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Ministry of Education, Culture and Science

Risk management for collections

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Colophon

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Security starts with awareness, procedures for access to the building and collection and high quality locks. Seals show immediately whether someone has been inside

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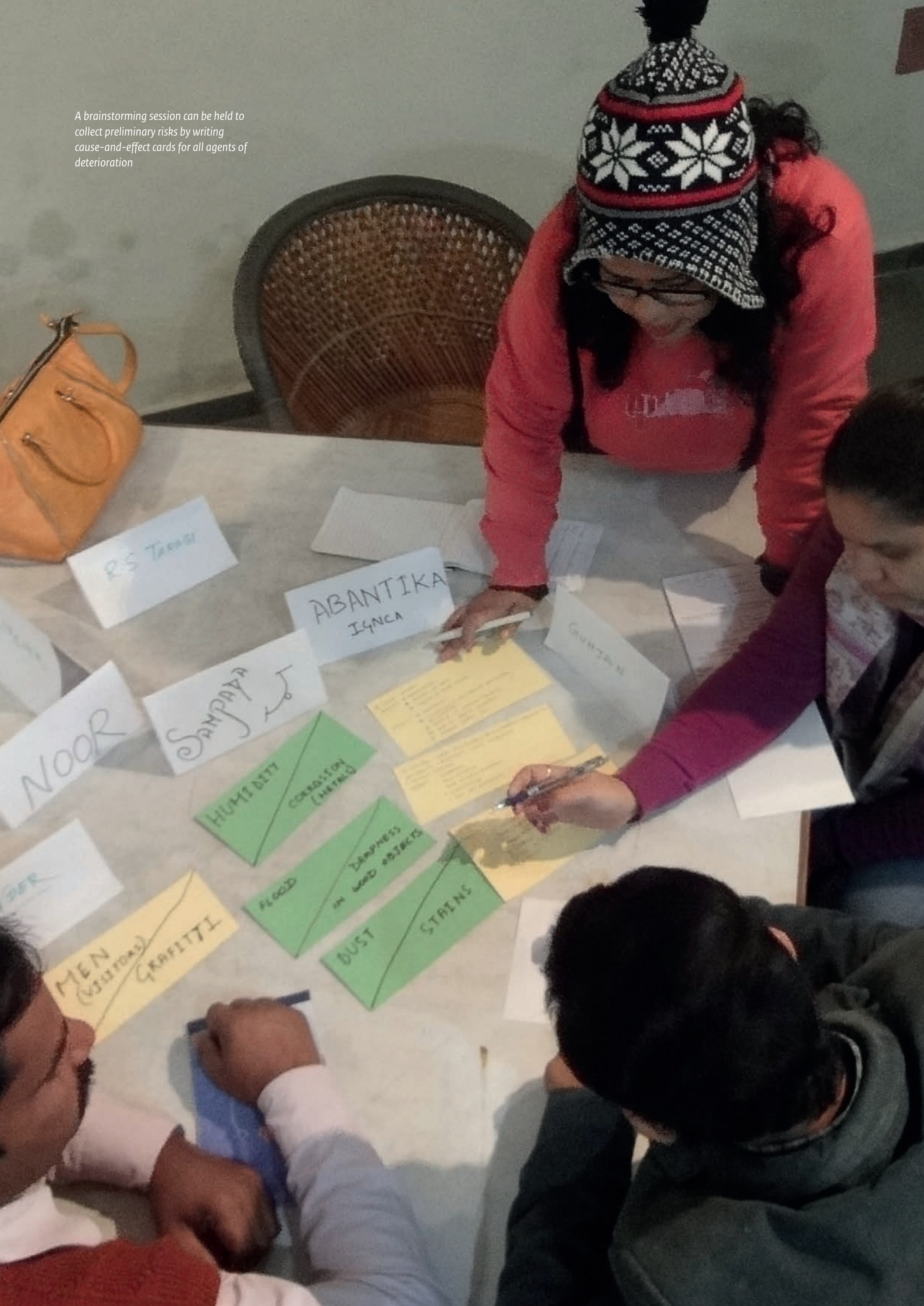


A brainstorming session can be held to collect preliminary risks by writing cause-and-effect cards for all agents of deterioration

Preface

Heritage connects us to the past, present and future. After all, as our legacy from the past, heritage gives meaning to our present to such an extent that we would like to pass it on to future generations. Those who manage and curate heritage play an important role in this, ensuring that our heritage is not only preserved, but also used responsibly.

Preservation and responsible use of heritage collections is a continuous fight against the threats facing them. Thousands of potential risks could lead to loss. Fire, water, theft, vandalism, pests, contaminants, light and UV radiation, custodial neglect: these are only a few of the looming threats to heritage collections.

Through this publication, the Cultural Heritage Agency of the Netherlands aims to support collection managers, curators and conservators. By offering methods and knowledge, we seek to equip these professionals with tools to make suitable choices, set priorities and implement appropriate measures to reduce loss of value.

This publication was produced within the Shared Cultural Heritage programme of the Cutural Heritage Agency. Through knowledge exchange, the Cultural Heritage Agency cooperates with professionals in partner countries to contribute to the sustainable preservation and use of shared heritage. An example is the risk management workshop that took place in January 2015 in collaboration with the Indira Gandhi National Centre for the Arts in New Delhi. Connecting theory and practice is an essential step in developing new knowledge and tools.

Before you sits such a tool. Its origin lies in another programme of the Cultural Heritage Agency: the Collection Risk Management programme. Within that programme, several components of this publication were developed in close collaboration with the Canadian Conservation Institute (CCI), the International Centre for the Study of the Preservation and Restoration of Cultural Property in Rome (ICCROM), the British Museum and other heritage organisations.

This tool makes expertise and information about risk assessment and risk management easily accessible. It assists in answering questions such as: how does one exhibit objects responsibly, what are the priorities for a preservation strategy, what climatic conditions are adequate, and have appropriate security measures been taken? Questions that every collection manager faces regularly.

I wish the collections under your care a sustainable future.

Jinna Smit
Programme Manager Shared Cultural Heritage
Cultural Heritage Agency of the Netherlands

The Rijksmuseum in Amsterdam has more than 2 million visitors per year. Museums and galleries attract increasing numbers of visitors putting pressure on buildings and collections.

Introduction

Over the years, an increasing number of museums, archives, libraries and other heritage organisations have used some form of risk management. At a business level, it is already good practice to assess and manage financial, legal, business and reputational risks. For example, when exhibitions are planned and delivered the potential hazards that may threaten the project are taken into account. However, it is now common also to think about 'risks to cultural capital' as part of an organisation's collection management practice.

Following the work of pioneering researchers, including Michalski (1994), Waller (1994; 2003) and Ashley-Smith (1999), risk management for collections has proved its usefulness. It is used in setting priorities and in providing arguments for decisions about affordable and adequate measures to manage and preserve collections (for example Brokerhof et al., 2005; Versloot, 2010; Ankersmit and Brokerhof, 2012). It helps to answer questions such as: how do you exhibit objects responsibly; what are the priorities for the collection care plan; are particular climatic conditions adequate, and have appropriate security measures been taken?

Risk management does not only involve immediate risks to the safety of objects and collections, but encompasses all the threats to which they are exposed; both *events* (such as fire, flooding and theft) as well as *processes* (including fading due to light, cracks from dehydration, and tarnishing caused by pollution). Risk-based thinking forms the foundation for the Dutch guidelines for museum lighting (Brokerhof, 2005) and the museum indoor climate (Ankersmit and Stappers, 2016).

To support the implementation of risk analysis in heritage institutions, the Cultural Heritage Agency of the Netherlands (RCE) developed the *Digital Handbook for Collection Risk Management* (in Dutch, Brokerhof et al., 2013). This computer application is intended to guide users smoothly through the steps of the risk management process. It consists of a workbook with explanations and forms that allow the user to collate and process data, evaluate risks and prioritise options for risk reduction. It also contains a handbook with relevant information on the 'Ten Agents of Deterioration' – from 'Fire' and 'Contaminants' to 'Pests'. The digital handbook follows the 'ABC method' developed by the Canadian Conservation Institute (Michalski and Pedersoli, 2016). In this method, which works with risk scenarios, all those things that could go wrong are identified comprehensively, after which each scenario is developed, analysed and scored so that all risks can be compared and ranked. Finally, priorities can be set, based on the magnitude and urgency of the risks.

New Publication

Although everyone who has gone through the risk management process is enthusiastic about the insights gained and realises in retrospect how it has contributed to professionalisation in their organisation, most people experience a considerable reluctance to embark upon the process; they generally fear the amount of work needed for an in-depth risk analysis. Furthermore, experience in the Netherlands has shown that many organisations encountered technical problems downloading and installing the *Digital Handbook*, partly because of IT security issues.

These two objections have encouraged RCE to publish *Risk Management for Collections* in a pdf format. This publication includes the most up-to-date knowledge, information and tools from the application. In addition, a faster and simpler risk assessment methodology has been included, called *QuiskScan* (Brokerhof and Bülow, 2016). This 'quick risk scan' bridges the gap between a decision based on a gut feeling – or *best practice* – and a more thorough risk analysis such as the ABC method or CPRAM (Waller, 2003).

With the different methods described in this manual, we hope to offer every user access to risk analysis and risk management. As is the case with all models and tools, the outcome is only as good as the knowledge and information that are input; the more general the methodology, the less accurate the outcome will be. One should, therefore, always be aware of these limitations and consult experts when and where necessary.

Whether general or detailed, the added value of carrying out a risk assessment is that it is conducted by a group of people. Everyone's knowledge comes together, which creates a shared awareness of the importance of the cultural capital that is managed *together* and a common understanding of risks to its preservation. Joint input delivers shared output, creating wide support for the outcomes and decisions that follow from the risk assessment.

Why risk management?

Risk management does not stand on its own; it is part of a decision-making process. When considering options or determining the need to act, one wants to know what the consequences are of choosing either option A or B, or of taking action or not. Risk management is a process that tries to make the uncertainties of the future explicit and controllable by listing the consequences and assessing their likelihood and effect.

We do this on a daily basis – almost unconsciously – when we cross the street; we weigh our chances of crossing unharmed. We also make choices consciously, for example when we must choose between two medical treatments. The greater the consequences, the more time we are willing to spend considering the options. But we only do this if it contributes to making a decision, helps to verify choices, or convinces others of our choice (for instance, because they will need to finance it). Some examples are given below of reasons to carry out a risk assessment in the museum context and the level of thoroughness that may be required.

Choosing between options A or B

When choosing between real or electric candles in chandeliers, lists of the advantages (e.g. positive experience, historical value and financial benefit) and disadvantages (fire risk, light levels and financial costs) may suffice to underpin the decision. If one of them prevails over the other, the choice is easily made.

Deciding whether a certain measure is necessary

When questioning whether a climate control system is required, its necessity needs to be established and weighed against its side effects, any additional risks and the costs of such a system. An analysis of specific climatic risks will help: what is the current climate; how vulnerable is the collection; how likely is it that damage will occur due to an incorrect climate; and how severe will that damage be?

