and maintenance intervals for cultural heritage materials.

Material	Type of surface	Tolerable corrosion before action	Tolerable time between maintenance	Tolerable corrosion rate
Limestone/marble	Ornament, aged	100 µm	12 years	8.3 µm $year^{-1}$
	Ornament, corrodec	50 µm	6 years	8.3 µm $year^{-1}$
Sandstone calcareous	Ornament, aged	100 µm	12 years	8.3 µm $year^{-1}$
	Ornament, corrodec	50 µm	6 years	8.3 µm $year^{-1}$
Copper monument	Ornament, aged	50 µm	50 years	1.0 µm $year^{-1}$
	Ornament, corrodec	10 µm	20 years	0.5 µm $year^{-1}$
Bronze monument	Ornament, aged	50 µm	50 years	1.0 µm $year^{-1}$
	Ornament, corrodec	10 µm	15 years	0.7 µm $year^{-1}$
Zinc monument	Evenly corroded	80 µm	50 years	1.6 µm $year^{-1}$

The tolerable corrosion rate calculated from a tolerable corrosion before action and tolerable time between maintenance in Table 2 corresponds with the background corrosion rate multiplied with a factor n = 2.5 as can be seen in Table 3.

Table 3. Tolerable corrosion rate based on background corrosion rates and n=2.5.

Material	Background corrosion rate	Tolerable corrosion rate
Limestone	3.2 µm $year^{-1}$	8 µm $year^{-1}$
Sandstone	2.8 µm $year^{-1}$	7 µm $year^{-1}$
Copper	0.34 µm $year^{-1}$	0.8 µm $year^{-1}$
Bronze	0.25 µm $year^{-1}$	0.6 µm $year^{-1}$
Zinc	0.46 µm $year^{-1}$	1.1 µm $year^{-1}$
Carbon steel	8.5 µm $year^{-1}$	20 µm $year^{-1}$

3.1.2 Dose response function based lifetime estimates

From lifetime equations based on dose response functions for the separate materials it is then possible to calculate the lifetime for a building surface between maintenance. The following equations are examples of dose response and lifetime functions for Portland limestone found from statistical analysis of field test data in the MULTI-ASSS project. The lifetimes will vary depending on climatic conditions and on the pollution level. In more severe climates and at higher pollution levels the lifetimes will be shorter.

Dose response function for Portland limestone :

$R = 3.1 + \{0.85 + 0.0059[SO_2]RH_{60} + 0.054Rain[H^+] + 0.078[HNO_3]Rh_{60} + 0.0258PM_{10}\}t$

Lifetime function for Portland limestone :

$t = (R - 3.1) / \{0.85 + 0.0059[SO_2]RH_{60} + 0.054Rain[H^+] + 0.078[HNO_3]Rh_{60} + 0.0258PM_{10}\}$

where R is the recession rate in $\mu m\ year^{-1}$, Rh_{60} = (Rh-60) when Rh>60, otherwise 0, and the other parameters area given as:

- Time (t) / years
- Gaseous pollutants SO_2, NO_2, O_3 and HNO_3 / $\mu g\ m^{-3}$
- Temperature (T) / °C
- Relative humidity (Rh) / %
- Amount of precipitation (Rain) / mm
- pH of precipitation / decades
- H^+ of precipitation ($[H^+]$ / $mg\ l^{-1}$
- Total amount of deposited particulate matter (PM_{dep}) / $mg\ m^{-2}\ year^{-1}$

3.1.3 Experienced lifetime estimates

Actual experienced lifetimes and maintenance intervals are complex subjects. Pollution will always reduce lifetimes of building materials and induce a cost when lifetimes are related to the chemical and physical properties of the materials. Another matter is that lifetimes are often determined by totally different aesthetical, architectural, social or other reasons.

3.1.4 Discussion on lifetime estimates in relation to the pollution cost calculation

Real lifecycles and intervals between maintenance, conservation or renovation of materials or building elements can vary for a range of different reasons. The tolerable corrosion depths given in Table 3 are guidelines. The dose response functions consider chemical degradation whereas many other degradation factors, e.g. physical, structural or human wear factors, may also influence build structures and monuments. In practise many concerns pertaining to the particular building or object to be maintained, and its building materials and elements, will affect decisions about maintenance intervals. Judgements about the severity of degradation of a surface will vary depending on the wide variation in properties of the building materials and their purpose of use. For some buildings very little degradation may be acceptable and replacement is considered as a good option. For others, e.g. many historical buildings, the original materials are kept in place even if severely degraded, and the cost of maintenance is due to measures to reduce degradation and careful restoration work. It is therefore very important to investigate the real experienced intervals for maintenance, conservation and renovation for different kinds of structures. These values can be compared with theoretical intervals as those calculated from lifetime equations. It would be useful to discuss the total rationality of real life decisions about maintenance, conservation and renovation intervals, compared with the theoretical lifetimes based purely on chemical corrosion rates for materials. This would add to the understanding of the relative importance of chemical weathering and degradation for the practical maintenance and life cycles of materials used in cultural heritage buildings and monuments.

The lifetimes for sculptures and sculptural items in chapter 1.7 are by comparison generally longer than the tolerable times for maintenance (stone materials) in Table 2, except for the three surface protection measures (no. 88. 103, 107). The intervals (22.5 years) for the treatments (no. 91, 93 and 94) which are more comparable to those for the maintenance due to corrosion (12 years) assumed in Table 2 are about the double of this. Accepting the value for "Tolerable corrosion before action" in Table 2 this would mean that the actual corrosion rates are below the threshold levels or "tolerable rates". A typical recession rate for limestone in unsheltered position in Europe is between 6 and 8 µm/year. This can be seen in Figure 1(Kucera, 2005) and in Figure 2 for the city of Oslo.