Installing a climate control system will cause temporary and permanent new risks and introduce new costs. An overview of the risks, the costs and options to reduce risks helps to determine if implementation of an HVAC system is a cost-effective investment or a superfluous luxury.

Deciding if something needs to be restored, and how

A risk assessment will always help determine whether an object needs a conservation or restoration treatment and, if so, what type of treatment and how it should be conducted. It is particularly useful in comparing the loss of value that may result from inaction with the further loss of value through conservation or the recovery of lost value through restoration (and the possible side effects of the different options). The assessment gives a better understanding of the necessity, the benefit and the side effects of conservation and restoration treatments.

Setting priorities for a preservation plan

The question of how limited resources can most effectively be used to provide the best collection care arises frequently, and requires an overview of the threats to the entire collection and a full-scale risk assessment. When priorities need to be set for a preservation plan, many risks need to be identified. These can be ranked in a risk matrix such as the QuiskScan matrix or a matrix that plots likelihood and impact of the risk scenarios identified with the ABC method.

Even though it contains only limited information, a risk matrix is a straightforward method to give an overview of the magnitude of risk, and can be the starting point for further discussion with decision makers and other stakeholders. If, during the first evaluation, a few risks stand out above the others, a detailed analysis of these risks would suffice. If a more detailed or nuanced view is needed, it is worth considering conducting an extended risk assessment, but this will require more time and information.

Benchmarking – Comparative performance

It is possible to set priorities and plan mitigation strategies for similar collections located in different places, such as the preservation of collections in a number of historic houses. In that case, carrying out a risk assessment for a house that exemplifies a good level of collection care sets the 'benchmark' for the other houses.

The scenarios for the ten biggest or most urgent risks can then be assessed for the other houses to see how they compare to the benchmark. The result is an overview of the performance of the different houses in relation to the benchmark.

Figure 1. Air conditioning is a rather demanding and costly control method. Is the effort of its installation justified by the reduction of climatic risks?

Figure 2. Assessment of the climate control system at the Martena Museum revealed that it did not reduce climatic risks to the collection; the plant has been shut down and serves now as storage for supplies.

Assessing cost savings
In times of scarcity, everyone tends to ask if it is possible to save money. Even in collection preservation it might be possible to economise without introducing unacceptable risks. Many standards were introduced during a period when it was common to strive for the 'best possible', so it may be feasible to widen these often narrow recommendations.

In the 1990s there was a strong focus on creating a relative humidity (RH) with very small fluctuations: in the Netherlands a standard of 50 ±2% was used. For a small group of extremely sensitive objects this is indeed beneficial, but most objects will not be damaged in the range of 40–60% RH. When the needs of the collection have been mapped out and it is clear where smaller and larger margins can be tolerated, intelligent ways to economise can be formulated.

An example is offered by a project at a small city museum in the Netherlands, the Martena Museum in Franeker. The maintenance and energy consumption costs for the air treatment system placed a heavy burden on a limited budget, while it proved impossible to maintain the indoor climate as specified in the original plan. A risk assessment indicated that the system could be switched off without increasing the climatic risks to the house and the collection. Climate monitoring data from the following year confirmed this and, furthermore, revealed that the indoor climate had actually become more stable while allowing considerable financial savings to be made (Ankersmit, 2012).

Risks and collection management
Risk can be defined as the 'effect of uncertainty on the achievement of objectives' (ISO, 2009). For museums and other institutions that manage collections, the objective is formulated as: passing on heritage that has been entrusted to us to the next generation with optimal value and accessibility.

Collection management is about taking well-argued decisions concerning the allocation of resources so as to optimise the value and accessibility of the collection. This can be done by investing in an increase in value (acquisition, research into origin, restoration) or by limiting the loss of value (storage conditions, security, maintenance). At the same time income needs to be generated from the value of the collection in order to be able to invest in anything at all (exhibitions, availability for study).

The *value* of heritage is, therefore, core. In the Collection Management Triangle (Figure 3) value has a central position, between the processes 'Use', 'Preservation' and 'Development'. These three processes require accessibility to the collection: to the 'container' (the objects themselves); to the ' content' (the information that lies hidden within the objects, be that text in a book, sound on a tape or image on a film); and to the 'context' of

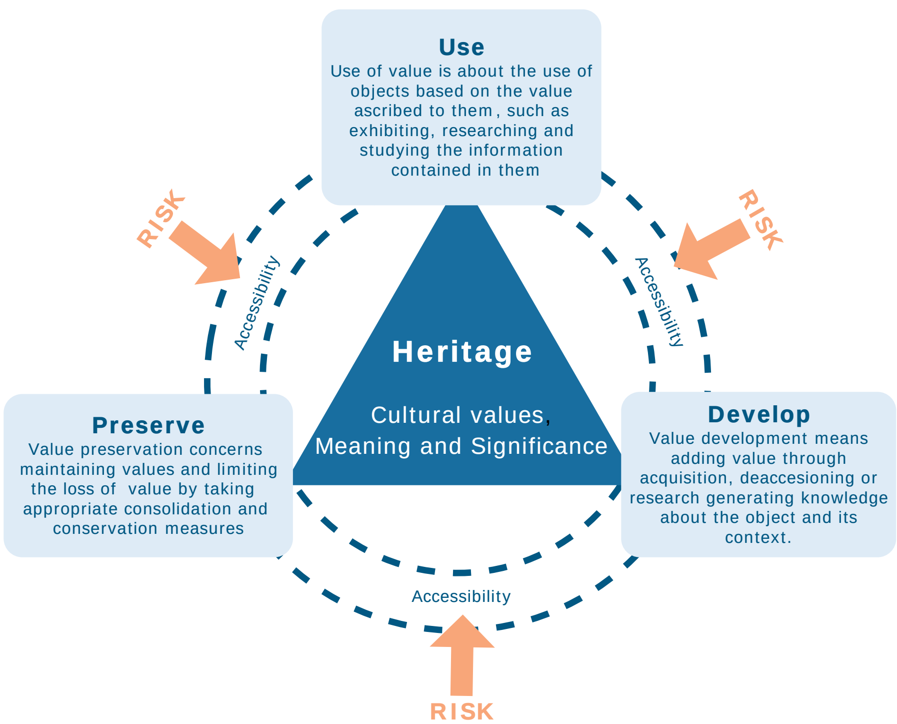
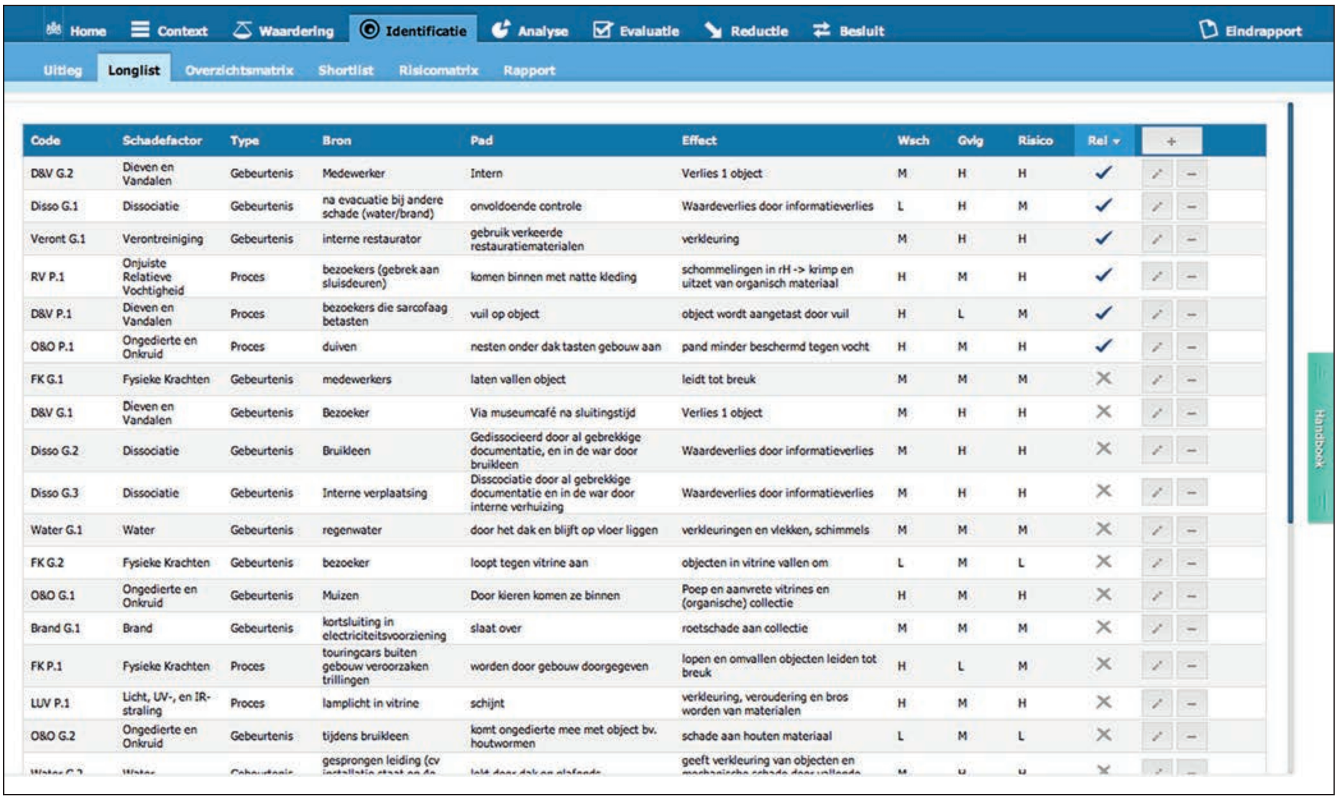


Figure 3. The Collection Management Triangle (after Waller, 2003).