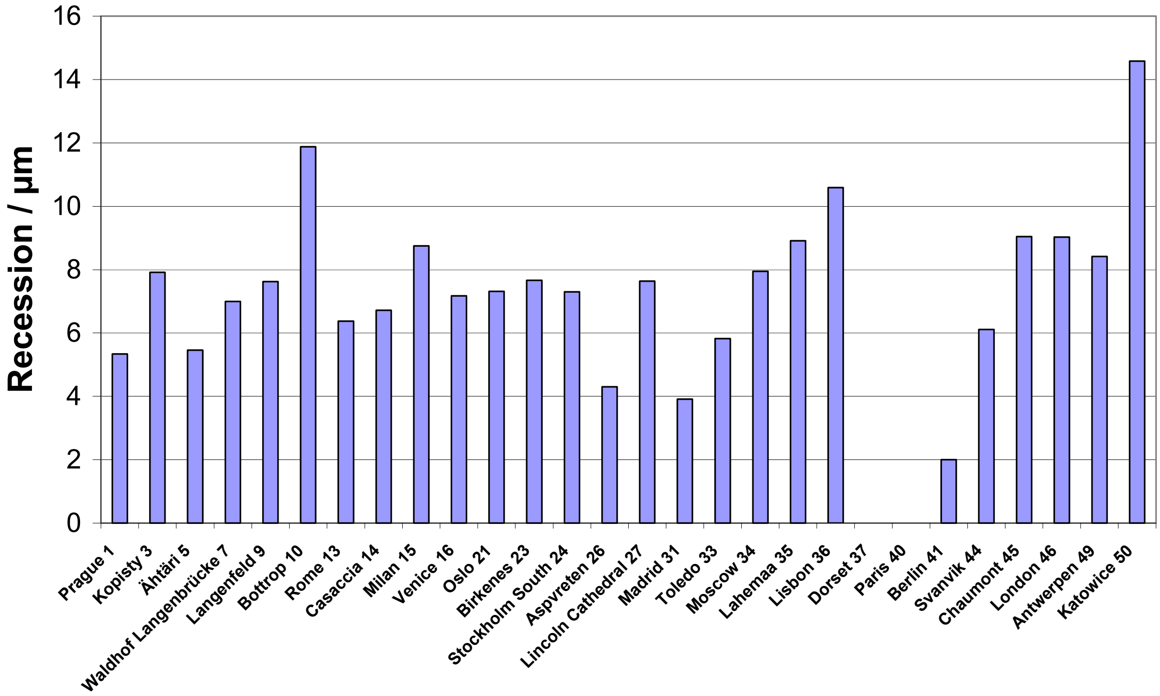

Figure 1. Corrosion attack of limestone in unsheltered position (2002-2003)

For a value of 6 µm/year the theoretical time before maintenance would be 100/6 = 17 years which is within the limits of observation (Table 1). Thus there is quite good correspondence between the values in Table 2, which were derived based on conservators experience about maintenance intervals transformed to tolerable corrosion rates by using typical measured values for the yearly corrosion, and the directly observed maintenance intervals in Table 1. The values in Table 1 and 2 are independently derived and gives increased credibility to the lifetime estimates. It is however important to be aware that maintenance intervals may partly or in some cases wholly be determined by other factors than the corrosion rate, and that corrosion may not have reached the tolerable levels set in Table 2 before maintenance occurs. The values in Table 2 for the tolerable corrosion before action must be regarded as the maximum values of corrosion that should in any case be observed before maintenance, - when maintenance is performed due to corrosion degradation only.

It can be argued that the factors apart from air pollution, and possible climate change that affect maintenance intervals and lifetimes would do this equally much in a background ambient situation and in the actual exposure situation. The difference between

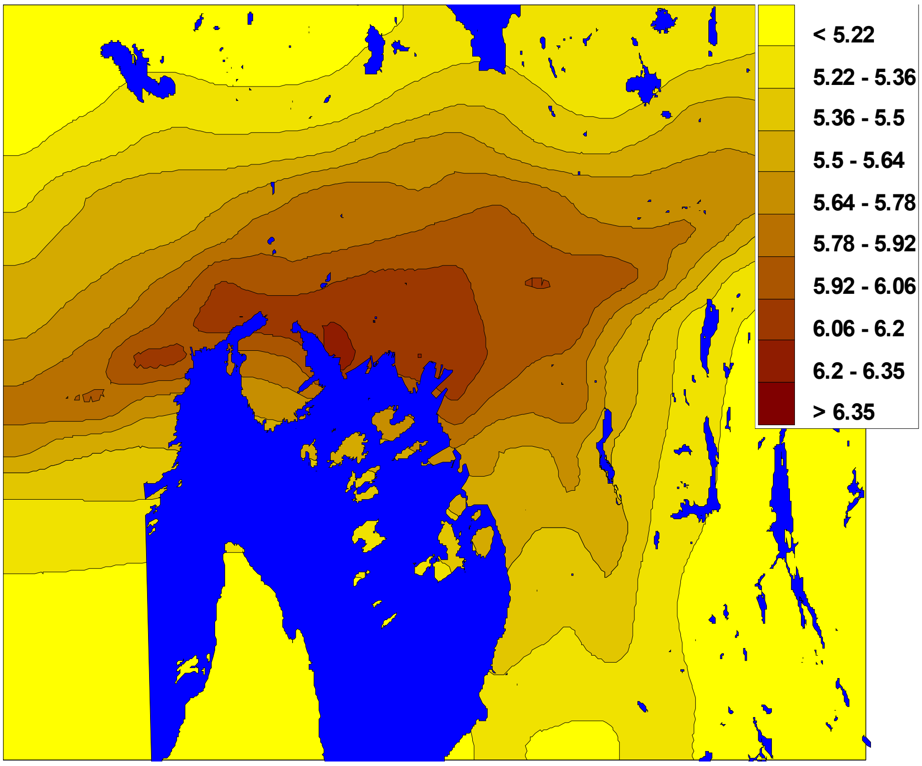

Figure 2: Corrosion (μm year^{-1}) of Portland Limestone in Oslo calculated from statistical dose-response functions from the EU project MULTI-ASSESS (Kucera, 2005)

lifetimes of materials in the "clean" and polluted situation, t_{ti}-t_{pi} in Eq. 1 would then not change depending on these factors. This means that even if real lifetimes and maintenance intervals may depend on other factors than purely corrosion as assumed for the values calculated from equations above and given in Table 2 (for the tolerable situation), the calculation of pollution costs using Eq. 1 would still be valid. The important factors that then determine estimates of pollution costs are the tolerable corrosion before action (maintenance), e.g. as suggested in Table 2, and the background and the tolerable rate determined for the corrosion, as given in Table 3. The background rate and tolerable rate determine the number of years needed to reach the technical lifetime (t_{ti}) and the lifetime in polluted air (t_{pi}) respectively.

3.2 Calculation of general pollution costs

Atmospheric (air) pollution over a territory is usually characterized by values constant within chosen grid units. Therefore, it is reasonable to calculate the pollution costs typical for the same grid scheme. We combine the knowledge of cultural heritage materials stock in the territory with data on air pollution over the same territory. The general pollution costs can then be calculated from the prices given in Table 1 as a sum of pollution costs of interventions on individual building surface materials or systems using Equation 1:

$$\mathbf{C_p = sum\ (Q_i*f_i*(t_{ti}-t_{pi})/(t_{ti}*t_{pi}),\ i = 1.....n)} \qquad (1)$$

where:

C_p = pollution cost in EUR/year/grid unit

Q_i = the amount of one type of building material or system within the grid unit
f_i = the price for maintenance or repair for the given material in EUR/m^2.
t_{ti} = the technical lifetime for the given material in "clean" atmosphere in years.
t_p = the lifetime for the given material exposed to characteristic grid pollution in years.
i = 1 …..n where n is number of historic materials or conservation systems present in the grid and subjected to air pollution action

4 Diversities in general pollution costs

4.1 Diversities in cultural heritage stock at risk

The variation of materials used for architectural heritage objects across Europe is relatively low in types but quite high in volumes of materials typical for different regions. Thus in Scandinavia and in mountain regions timber houses prevail, whilst in Western and Central Europe plastered façades and roof tiles are most important. In Southern Europe limestone and clay flap pantile roofing are common materials. The volume attacked is further influenced by different country policies for listing buildings and structures as architectural heritage. This diversity is a subject of stock at risk mapping within another CULTSTRAT project work package, therefore, it is not discussed here in detail.

4.2 Diversities in conservation and renovation costs

The costs have been gathered from four typical European regions – Central Europe (Czech Republic), Southern Europe (Italy), Scandinavia (Norway) and Western Europe (United Kingdom). These countries exhibit different economic conditions and produce different GNP (Gross National Product) or PPP (Purchasing Power Parity), which probably better expresses the socio-economic conditions. The ratio of the PPP for the analysed countries is Czech Republic : Italy : UK : Norway corresponding to 1 : 1,5141 : 1,7098 : 2,0951 (Finfacts 2004).

Comparison of conservation and renovation costs in different countries which contributed to the report is presented in the following Figures 3 – 6.

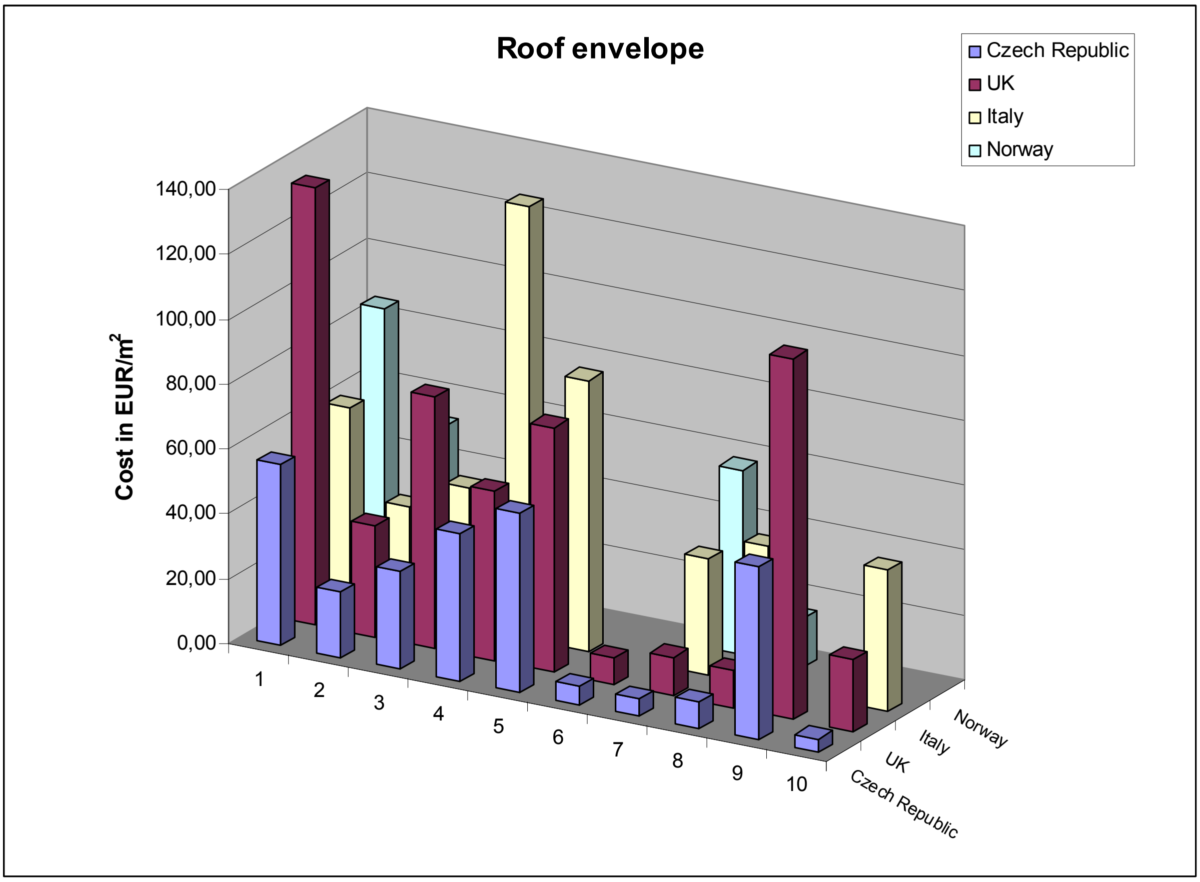

Figure 3. Cost diversity of roof surface conservation and renovation.