Code	Schadefactor	Type	Bron	Pad	Effect	Wsch	Gvlg	Risico	Rel
D&V G.2	Dieven en Vandalen	Gebeurtenis	Medewerker	Intern	Verlies 1 object	M	H	H	✓
Disso G.1	Dissociatie	Gebeurtenis	na evacuatie bij andere schade (water/brand)	onvoldoende controle	Waardeverlies door informatieverlies	L	H	M	✓
Veront G.1	Verontreiniging	Gebeurtenis	interne restaurator	gebruik verkeerde restauratiematerialen	verkleuring	M	H	H	✓
RV P.1	Onjuiste Relatieve Vochtigheid	Proces	bezoekers (gebrek aan sluisdeuren)	komen binnen met natte kleding	schommelingen in rH -> krimp en uitzet van organisch materiaal	H	M	H	✓
D&V P.1	Dieven en Vandalen	Proces	bezoekers die sarcofaag betasten	vuil op object	object wordt aangetast door vuil	H	L	M	✓
O&O P.1	Ongedierte en Onkruid	Proces	duiven	nesten onder dak tasten gebouw aan	pand minder beschermd tegen vocht	H	M	H	✓
FK G.1	Fysieke Krachten	Gebeurtenis	medewerkers	laten vallen object	leidt tot breuk	M	M	M	✗
D&V G.1	Dieven en Vandalen	Gebeurtenis	Bezoeker	Via museumcafé na sluitingstijd	Verlies 1 object	M	H	H	✗
Disso G.2	Dissociatie	Gebeurtenis	Bruikleen	Gedissocieerd door al gebrekkige documentatie, en in de war door bruikleen	Waardeverlies door informatieverlies	M	H	H	✗
Disso G.3	Dissociatie	Gebeurtenis	Interne verplaatsing	Disscociatie door al gebrekkige documentatie en in de war door interne verhuizing	Waardeverlies door informatieverlies	M	H	H	✗
Water G.1	Water	Gebeurtenis	regenwater	door het dak en blijft op vloer liggen	verkleuringen en vlekken, schimmels	M	M	M	✗
FK G.2	Fysieke Krachten	Gebeurtenis	bezoeker	loopt tegen vitrine aan	objecten in vitrine vallen om	L	M	L	✗
O&O G.1	Ongedierte en Onkruid	Gebeurtenis	Muizen	Door kieren komen ze binnen	Poep en aanvrete vitrines en (organische) collectie	H	M	H	✗
Brand G.1	Brand	Gebeurtenis	kortsluiting in electriciteitsvoorziening	slaat over	roetschade aan collectie	M	M	M	✗
FK P.1	Fysieke Krachten	Proces	touringcars buiten gebouw veroorzaken trillingen	worden door gebouw doorgegeven	lopen en omvallen objecten leiden tot breuk	H	L	M	✗
LUV P.1	Licht, UV-, en IR-straling	Proces	lamplicht in vitrine	schijnt	verkleuring, veroudering en bros worden van materialen	H	M	H	✗
O&O G.2	Ongedierte en Onkruid	Gebeurtenis	tijdens bruikleen	komt ongedierte mee met object bv. houtwormen	schade aan houten materiaal	L	M	L	✗
[illegible]	[illegible]	[illegible]	gesprongen leiding (cv [illegible]	[illegible]	geeft verkleuring van objecten en [illegible]	[illegible]	[illegible]	[illegible]	✗

Figure 4. Examples of the list approach: a longlist with risk scenarios from the Dutch Digital Handbook for Collection Risk Management.

these objects, which gives them meaning. While in use or in store, the collection and its value are constantly threatened by external and internal risks. As risk management helps to limit the loss of value as much as possible it forms an important part of collection management.

Lists and maps

A general definition of a risk is the 'likelihood of a hazard causing damage or loss'. The risk that preservation managers wish to reduce is the chance of losing cultural value of their collections, for instance through the loss or theft of objects or from damage caused by falling, fading or burning.

The magnitude of the risk depends on both the likelihood (or probability) that something will happen and on the consequence (or impact) of that event on the object. The magnitude of the risk (MR) corresponds to likelihood (L) multiplied by consequence (C), i.e. MR = L x C, and is expressed as an expected loss of cultural value. In practice, we want to know 'how fast' something will happen and 'how bad' it will be. That 'something' can happen as a discrete *event* or as an ongoing *process*.

An *event* occurs with a particular probability or, if it happens repeatedly, with a particular frequency (time between events), and leads to a sudden change. A *process* takes place over a period of time and leads, with a certain speed or rate, to an ever-increasing change.

There are several ways to perform a risk assessment and to structure, evaluate and visualise the outcome. In this publication we use lists and maps. Using lists we first identify as thoroughly as possible everything that could go wrong as so-called 'risk scenarios'. Every scenario describes an event or process and has a particular probability or rate, effect and magnitude of risk. A long list of scenarios develops that can be rearranged and ranked in numerous ways. The ABC method is an example of a list approach.

The outcome from the list approach can be represented graphically in a risk matrix. The risk scenarios can be placed in the matrix according to their likelihood and effect (Figure 5a). With the ABC method, the likelihood is determined as the period within which damage is expected (A score), and the effect is expressed as the loss of value for each affected object (B score) combined with the fraction of the total collection value that is affected in this way (C score). The sum of these three logarithmic scores gives a magnitude of risk that can be ranked in a number of ways, for example in a bar chart (Figure 5b).

With the map approach, the highest risks in a particular situation or space are mapped out by considering where the most valuable and most vulnerable parts of the collection are located and where the biggest exposure to a hazard is expected. For example, the risks due to light in a room can be visualised by using separate floor plans of the room that show – on transparent overlays – the cultural value of the objects and their vulnerability to light. These are then overlaid onto a floor plan on which the light levels in the room are marked. The largest risks are expected where valuable objects that are light sensitive are exposed to high light levels

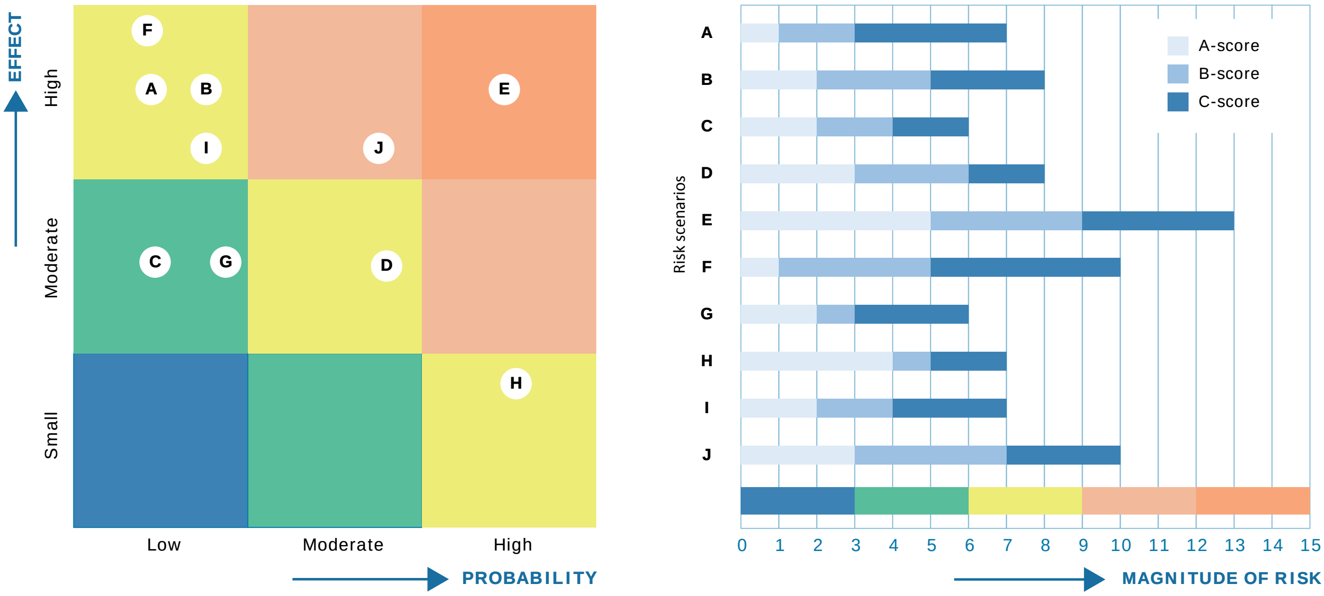


Figure 5. Examples of graphic representations of risk assessments: risk matrix (a) and ABC bar chart (b).

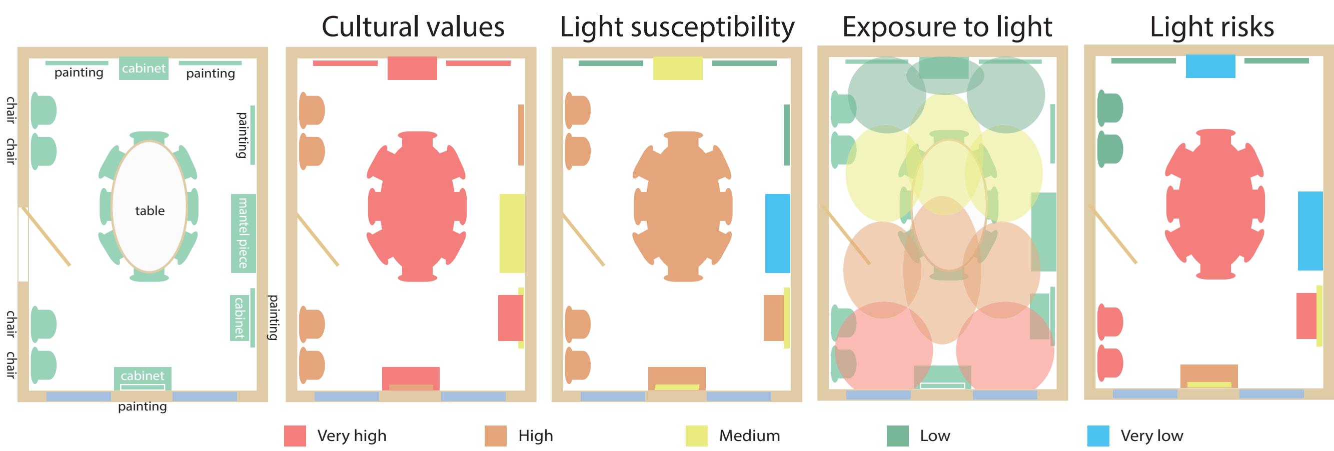


Figure 6. An example of the map approach. By overlaying different maps one can identify high risk areas easily. High light risks (coloured red on the floor plan to the right) are expected where high cultural value (second from left) overlaps with high light sensitivity (third from left) and high exposure to light (second from right).

I Collection anatomy		II Value		III Susceptibility to agents of deterioration				
Collection unit	Number	Relative value	Weight	I	II	III	IV	V
A	500	H	10	H	L	M	L	L
B	1,000	H	10	H	M	M	H	H
C	5,000	M	1	H	M	H	H	M
D	300	L	0.1	L	H	L	L	L
E	1,500	L	0.1	L	L	L	M	M

Figure 7. Example of a risk assessment represented in the form of a QuiskScan matrix.

(Figure 6). For those objects one has to consider whether the risk is acceptable or whether the exposure should be reduced, for example by moving or replacing objects or by hanging curtains in front of the windows.

The QuiskScan method is a variation on the map approach; it 'maps out' the risks to the collection in a matrix – not a map – in which the value of 'collection units' and vulnerability to particular agents of deterioration are combined. Colour codes – such as those used for temperatures on a weather map – indicate where 'vulnerable value' lies (Figure 7). By next analysing whether those units are indeed exposed to a hazard it becomes apparent whether big losses are to be expected. QuiskScan lacks the level of detail of comprehensive methods, but it gives a quick insight into which parts of a collection may be at high risk, allowing these to be analysed in more detail.