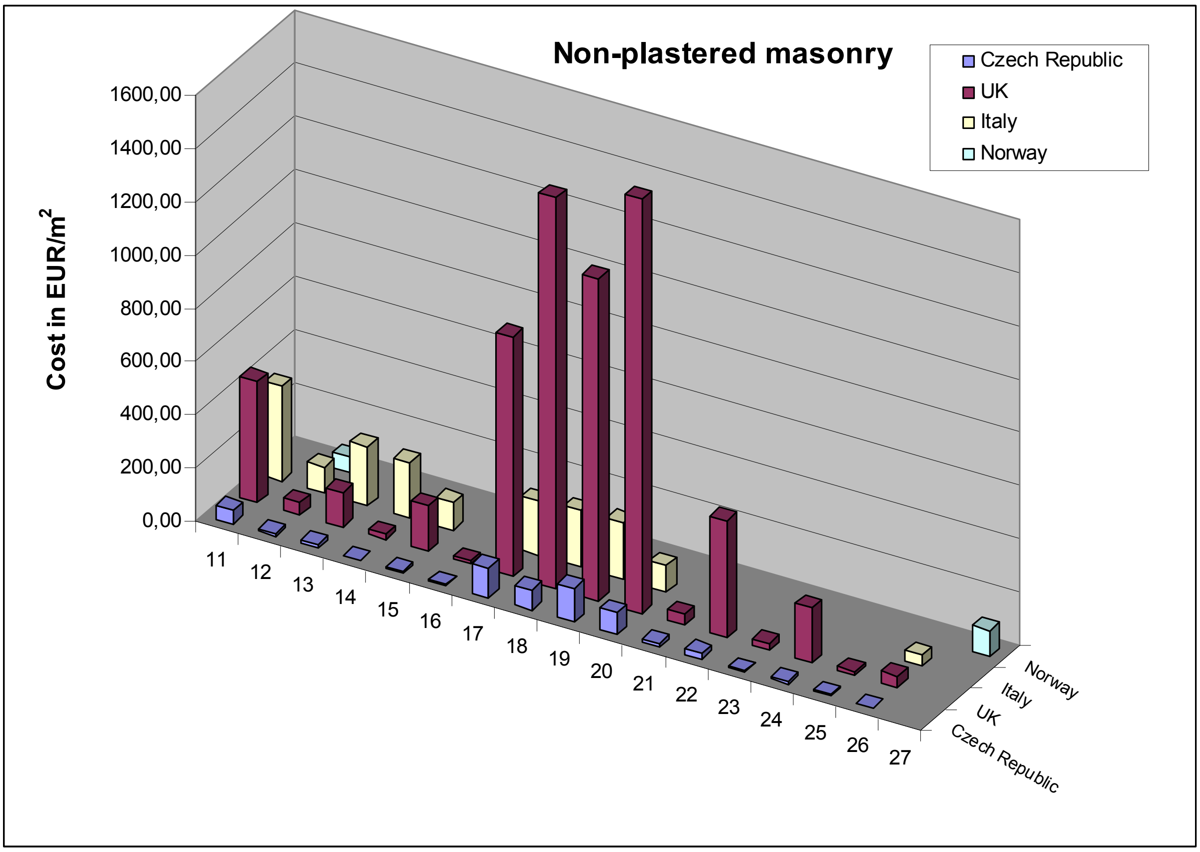

Figure 4. Cost diversity of surface masonry conservation and renovation.

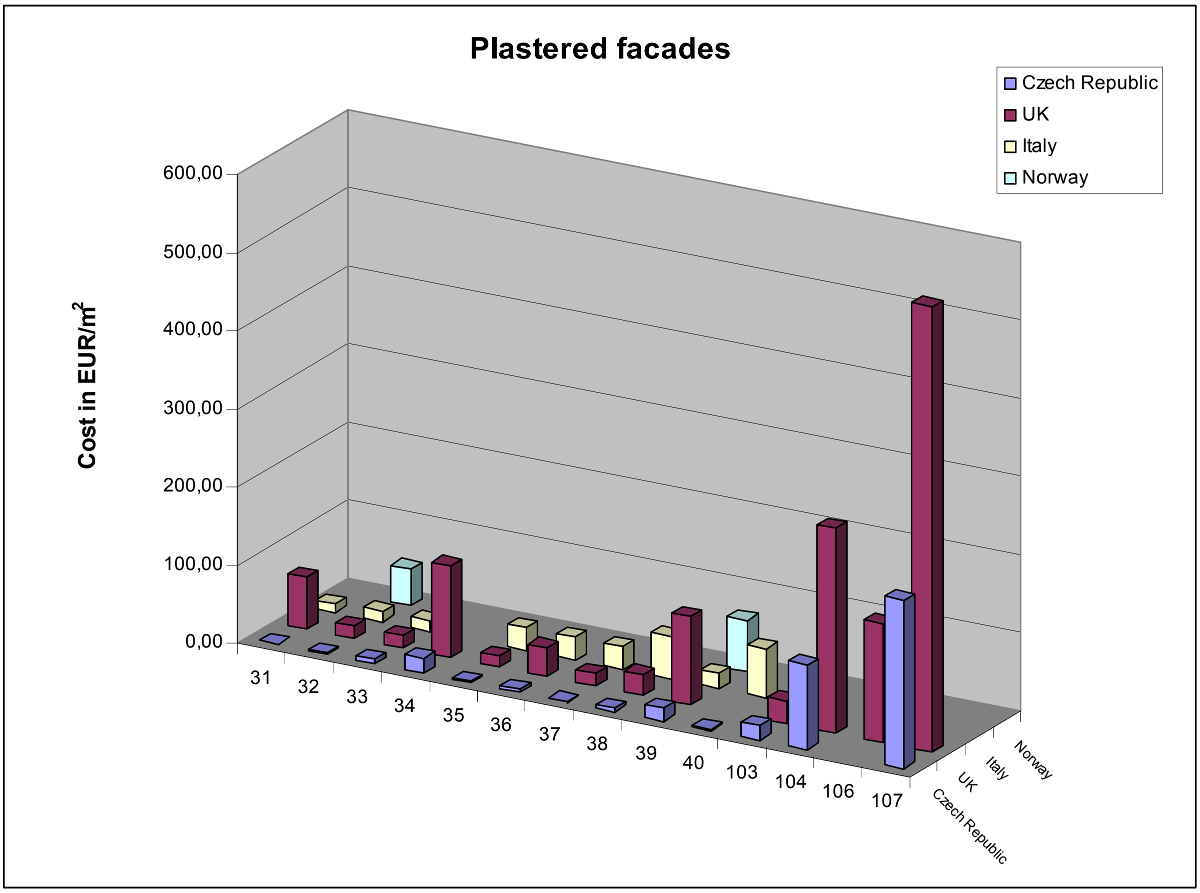

Figure 5. Cost diversity of plastered surface conservation and renovation.

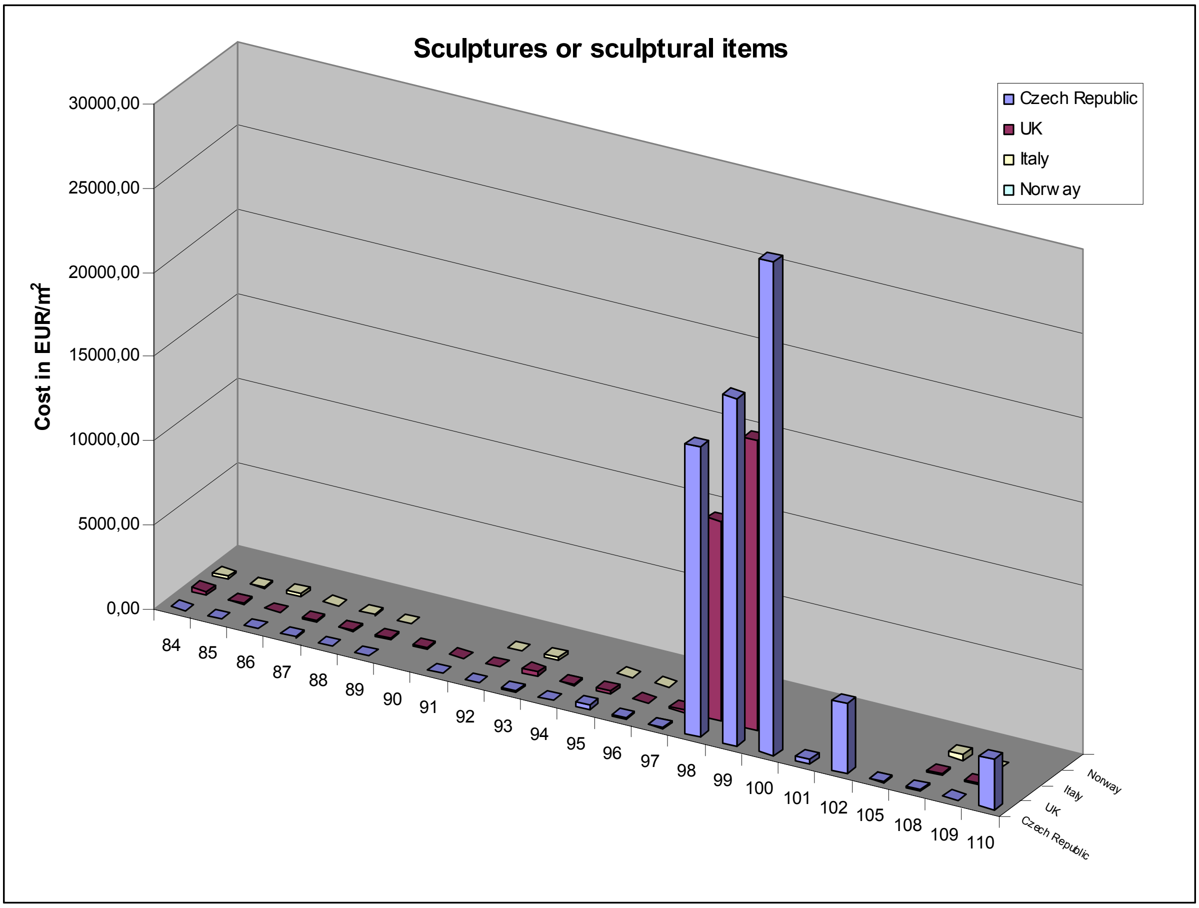

Figure 6. Cost diversity of surface conservation and renovation on sculptures.

In the figures the individual items are marked with the same numbers (x axis) as in the Table 1. The comparison shows that the cost diversity across Europe is quite significant and uneven. It seems that in typical construction works on architectural heritage the costs in Central Europe (new member state) are mostly substantially lower than in the original EU countries. On the other hand, the artistic works on stone sculptures are higher in Central European countries.

Details for selected items can be studied in the Annex where tables containing the complete data are presented from all four contributeing countries: Czech Republic, Italy, Norway and UK. The other items in Table 1 are mostly from the Czech Republic and UK (if all three values in the row are identical, then they represent data from one country only).

In order to suppress the influence of local economy in individual reporting countries, the same data as in Figure 1 are compared after reduction by the ratio of PPP (Purchasing Power Parity) values to the PPP in the Czech Republic in Figure 7. There are still significant regional differences which are mostly caused by the cost of labour in the respective countries (in fact, the material costs are very similar in all countries, especially concerning the materials for restoration works).

Generally, the average costs in Table 1 calculated from the reported data gathered in four European countries are sufficiently representative for the project aims, even though they are quite approximately estimated. Better results can be achieved only by a systematic cost monitoring and collection which can be ensured using relevant information systems. Such a need had been identified in other economy assessment fields long time ago, e.g. in the cultural heritage tourism cost/benefit analysis, nevertheless, no measures have been adopted so far.