Principles and process

Whichever method is used to determine the magnitude of risk, they all follow a similar process, described in the international guideline *ISO 31000: Risk Management – Principles and guidelines* (ISO, 2009). It is a cycle of five steps accompanied by two continuous processes. The steps are:

- **Establish context.** The first step explains the occasion or reason for undertaking a risk assessment and the choices and decisions that need to be made. It sets out the questions that need answering, establishes the collection anatomy, sets the scope for the assessment, and determines the time horizon. To determine the loss of value in a particular risk scenario, it is first necessary to know who attributes value to the collection units, why and how much.
- **Identify risks.** In the next step as many events and processes that could lead to loss of value as possible are identified as specific risks.
- **Analyse risks.** For every specific risk, the magnitude of risk is determined by analysing the likelihood of losing value in a certain period of time and how big that loss will be. Indicating the highest and lowest possible score in comparison to the expected score in each analysis provides an insight into the degree of uncertainty.
- **Evaluate risks.** All the risk scenarios are compared with each other. Ranking them according to magnitude, urgency or uncertainty allows priorities to be set. Grouping the risk scenarios, based for example on common sources, effects or weak links in combatting loss, makes it possible to develop effective options for risk reduction.
- **Reduce risks.** Finally, options can be developed to reduce the high priority risks. Comparing effectiveness and cost leads to recommendations or implementation of the best option for risk reduction.

The two accompanying processes are:

- **Communication and consultation**. The whole process takes place in an environment in which there is constant communication and consultation: with stakeholders, about the reason for the assessment and the value of the collection; with experts, on the probability and impact or about the possibilities for reducing risk; and with managers, who must decide or approve actions.
- **Monitor and review**. There is also a continuous monitoring and reviewing to improve the information and the inputs for the risk assessment, to keep track of changes, and to determine the effectiveness of the measures that have been carried out.

The ABC method in the digital handbook follows this process from beginning to end. In this publication we offer the possibility of using a broad-brush, but faster, parallel track via QuiskScan. Both tracks start by determining the context and value of the collection. In the ABC method, risks are identified and the list of risk scenarios is compiled, before each is then analysed and evaluated.

The QuiskScan method maps out the high risk areas in the collection by combining value with vulnerability and exposure. For these areas relevant risk scenarios can be further developed using the ABC method. Both tracks come together again when evaluating risks, determining priorities, developing options to reduce unacceptable risks and determining their cost-effectiveness. In this way, they eventually provide a rationale for the choices and decisions that prompted the risk assessment. The steps of both the ABC method and QuiskScan process will be dealt with further in the next chapter.

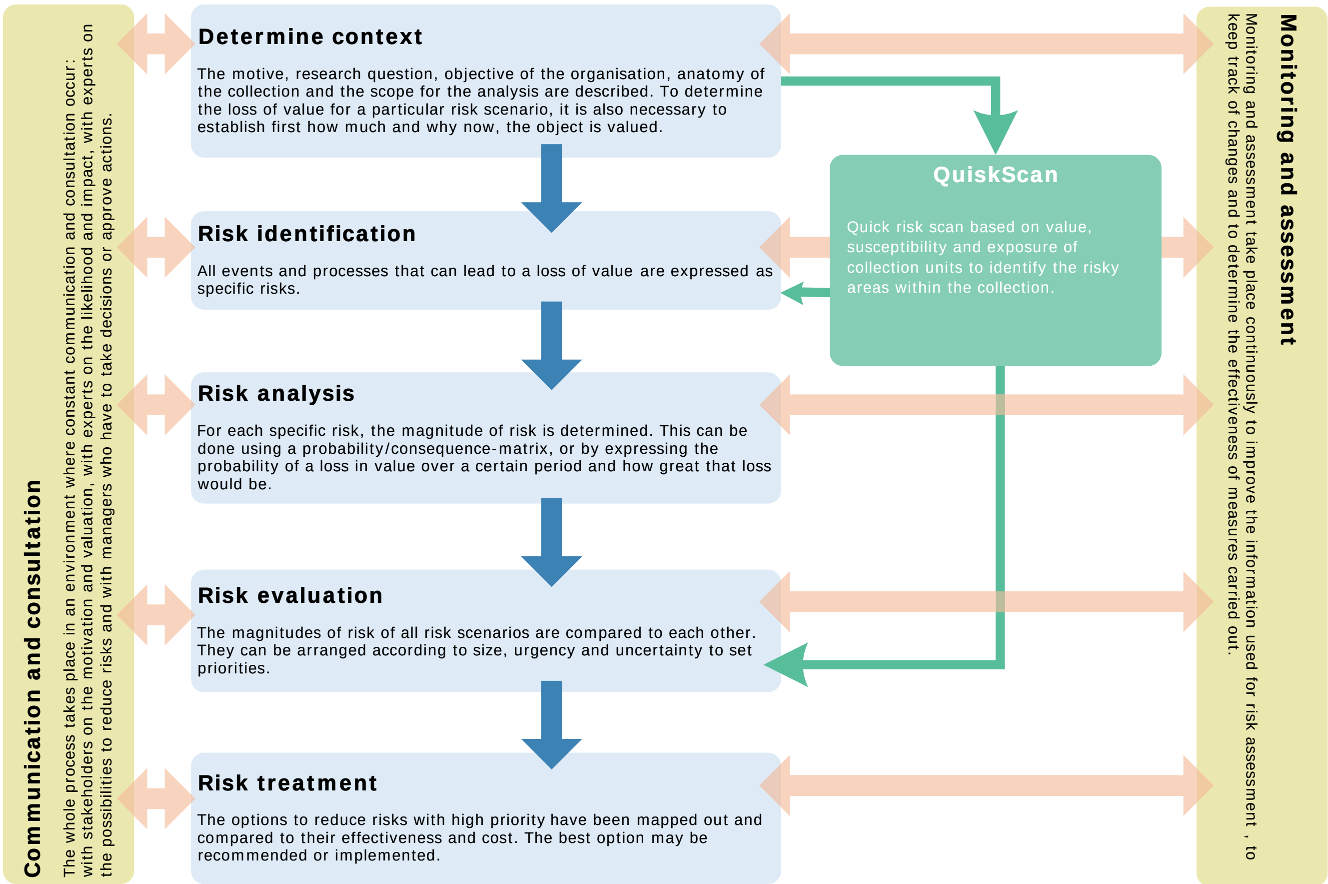


Figure 8. The risk management process as defined by ISO 31000, further clarifying what each step entails and what the results are, and showing where and how the QuiskScan fits in.

Challenge

The book collection is extremely acidic, is that a problem?
I would like to allow natural daylight in my museum, but is that safe?
I would like to know which part of the collection deteriorates the quickest.
I have a small conservation budget; which object should I preserve first?
I would like to honour a loan request, but is this safe?
I would like to know how safe my storage is.
I would like to use my limited resources as efficiently as possible.
I would like to know if last year's investments were actually useful?

Why is the challenge of importance?

Motive

There should be an expenditure plan;
Preparing the annual budget and the reasoning for requested budgets;
Developing work plans;
Setting priorities;
Implementing budget cuts;
Well thought-out use of money and resources for collection preservation;
Restoration;
Loan request.

Has the challenge been removed by the result?

Result

A report with a risk profile for my collection in storage;
A prioritised work plan;
A longlist with prioritised risks for the (temporary) exhibition;
A floor plan identifying the collection risks;
A prioritised expenditure plan;
A suported collection (conservation) plan;
A presentable collection.
A satisfied feeling.

Does the intended result answer the objective?

Objective

I would like to reduce the degradation rate of my collection;
I would like to conserve the object that is threatened the most;
I would like to know to which risks the collection in the exhibition is exposed;
I would like to know which measure is the most effective;
I would like to pass on my collection, with as much value as possible, to the people after me;
I would like to exhibit or use my collection safely;
I would like my collection to last as long as possible;
I would like my collection to look presentable.

Identifying the context for a risk assessment shows strong parallels with formulating the challenge, cause, objective and results at a project start-up. These four criteria can be explored further by posing a few questions (Reference: Jo Bos and Ernst Harting, Projectmatig creëeren 2.0, Scriptum Management 2015).

- **Challenge**: *Which problem needs to be solved and what makes it worthwhile to undertake this 'project'?*
- **Cause**: *Why is the challenge urgent? Has it been researched or considered before?*
- **Objective**: *How will the results contribute to making the decision?*
- **Result**: *What will be the specific results when the project has been concluded?*

Martijn de Ruijter

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In the first year of the course, our students learn everything about the ten agents of deterioration that can threaten a museum collection: fire, insects, a high humidity, contamination, etc. Then they find out how to manage them by using the five well-known steps: avoid, block, detect, respond and treat. At the end of the first year they compare the threats in two exhibitions with each other; for example, in the Willet-Holthuysen historic house and the Stedelijk Museum Amsterdam – two very different institutions. In this way, the students gain a better understanding of all possible risks in different contexts. So, by then, they know all the basic theory.

In the second year at the Reinwardt Academy we go a step further, however, putting this into practice. The students make their own exhibitions with objects they choose themselves, and they must think of measures to minimise the dangers as far as possible. This is always a very nice experiment. Sometimes it leads to exhibitions in which objects are placed in showcases that closely resemble bunkers; Fort Knox is nothing in comparison. Extremely safe for the objects – no doubt – but not in the least attractive to visitors. My advice is to search for a compromise and to "kill your darlings".

In the third year, the students can choose the collection management programme as a minor. In this, they conduct a total risk assessment, complete with graphs, pie charts and tables. Two RCE colleagues visit to tutor the students and answer their questions. At first they find the process quite complex, but in retrospect, the students are happy that they were able to carry out a risk assessment on site, where they also learn about teamwork and creating support for solutions. Risk management will be an important aspect of their later careers, which is why we offer this course at the Reinwardt Academy – and will do so every year, with much pleasure.

Transportation and installation of heavy objects require careful and deliberate planning (photo: Rijksmuseum van Oudheden, Leiden)

The risk management process

In practice – the steps of the risk management process

The preparation

Form a group in which all the knowledge held by the museum or heritage institution is brought together: organisation, collection, building, security, exhibitions and education. In short, a group that can view the various questions from different perspectives and can contribute diverse knowledge and information.

Select an experienced moderator who can lead the group through the process and discussions. Appoint a rapporteur who documents the discussions and arguments and writes the final report. Plan a one-day work session; or better still two separate half-day sessions, so that there is time between sessions to collect additional information. It will become clear during the sessions whether further sessions are needed. If all goes well, everyone should be enthusiastic and will agree to an extra meeting.
Collect as much relevant information as possible for the work session. The vision, mission, and strategy of the organisation and its collection policy form starting points for the value assessment of the collection. The collection preservation strategy and the building maintenance plan provide insight into issues, possible hazards and ambitions the organisation has already identified for its collections and buildings.
Proceed through the steps of the risk management process. Set off on the QuiskScan track to get a general idea, and subsequently carry out an in-depth analysis of the relevant risks via the ABC track if needed.