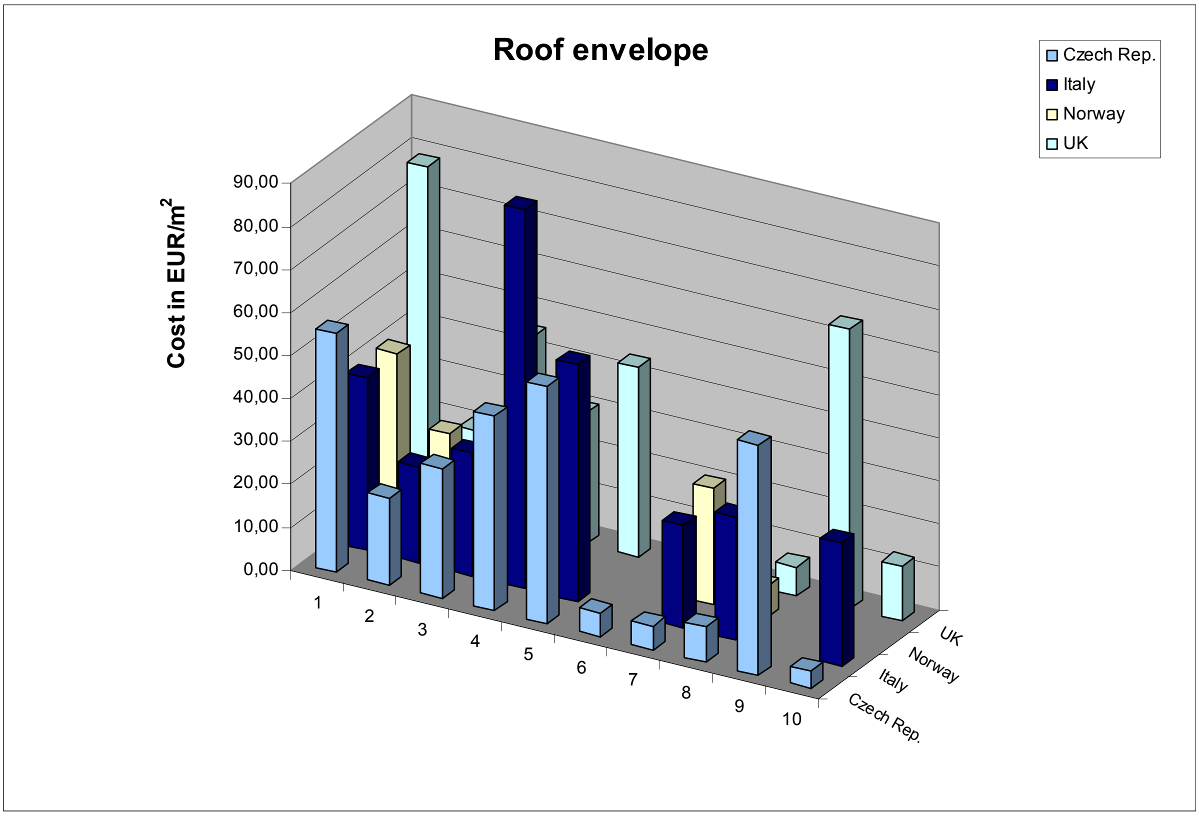

Figure 7. Costs reduced by the ratio corresponding to the PPP in the relevant country.

Regional cost diversity is further shown in Figures 8–10 where average coefficients of cost ratios for groups of maintenance, restoration and conservation works in individual countries are presented. They are calculated in relation to the costs in the Czech Republic.

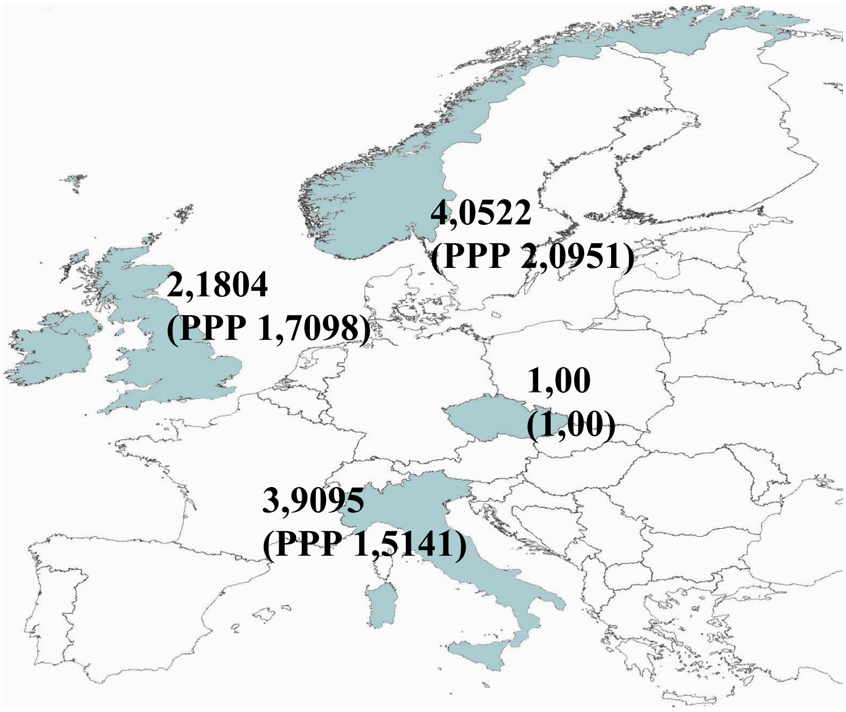

Figure 8. Average coefficients of cost ratios of roof envelope maintenance, renovation and conservation works related to the Czech Republic (country PPP ratio for comparison).

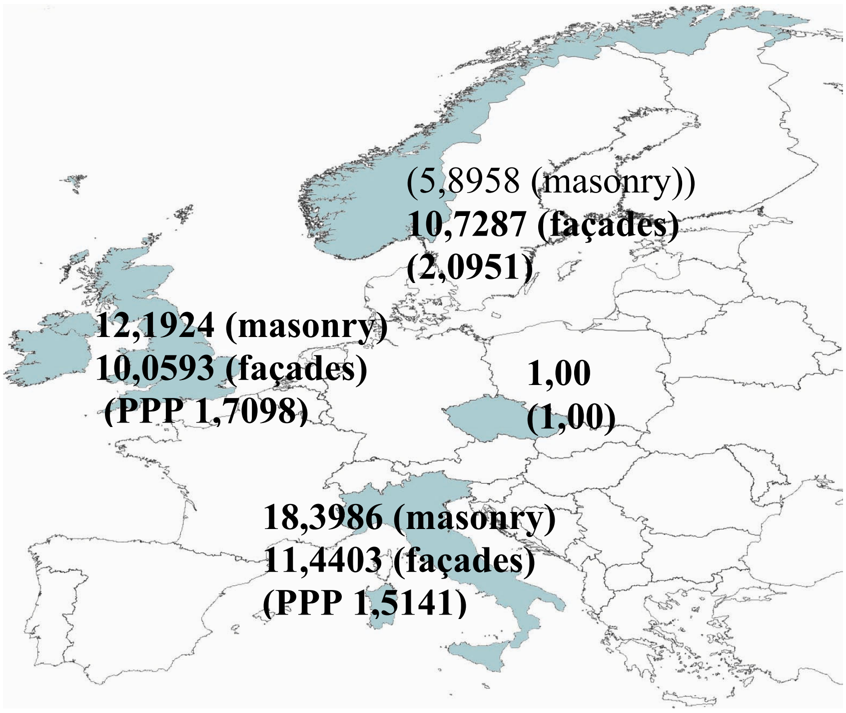

Figure 9. Average coefficients of cost ratios of stone or brick masonry (upper row) and plastered façades (lower row) maintenance, renovation and conservation works related to the Czech Republic (country PPP ratio for comparison).