Description of the organisation

Each organisation has its own approach to heritage and the value of its cultural capital. To one, a book is a beautiful example of craftsmanship and possesses great artistic merit, to another it is mainly a useful source of information. The reasons to keep objects differ between organisations, which is why it is important to understand what a specific organisation wishes to achieve and what role the collection plays.

An organisation must deal with risks other than those that affect only the collection. Collection risk management takes place in the context of the institution, which must also consider health and safety, corporate, financial and legal risks, and risks to reputation. All these risks influence each other and may ultimately play a predominant role in the decision-making process at the expense of collection risks. Clarifying the context at the start of the process will avoid surprises or disappointments at the end.

Mission and objectives

Because each organisation has its own mission and objectives, it will also have different reasons to collect, preserve and use collections. In principle, these also determine how much loss of value is accepted over a given period.

Archives aim to make the record's information accessible for current and future users. Natural history museums often allow destructive sampling of objects for research purposes if they expect this to add to their knowledge and value. A painting gallery must decide to what extent the paintings may be allowed to fade before they lose their exhibition value. Museums with mobile heritage, such as cars and trains, must often choose between preserving form and original parts, or function, thus accepting that parts will need to be replaced.

All these aspects are encountered during the risk assessment process, when material changes need to be related to their associated changes in value.

Policies and strategies

Risk management for collections focuses on the risks for collection management and is, therefore, closely linked to the collection's preservation strategy. The latter states what should be preserved, why, for whom, for how long and in what manner. The preservation strategy is that part of an overall collection policy in which 'what', 'why', 'for whom' and 'how' of preservation has been specified in the context of acquisition, accessibility and use (exhibitions, loan) of the collection. The collection policy is in turn part of a broader business strategy or policy in which it sits alongside policies for staff, training and education, finances, property, the public, etc.

To understand the status, function and values of the collection within the organisation, it is important to be aware of all these policies and plans. At the same time, the risk management process can help to fine tune existing strategies and encourage the drafting of missing policies.

Stakeholders and information sources

When a decision needs to be made or supported by many people or groups, it is wise to identify them in advance and include them in the project. They can also be important in determining value and the potential loss of value. In addition, existing documentation, employees and experts should be consulted during different phases of the process. This list will grow once there is a deeper understanding of the risks. It is useful to indicate not only who should be consulted, but also what knowledge is missing and who else should be asked.

Step 1 - Establish the context

As risk management is a group process in which staff members from different departments participate, bringing their own work objectives, it is important that all team members have a shared understanding of the situation and the challenges. The process needs, therefore, to be framed in a context that is agreed by all. Why is this risk assessment being undertaken? What are the objectives of the team? What does the assessment cover – what is its scope? Who are the stakeholders? How far into the future does the team want to look when determining risks?

Subsequently, the team needs to determine how thorough the analyses should be and how much time will be needed for them. They should also decide who has the necessary information and knowledge, and who should be involved in the process in order to expand the range of expertise and create support for the outcomes, as there are also financial, legal and political factors that could influence the risk management decisions. The following should be clear to everybody involved.

Purpose

What is the reason for carrying out the risk assessment? What do the team members want to know and why? It simplifies the process if it is clear beforehand which questions need to be answered or which choices must be made. Furthermore, such clarity helps to focus and limit the assessment, thereby avoiding work that does not directly contribute to an answer or choice, and is thus unnecessary.

Scope

Which (parts of the) collections are to be considered in the risk assessment? The purpose or primary challenge will determine the range of the assessment. If the final choices do not concern the entire collection, the assessment can be limited to the relevant parts of the collection. It will still be possible to expand the assessment in the future if there is a need for it.

Collection anatomy

An assessment of the entire collection as one unit will be difficult and will not give a useful output for decision making. The collection must, therefore, be divided into logical units or sub-collections. This division creates a so-called 'collection anatomy'. However, the more units, the more work to be done, so the key in determining the collection anatomy is to identify as few units as possible, while retaining a level of differentiation such that the objects within each collection unit show a high degree of similarity and are easily distinguished from those in other units.

I. Collection anatomy

Collection unit	Quantity (number of objects)
A - Manuscripts	500
B - Ceramics	1,000
C - Drawings & prints	5,000
D - Archaeology	300
E - Toys	1,500

Table 1. Collection anatomy for a fictional example of a collection with 8,300 objects divided into collection units A to E with their quantity in number of objects.

Differentiation between units can be based on, for instance, curatorial classification, departmental division, type of object, material or location. Each unit is described briefly, so that everyone understands what it is, with information on the quantity in a logical dimension, such as number of objects or boxes, linear metres of shelving, volume, weight or number of bytes. Table 1 shows the results of this step for a fictional collection divided into five units – A to E.

Examples of collection anatomy

The division of the collection into units depends on the challenge or question that needs to be answered. Imagine a mixed collection with masterpieces, core collection and reserve collection, which is kept in four storage rooms and exhibited in one gallery.

For a full risk assessment – to get an overview of the situation and set priorities for the preservation strategy – a division into object type and material is probably the easiest, as groups of objects will then react in the same way when exposed to a certain agent of deterioration. In the first instance, all wooden objects form one unit. If it turns out that there are differences between the wooden sculptures and the furniture, then the unit can be subdivided. The part of the collection on display is subject to different risks to those objects in storage.

If the different curators of the sub-collections all participate in the team, it may be practical to divide the collection corresponding to their knowledge and responsibilities. Again, there will be a difference in exposure between the collection on display and in storage.

If the question is what needs to be done to improve storage conditions, and those conditions are controlled at room level, then a division by location will be logical as improvements may differ per room.

When assessing the risks for objects on exhibition, the collection in storage can be ignored, unless objects on display are changed regularly, in which case it is necessary to know which part of the collection will be used during a defined period and for how long individual objects will be displayed. The collection can be divided into object type and material, because these react similarly to certain exposures, but there will be a difference between objects on open display and those in display cases.

If it is established in advance that masterpieces will be given priority, then a division into value categories is most obvious. This can work well for large collections with similar materials, such as books in libraries and documents in archives.

If it has been decided that the scope is limited to only a part of the collection, then it needs to be agreed whether the loss of value is determined only with respect to this part or in relation to the entire collection. In the former case, it is advisable to record how the value of this part relates to that of the entire collection.

Time horizon

Risk management involves getting a grip on uncertainty and making a prognosis for the future. But, how far into the future? When setting priorities and determining the cost-effectiveness of a range of options, it makes a difference whether the risks lead to a loss of value within the next decade or within the next century. Risks that lead to a loss of value in the long term usually have a lower urgency. The more distant the time horizon, the larger the uncertainty and the more meaningless it is to make statements about the value of our heritage for future generations. Even if our objective is to preserve collections ‘for eternity’, reality show that we cannot envisage periods of more than 100 years (Lindsay, 2005; Michalski, 2008).

When the time horizon changes, the urgency of risks changes as well. The likelihood that an event with a low frequency, such as a fire or flood, will occur within the time horizon increases as the time horizon is extended. The loss of value resulting from a degradation process, such as the fading of colours due to light, is smaller over a shorter period than over a longer time.

If the objective is to minimise the loss of value over a period of ten years, then the urgent risks are relevant. However, over a period of 100 years, those risks may become negligible compared to risks with a small probability but large impact, or risks that result in a large cumulative impact over the longer period.

Step 2 - Collection assessment and valuation

Part of the process of establishing context is making explicit which values the organisation attributes to its collection and units and why this is so. To map the relative value of the units in QuiskScan or to determine the loss of total collection value for risk scenarios using the ABC method, it is necessary to know if all objects or units are of equal value or whether some are more valuable than others, which would mean that damage to them has a greater impact on the institution.

Assessing and valuing the collection reaffirms the essence of the collection: why were the collections acquired and why are they still kept? What is their meaning? How are the collections valued – by whom and why? The units are compared with each other within the context of the organisation’s mission, and are given a value score of ‘high’, ‘medium’ or ‘low’ – along with the arguments for that valuation.

The starting point is that all units have equal value, unless there are solid arguments to attribute a higher value to a particular unit. The high value units will be the ‘masterpieces’. Similarly, there may be units with a lower relative value, e.g. the reserve collection, or which might have no value at all to the organisation. Consequently, the core collection is formed from the medium value units.

Assessing museum collections

Collections are assessed and valued against a standard set of criteria described in the publication *Assessing Museum Collections; Collection Valuation in Six Steps* (Luger *et al*., 2014). Although the methodology was initially developed for museum collections, it has also proved suitable for archives, libraries and other types of heritage.

The method distinguishes between *attributes* and *value criteria.* The value-neutral attributes consider condition and state, ensemble or completeness, provenance and rarity. These properties do not make something valuable or not, but they can enhance or reduce the value. Units can score ‘good’, ‘average’ or ‘poor’ for these attributes.

The value criteria are divided into cultural-historical values (information, historical, artistic values), social and societal values that reflect contemporary connections with stakeholders (broad societal and personal experience values) and use values (related to the organisation’s use for study, education or presentation, as well as their economic utility as cultural capital, public favourites or for the reputation of the organisation). Collection units can score ‘high’, ‘medium’ or ‘low’ for these criteria.

For consistency and to be able to explain to outsiders how and why units are assessed in a particular way, it is essential to agree on the assessment and valuation framework at the outset. This framework describes the attributes and criteria, and provides the rationale for what makes a unit score ‘high’ or ‘low’, ‘good’ or ‘poor’. The team only has to provide arguments for those criteria that are used in the discussions and that underpin the scores. The other criteria can always be added at a later stage.

In the QuiskScan matrix, only an overall score for each collection unit is given. One should be aware, however, that this is not

	Criteria	Assisting questions
Attributes	**State** (condition, intactness, material authenticity, material integrity)	*Are objects in good condition, complete, in their original state?* *Are objects chemically stable?* *Are they mechanically stable?* *Are they fit for use?* *Are digital formats stable?*
	Ensemble (completeness, unit, connection, conceptual integrity, conceptual authenticity, contextual authenticity)	*Do objects form a whole that is more valuable than its parts? Is that whole complete?*
	Provenance (documentation, biography, source, pedigree)	*Is the provenance of the collection known, documented, trustworthy?* *Is information authentic or valid?*
	Rarity and representativeness (uniqueness, example, prototype, type-specimen)	*Are objects unique, in the world, in the country, within the collection?* *Is it highly representative of a particular time, place, style, use, theme or community?*
Cultural-historical	**Historical** (biographic, evidence, association, commemoration)	*Is there a connection to a specific person, group, event, place in the past?* *Is there an association with a period, process, or development?* *Does it help interpreting the past?*
	Artistic (art historical, architectural history, design, style, craftsmanship, technique, decoration)	*Are objects special in terms of design, concept, make, technique, creativity? Are they representative of a particular period, style, artist?* *Is the maker famous?*
	Informational (study, research, science, documentation, reference, archival)	*Are objects kept for the information they contain which can be used for study and research, now or in the future?* *Do they contain information that serves as evidence for an event, theory, science?* *Do they contain information that serves to study the functioning of government or law?*
Social-societal	**Societal** (social, spiritual, religious, political, symbolic, community, identity)	*Do the objects fulfil a function for a group of people or society at present?* *Are there groups that have a current connection with the objects?* *Do the objects have current meaning for political, social, religious reasons?* *Are they important for the identity of a community in the present?*
	Experience (emotion, sensory, aesthetic, associative)	*Do the objects evoke a collective or personal experience or emotion?* *Do they trigger the senses?* *Do the contribute to personal identity?*
Use-usability	**Museum context** (presentation, education, research, public)	*Are the objects interesting and useful for exhibition, education or research?* *Are they important in the exhibition? Can they be used to tell or illustrate stories?* *Do they feature in publications?*
	Business, economic (asset value, financial possibilities, tourist attraction, reputation)	*Do the objects generate income for the museum?* *Do they attract visitors?* *Are they crucial for the image and reputation of the museum?* *Are they used?*

Example of an assessment and valuation framework

Assessment and valuation framework

Example for a regional museum, 2017

Poor/Low	Use-usability	Good/High	
Bad condition, incomplete, information or image obscured (e.g. dirt, stains, tears, folds, missing parts) Chemically unstable - short life expectancy Fragile - unfit for handling Unfit for use Obsolete format or equipment	Reasonable condition, information or image acceptable (nearly complete, stable damage or stains) Chemically semi-stable - medium life expectancy Weak - handle with care May require cosmetic treatment for use Can be migrated to current format, equipment still available	Good condition, complete and clean Chemically stable - long life expectancy Strong for its material - fit for handling Fit for use Current format and equipment	Attributes
Meant to be an ensemble but not complete or intact	Mostly complete Minor or less significant parts missing	Complete and intact	
Unknown or unreliable Information not valid	Known but unconfirmed	Known and reliable Well documented or described Information valid	
Not rare, more of its kind existing (editions, prints, cast etc.) Not representative	Rare in the region Representative for the region	Rare in the country or world One of its kind Representative at national level	
No or vague historical connection Association with person, group, event, place, time, theme, development of lesser significance	Association with person, group, event, place, time, theme, development of regional significance	Association with person, group, event, place, time, theme, development of (inter)national significance	Cultural-historical
Low quality Not special beyond local interest Not particularly representative No important name or fame	Good quality Special for the region Represenative of artistic expression in the region Regional name and fame	Excellent quality Representative of (inter)national artistic expression, design, technique, period (Inter)national name and fame	
Does not contain any particularly significant information or can be found elsewhere Not kept or used as a source of information	Contains interesting information to support research Supporting evidence	Good or pre-eminent source of information Prime evidence	
No particular current relationship with communities or stakeholders No societal meaning or significance Not important for identity	Current relationship with local or regional communities or stakeholders Meaningful for local or regional society Determining the identity of local or regional communities	Strong current relationship with communities or stakeholders Meaningful for national society Determining the identity of (inter)nationally significant communities	Social-societal
Does not evoke specific emotions Touches the individual Personal beauty or taste	Evokes average emotions Touches the group Expert-agreed beauty or ugliness Normal source for personal stories, family history and genealogy	Evokes strong emotions Touches many or most Generally agreed beauty, or lack thereof Rich source for personal stories, family history and genealogy	
Not or hardly interesting for use Never or rarely requested for consultation, exhibition or loan Hardly used for study, publication or reference	Interesting for use Occasionally requested for consultation, exhibition or loan Context for star objects and crowd pullers Occasionally used for study, publication or reference	Very interesting for use, rich source for stories Frequently requested for consultation, exhibition or loan Star objects - crowd pullers Used for study, well published, often referred to	Use-usability
No potential for income generation No significance for reputation Publicly not known Not or hardly used, objects 'sleep' in storage	Generates a small income at best Affect the reputation of the museum Known by professionals and experts Occasionally used, mostly in storage	Income generators Determine the reputation of the museum and help to secure loans Publicly well known, crowd pullers Frequently used and requested	

I. Collection anatomy		**II. Value**			
Collection unit	Quantity (Number of objects)	Relative value	Weighting	% of total collection value	Rationale using the criteria
A - Manuscripts	500	H	10	24.8	Unique set full of historical information; often requested
B - Ceramics	1,000	H	10	49.6	Mostly masterpieces with high artistic and historical value; on permanent display
C - Drawings & prints	5,000	M	1	24.8	Core collection; used for exhibitions and education
D - Archaeology	300	L	0.1	0.1	Poor condition, provenance often unknown, medium historical, low artistic and information value
E - Toys	1,500	L	0.1	0.7	Moderate condition, creators unimportant; not used; does not fit in collection profile

Table 2. The fictional collection in Table 1 expanded with the value scores for each unit, the weightings of the value categories and the contribution of each unit to the total collection value

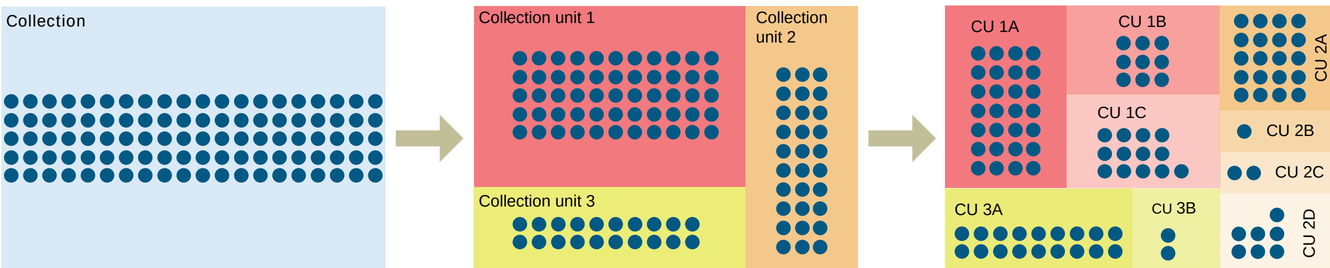
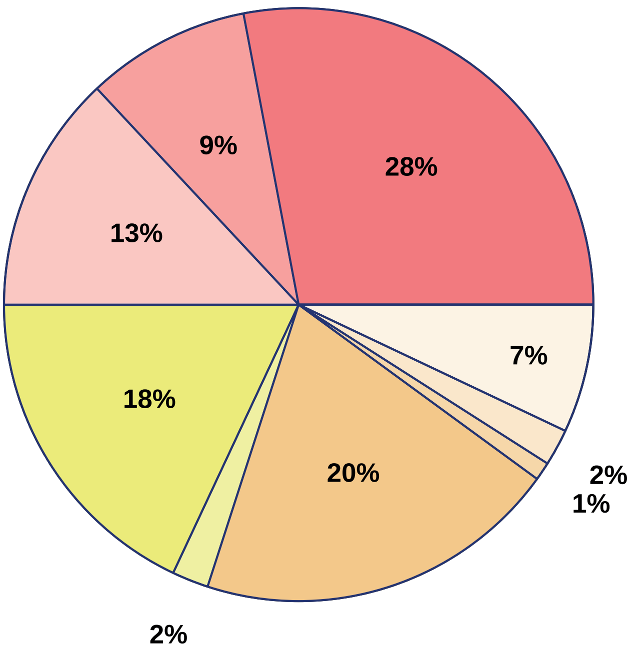


Figure 9. 100% collection value divided over collection units and sub-units according to the 'typesetter's tray' method, and the representation of the value distribution in a pie chart, or 'value pie'



the sum of the scores for the individual criteria. For example, a collection unit can be a masterpiece based only on its high historical values. Another collection unit with medium scores for both artistic and historical values may remain part of the core collection. The most practical approach is to give a general judgement first and then use the criteria to underpin that score and adjust the overall score as opinions unfold.

Most organisations are well aware of which parts of their collection are most valuable, but that is not always made explicit. Since everyone has their own specialisation and favourites, the group discussion is very important. Eventually, there should be a shared understanding of the values of the collection units relative to each other. The moderator has an important role in reaching an agreement and, if necessary, opinions can always be adjusted.

In the ABC method, the relative valuation and the division of the total collection value (100%) over the collection units, forms the basis for the C-score. The division can be established in two different ways. First, by awarding weighting factors to 'high', 'medium' and 'low' according to the equivalent value principle – so that an object of high value is equal to 10/100/1,000 objects

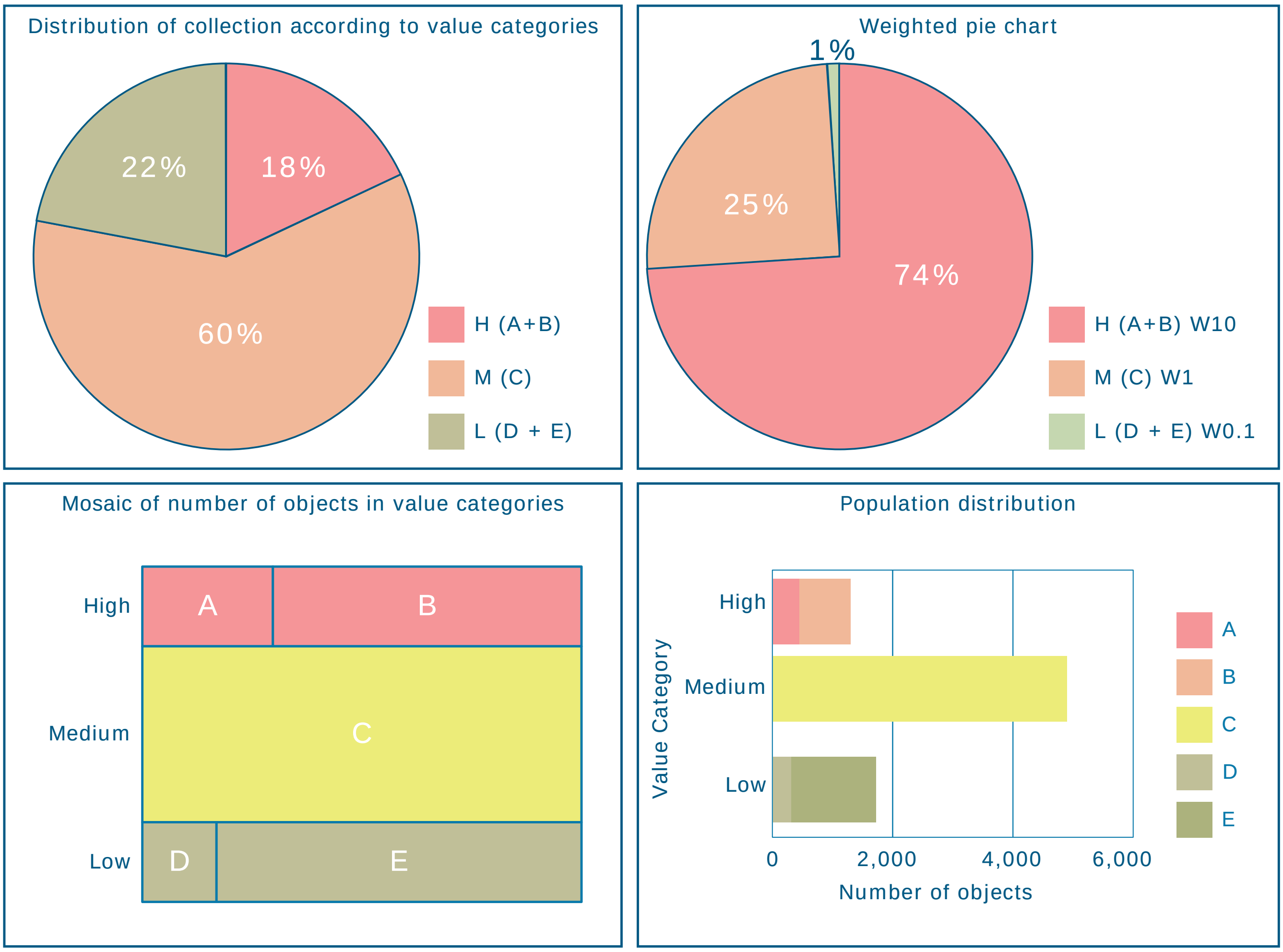


Figure 10. Distribution of the total collection value for the example in Table 2 over the value categories, presented in: a value pie chart (A); a weighted value pie chart (B); a mosaic plot (C); and a population distribution (D)