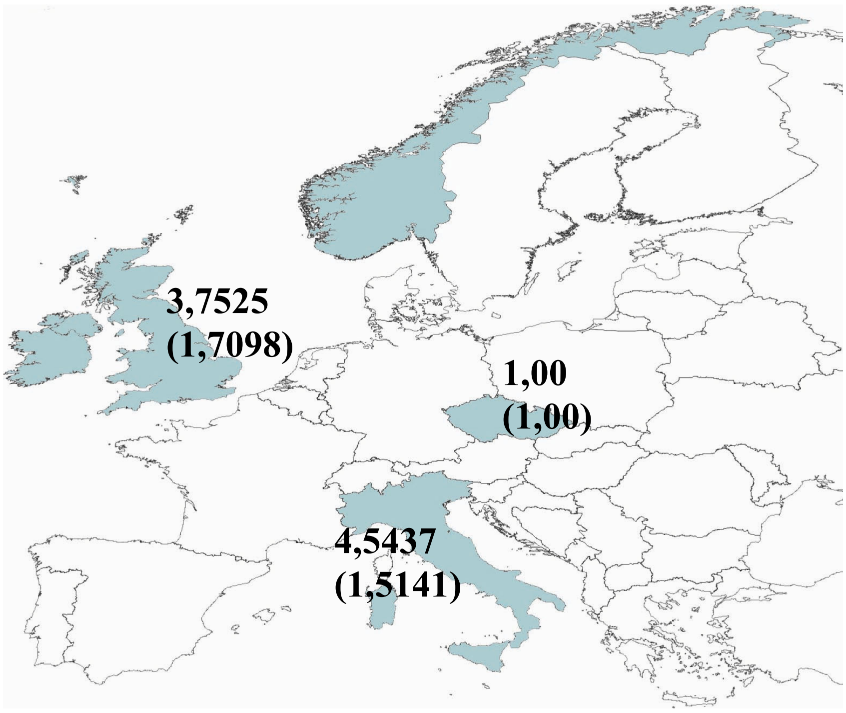

Figure 10. Average coefficients of cost ratios of maintenance, restoration and conservation of sculptures related to the Czech Republic (country PPP ratio for comparison).

4.3 Diversities in lifetime cycles

Lifetime is defined according to the contribution by BRE as a *mean time to failure (MTTF)* or a *return period (RP)*, which is dependent on the data available. The MTTF is estimated from the known lifetimes of several similar objects, the RP is calculated from data known for one object on which an identical element has failed several times during the life of the object. The MTTF is known and published for civil engineering materials and systems, the RP is rather a subject of individual studies associated with restoration works. Three selected examples of such studies are presented in Figures 11 – 13.

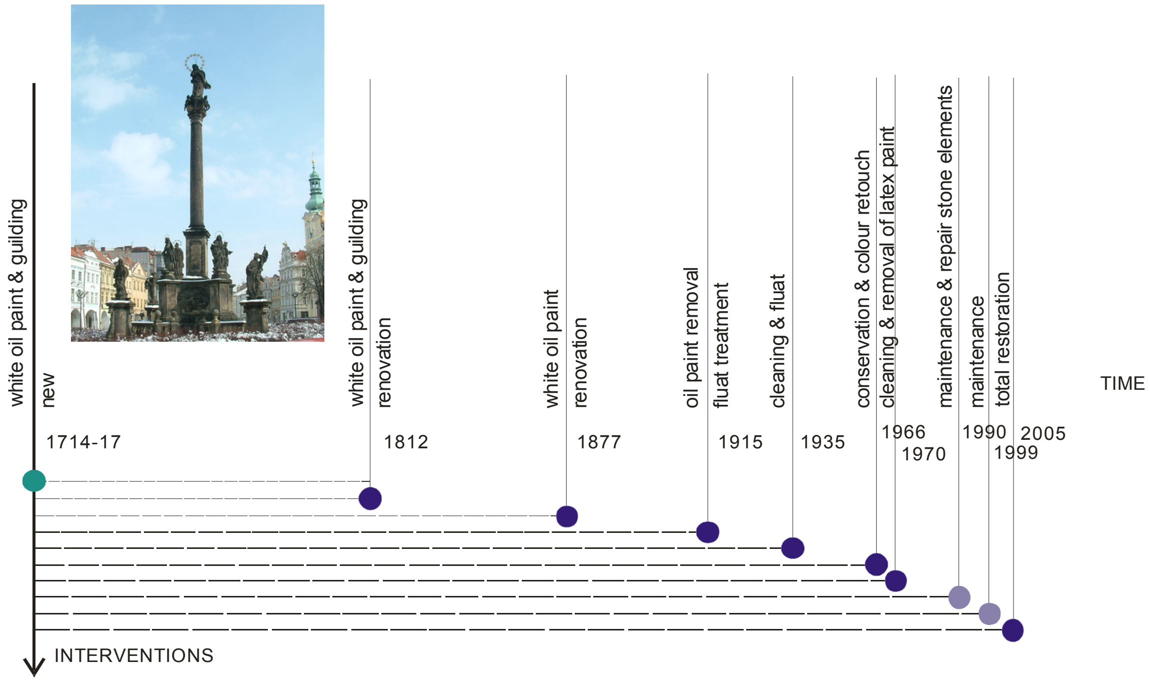

Figure 11. Experienced life time of maintenance, restoration and conservation measures applied on a St.Mary column

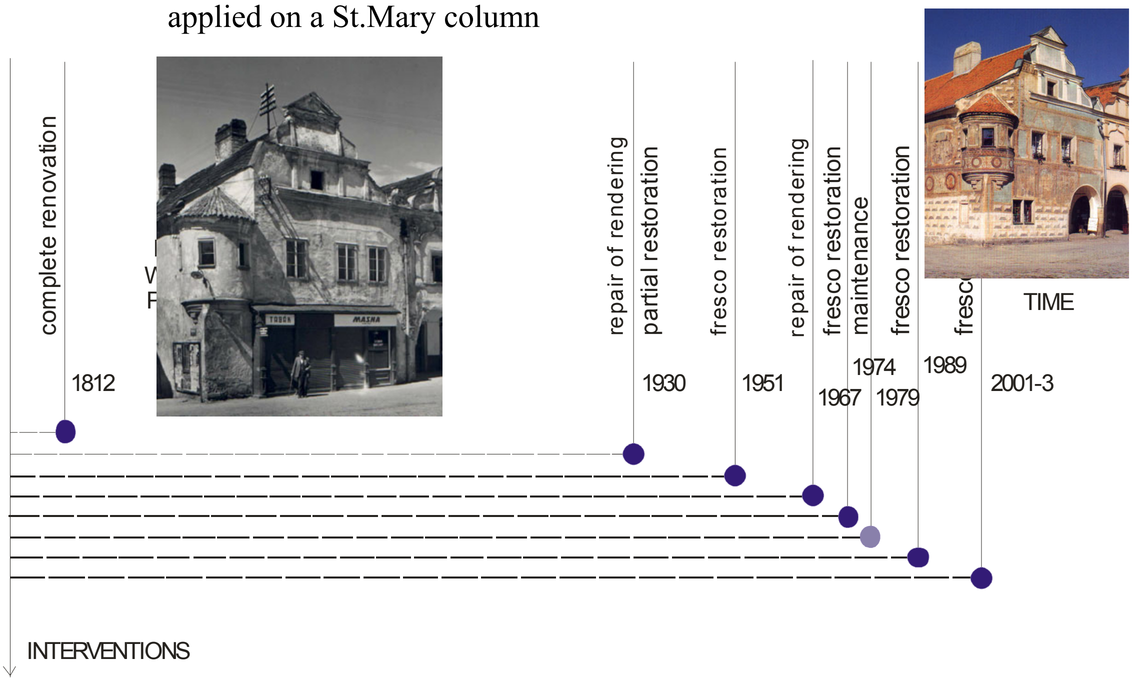

Figure 12. Experienced life time of restoration of a town house fresco façade.