of a medium value (see Table 2). A second method is to divide the total value of 100% over the collection units using the allegory of marbles in a typesetter's tray (Figure 9). The result of this step is the expansion of Table 1 to include the value scores given in Table 2.

Usually, the objects within a collection unit will not all have the same value. In that case, a practical solution is to take the most frequent value (the mode) or the middle value (the median). If there are clearly two groups within a collection unit, it might be easier to split it.

Total collection value

Based on the collection anatomy and the value assessment, it is possible to construct an overview of the division of the total collection value over the various units. This overview can be visualised in different ways. Figure 10 shows a value pie chart (A), a weighted value pie chart (B), a mosaic plot (C) and a population distribution (D) based on the example in Table 2. The number of objects in every value category is shown in the value pie chart (A), the mosaic plot (C) and the population distribution (D). The weighted value pie chart (B) gives a good picture of the division of the total collection value over the units. In the example in Table 2, the average value is normalised to one. High value objects are valued ten times more greatly and low value objects ten times less greatly. The 1,800 objects in units D and E contribute less than 1% of the total collection value, while the 1,500 objects in units A and B together represent more than 74% of the total collection value. For many museums, this intermediate result already offers a much better – and above all a *shared* – understanding of the collection than that before starting the process. This is the moment to review whether everything is correct thus far and whether everyone agrees. If so, there is now a solid foundation for the risk assessment.

Step 3 QuiskScan track - Vulnerability and potential loss of value

The biggest loss of value to the collection can occur where units have both a high value and a high vulnerability to certain agents of deterioration. In this step of QuiskScan the vulnerability of the units to each of the ten agents of deterioration ('physical forces', 'fire', 'water', 'thieves and vandals', 'pests', 'contaminants', 'light, ultraviolet and infrared', 'incorrect temperature', 'incorrect relative humidity' and 'dissociation') is considered. Information about vulnerability of materials and objects is provided in the chapters on the agents of deterioration.

Depending on the reason for the assessment and the questions posed, the collection is scanned for all agents or only for those that are relevant. For most typical generic scenarios the team assesses whether the collection units have a high, medium or low vulnerability to each agent of deterioration. Watercolours, for instance, are highly vulnerable to water, but have a low vulnerability to incorrect temperature. Again the moderator plays an important role in asking the right questions, extracting as much knowledge as possible from the team and ensuring that nothing is overlooked. It is important to remain honest and avoid the temptation to over- or underestimate. Initially, the team works with available knowledge, with unknowns noted so that they can be investigated at a later stage if required.

Vulnerable value

With the use of colour coding, the *vulnerable value* can easily be visualised. In the example presented in Table 3 the collection has been scanned for five unspecified agents of deterioration: I–V. The combination 'high value' x 'high vulnerability' (HH) indicates a possible large loss of value (HH = red) for which exposure and risk should be analysed further. The combinations 'medium value' x 'high vulnerability' (MH) and 'high value' x 'medium vulnerability' (HM) can also yield significant losses if there is exposure to the agent of deterioration in question (HM = MH = orange). Here the risks should also be analysed further.

The combination 'medium value' x 'medium vulnerability' (MM) gives a medium loss of value (MM = yellow), for which one should consider if the exposure is acceptable. The combination of high or medium value with low vulnerability, or low value with high or medium vulnerability, will only result in a small loss of value when there is exposure (HL = LH = ML = LM = green). These risks do not have a high priority. Upon exposure the combination 'low value' x 'low vulnerability' (LL) will result in a very small loss of value and the risks can be ignored (LL = blue).

The result of this step is that the vulnerability value within the collection is 'mapped', as shown in the further expansion of Table 1 to Table 3. Appendix 1 provides a QuiskScan form.

It is next necessary to identify the specific risk scenarios that could lead to a loss of value for those collection units that show up in QuiskScan with high vulnerable value. First, the team needs to consider if there is any exposure, by identifying possible sources (of fire, water, incorrect temperature, physical forces, etc.). If they are absent or if mitigation measures to minimise exposure have already been taken, then the risk will be small and needs no special attention.

When identifying sources and mitigating measures, the scenario schemes provided in the chapters on the agents of deterioration can be very useful, as is the checklist for step 3 in the ABC method (Table 5).

The results of the analysis can be represented in a QuiskScan matrix by correcting the coloured cells for exposure. If there is no exposure the cell is hatched to indicate that although there is

I. Collection anatomy		II. Value		III. Vulnerability to agents of deterioration				
Collection unit	Quantity (Number of objects)	Relative value	Weighting	I	II	III	IV	V
A - Manuscripts	500	H	10	H	L	M	L	L
B - Ceramics	1,000	H	10	H	M	M	H	H
C - Drawings & prints	5,000	M	1	H	M	H	H	M
D - Archaeology	300	L	0.1	L	H	L	L	L
E - Toys	1,500	L	0.1	L	L	L	M	M

Table 3. The collection in the fictional example, expanded with the assessment of the vulnerability to agents of deterioration I–V. The combination of the scores for relative value and vulnerability for each agent of deterioration generates the 'vulnerability value', which is colour coded to indicate the extent of the possible loss of value upon exposure

no current risk, vulnerable value could be at risk if the situation changes. However, if there is exposure, the colours remain ‘bright’ (not hatched) and the specific risk scenarios need to be developed further. What is expected to happen? What is the likelihood and what changes will occur to the objects in the collection unit because of it? What form will the damage take and how great will be the loss of value? The analysis of the risk scenarios also reveals the sources of risk and weak links in protection, so that effective measures to reduce the risks can be found.

Identification, analysis and evaluation of the specific risk scenarios can be undertaken using the ABC method (see ABC track). Finally, the team can think about measures to manage those risks. The final QuiskScan matrix for the fictional example appears as shown in Table 4.

Evaluating the QuiskScan results

At this stage QuiskScan has reached its limits. For a full risk assessment one needs to continue using, for instance, a scenario-based approach. In this publication, the ABC method is used for this purpose. However, the results of the QuiskScan can be evaluated in a broad-brush manner, giving insight into the risks to which the collection is exposed from different sources. For the example in Table 3 it is noticeable that, due to their high vulnerable value, collection units A and B are at risk when exposed to agent of deterioration I. Furthermore, unit B is also vulnerable to agents IV and V.

Figure 11 shows the number of objects with a certain vulnerability to each of the five agents of deterioration (left). On the right this number is linked to their value, and the vulnerable value is shown as a percentage of the total collection value. It is the sum of the number of objects in the coloured cells in Table 3. Both graphs show what loss of value could occur in the case of

I. Collection anatomy		**II. Value**		**III. Vulnerability to agents of deterioration**				
Collection unit	Quantity (Number of objects)	Relative value	Weighting	I	II	III	IV	V
A - Manuscripts	500	H	10	H	L		L	L
B - Ceramics	1,000	H	10	H	M	M		
C - Drawings & prints	5,000	M	1	H	M			M
D - Archaeology	300	L	0.1	L	H	L	L	L
E - Toys	1,500	L	0.1	L	L	L	M	M

Table 4. QuiskScan matrix for the collection in the fictional example corrected for exposure to agents of deterioration I-V. If there is no exposure, shown by hatching, the risk has no priority as long as the situation does not change.

Figure 11. Left: the collection’s vulnerability to agents of deterioration I-V, taken from Table 3, stacked as number of objects per collection unit: high (red), medium (yellow) and low (green). Right: vulnerability multiplied by value, this shows the percentage of the total collection value that is vulnerable to each agent of deterioration. The colour coding corresponds to that in Table 3.

exposure. While almost 80% of the collection is susceptible to agent of deterioration I, only 20% has a high vulnerable value. The other 60% has medium value. Something else that stands out in Table 3 is that unit B is vulnerable to agents I, IV and V. It might be a small collection unit, but its value is high. If it turns out that there is indeed exposure to these agents, then a priority for risk management should be to reduce exposure to agents I, IV and V. Any measure that could reduce the risks from two or three of these agents simultaneously would be most effective.

Step 3 ABC track – Identify risks

For the risk scenario approach, the events and processes that can lead to loss of value should be identified as comprehensively as possible. These are the so-called 'specific risks'. Practice shows that there are topics for which much pre-existing knowledge is available and for which it is easy to come up with a large number of risks. Equally, there are many unfamiliar topics for which the limits of everyone's imagination are quickly reached. The 'Ten Agents of Deterioration' system offers guidance in identifying as many risk scenarios as possible, considering both events and processes that can lead to a loss of value (CCI, 1994; Waller, 2003).

Events

Damage only occurs when the event takes place. This happens with a certain frequency: once in a certain period or so many times per year or per century. Objects must be affected by the event, as not every event causes damage. Not every flood will cause objects to become wet; only the objects in the water's path or in the flooded area will get wet. During transportation there are regular occurrences of something falling, but not every fall results in a damaged object. Events can be small incidents that are within one's own control, but they can also be catastrophes that usually have an external cause.

Processes

Damage is cumulative and gradually increases during exposure to the agent of deterioration. These degradation processes range from wear-and-tear to fading or corrosion. When determining the effect, one must always take into account the extent of the exposure (friction, range of the RH fluctuations, light intensity, concentration of air pollution) and the duration of that exposure.