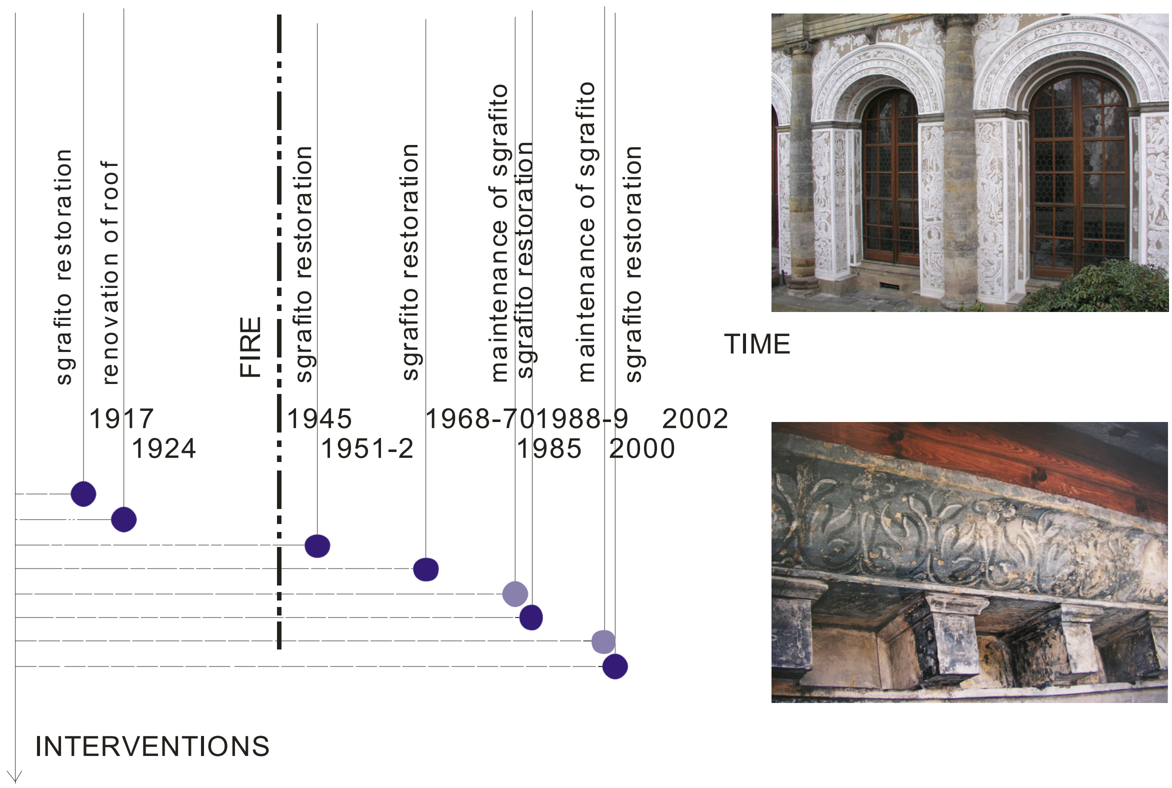

Figure 13. Experienced lifetime of maintenance restoration of a sgrafito façade.

The practical lifetime value changes in dependence of the environmental factors, conservation technologies, materials and approaches, state policy as well as to changes in critical damage or serviceability definitions.

5 Annex – conservation and renovation cost – detailed tables

Examples of costs of maintenance and repair in different countries

Table 5.1. National costs

Surface layer or system	Unit	Guided cost EUR			
		Czech Rep.	UK	Italy	Norway
copper sheet – total replacement	m^2	55,65	134,77	60,84	85
steel galvanized sheet – total replacement	m^2	20,37	34,43	33,93	52
paint on galvanized steel sheet – renewal	m^2	5,53	12,01	35,94	57
paint on wooden shingle roofing	m^2	8,21	11,43	43,32	15
non-plastered brick masonry – pointing renewal	m^2	9,67	43,95	98,98	57
lime plaster (rendering) simple I-II – colour paint lime based (Porokalk P+B)	m^2	2,68	15,38	13,98	47
lime plaster (rendering) simple I-II – total replacement	m^2	16,74	112,80	19,4	66

Table 5.1. National costs corrected by the PPP ratio

Surface layer or system	Unit	Guided cost EUR			
		Czech Rep.	UK	Italy	Norway
copper sheet – total replacement	m^2	55,65	78,82255	40,18229	40,57086
steel galvanized sheet – total replacement	m^2	20,37	20,13402	22,40935	24,81982
paint on galvanized steel sheet – renewal	m^2	5,53	7,025488	23,73687	27,20634
paint on wooden shingle roofing	m^2	8,21	6,682782	28,61106	7,159563
non-plastered brick masonry – pointing renewal	m^2	9,67	25,70301	65,37217	27,20634
lime plaster (rendering) simple I-II – colour paint lime based (Porokalk P+B)	m^2	2,68	8,996052	9,233208	22,4333
lime plaster (rendering) simple I-II – total replacement	m^2	16,74	65,97105	12,81289	31,50208

6 References

Kucera, V., 2005. EU 5FP RTD project. Model for multi-pollutant impact and assessment of threshold levels for cultural heritage. (EVK4.CT-2001-00044) Publishable Final Report.

Spon's Architects and Builders price book 2006: Spon Press
BMI Building Maintenance price book 2006; BCIS
Wessex Estimating price book 2006: Wessex Publishing Ltd

Specialist pricing assistance from:

Generally:
David Ball Restoration Ltd., London SE15 2PR
Cliveden Conservation, Berkshire SL6 0JA

For Glazing:
The Cathedral Studios, Canterbury CT1 2EG