Risk scenarios are summarised in a so-called 'risk sentence' that briefly describes what the cause or source is, the pathway that the agent of deterioration follows to reach the object, and what the effect will be. There are three approaches to developing

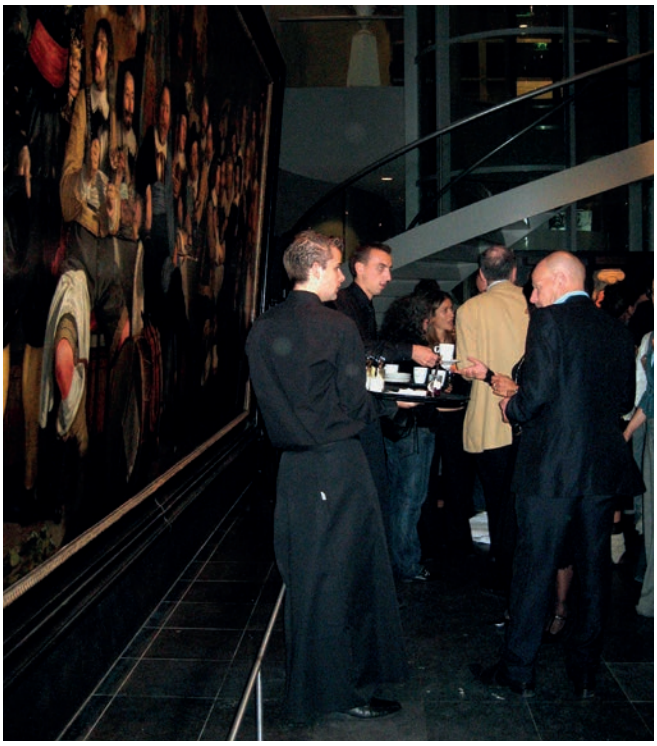


Figure 12. Receptions in museums can be risky events. Generally, measures to prevent spills of food and drinks are well covered. Experience shows that moving tables and chairs causes most damage (scratches and impact)

risks: from the cause towards the effect; from the effect back to the cause; and by considering the weak links in a pathway to see where protection might fail.

To ensure that no relevant risks are disregarded during the identification process, a number of methods and tools can be used.

- **Checklist**: Table 5 contains a checklist of common events and processes for each agent of deterioration, which can be used to begin risk identification. The list can also be used later to verify if both events and processes have been considered for each agent of deterioration.
- **Scenario schemes**: further on in this publication, scenario schemes are presented for each agent of deterioration that outline generic sources, pathways and effects. These can be developed for one's own situation.
- **Inspection of layers**: conduct an inventory and inspection of the perimeter, the building, the collection and the procedures to gain insight into the level of protection that the various layers around the collection offer. Indicate the weaknesses in

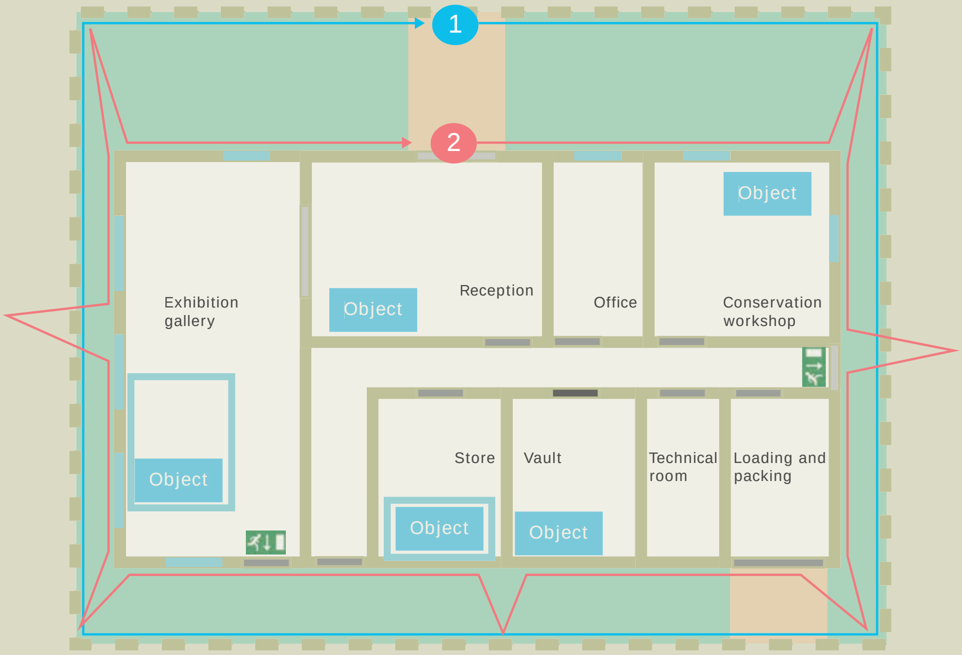
Agent of Deterioration	Event	Process
Physical forces	Earthquake leads to damaged buildings, collapse of (part of) the building, toppled cupboards, moving objects Collapse of neighbouring building leads to damage to the building Crashed aircraft or colliding lorry leads to damaged building and collection Snow on roof leads to overload and roof collapse Explosion leads to damaged building and collection Storm leads to damaged roof, falling trees and crushed collection Sampling of object for research leads to material loss Accident during maintenance, restoration or transportation (fall) leads to dents, scratches or failures	Continuous maintenance (cleaning) leads to material loss Vibrations (events, traffic, construction or transportation) lead to moving objects, scratches or material loss Use and handling objects lead to folds, scratches or material loss Use and visitors lead to wear Poor maintenance leads to deformation Overcrowded storage leads to scratches or deformation
Fire	Extensive fire at building level causes damage to large part of collection Fire limited to compartment damages part of collection Local fire (rubbish bin, candle or cigarette) leads to total or partial loss of objects Damage can be burnt material, soot, smoke, water or extinguisher residue	
Water	Pouring rain or melting ice on leaking roof leads to water entering Severe weather, flooding or melting snow leads to water entering via sewers and other entrances Breakage in drainage pipes leads to wet objects Spills (filling equipment reservoirs or watering plants)	Condensation on cold surfaces causes water stains and rot Rising damp Wet cleaning
Thieves and vandals	Theft outside opening hours by external persons Theft during opening hours by external persons Internal theft by own employees Intentional non-return of loaned objects Heavy damage due to vandalism Slight damage due to vandalism	Internal theft over a long period of time, causing loss of many objects
Pests and plants	Rodents chew, nest and pollute Insects drill, chew and pollute Birds nest and pollute Bats nest and pollute	Growth of algae and mosses Growth of creepers against façade Growth of bushes and trees that damage the foundations
Contaminants	Industrial disaster causes sudden increase in air pollution Construction causes temporary high concentration of dust Spilt chemicals, food and cleaning agents cause stains Disfiguring old or unsuitable (restoration) treatments	Industrial activities, agriculture or traffic cause high concentration of external air pollution that leads to corrosion of materials Collection emits volatile pollutants Construction materials emit pollutants Traffic causes a high concentration of particulates
Light, ultraviolet and infrared	Filming using bright lights Photography (cataloguing, reproduction or digitisation).	Incident sunlight and daylight Artificial light (outside or inside) Emergency and work lights cause discolouration or degradation
Incorrect temperature	Heater malfunction in winter causes thermal shock Overheating due to temporary heat sources (film lamps, projectors or halogen lighting) Transportation, cleaning or treatment (freezing) leads to thermal shock	Continuous exposure to high temperature leads to accelerated aging and softening of wax, resins or glue Extreme (seasonal) fluctuations lead to expansion or shrinking
Incorrect relative humidity	Malfunctioning of dehumidification system in the summer leads to temporary high RH Malfunctioning humidification system in the winter leads to temporary low RH Transportation or treatment at low or high RH leads to sudden large fluctuations with mechanical damage	Continuous high RH (local microclimate) leads to accelerated chemical breakdown, corrosion and mould Continuous low RH leads to dehydration of hygroscopic materials Extreme (seasonal) fluctuations lead to expansion or shrinking
Dissociation	Employees leaving leads to loss of unrecorded knowledge about the collection Putting (back) objects in the wrong place leads to (temporary) loss of object Computer crash without backup leads to loss of information	Aged storage devices, hardware and software lead to loss of object information Fading or loss of labels leads to separation between object and information

Table 5. Checklist for risk scenarios. Overview of common risks based on causes.

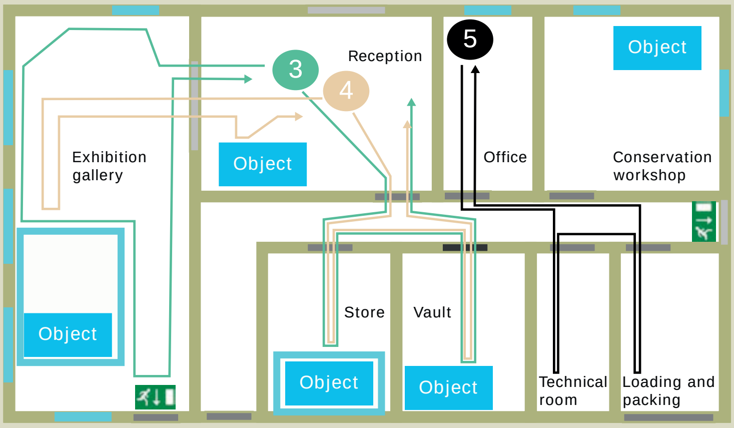
Inspection of the envelopes

An inspection of the quality of the envelopes, is in fact a search for weak spots that make it possible for agents of deterioration to reach the collection.
This inspection should preferably be done by a team of (museum) professionals.
- A facility employee who knows everything about the building envelope and the installations present as well as maintenance.
- A security staff employee who knows everything about zoning, security and security procedures.
- A conservator who knows the collection and can say something about the speed with which the collection changes over time due to the effect of the agents of deterioration.

Together, the following steps can be taken:
1 Collect experiences and knowledge from museum employees to get a better understanding of events and processes that take place in the middle to long term. Collect experiences from the residents in the vicinity of the museum to get a better idea of the risks on a site scale
2 Inspect the grounds and outer envelope and determine their quality (imagine you are the agent of deterioration and think how you could reach the collection):
Route 1 (blue line): Explore the immediate surrounding area of the building. Pay attention to the ground conditions, drainage, lighting, adjoining buildings and security.
Route 2 (red line): Look at the building. Check the roof, inspect the walls, the doors and the windows (leakiness, safety, isolation, locks), vegetation and rainwater discharge. Search for possible entry routes and determine the weak spots in the



3 Inspect the rooms inside:
Route 3 (green line): Explore the collection areas. Pay attention to ceilings, walls, floors, doors, windows, lighting, climate equipment, security, fire installations, presence of detectors, pipes, any traces of harmful incidents, moisture stains, musty smell, cracks and tears, etc.
Route 4 (brown line): Have a close look at the objects, the wrapping, the showcases, cabinets, boxes, bags. Pay attention to damage of the collection, air tightness of the showcases, materials used, etc.
Route 5 (black line): Check out the non-collection rooms. Pay attention to (water) pipes, waste, accessibility, etc.



4 Check the established procedures:
Is there an emergency plan? How is the collection handled, exhibited and stored? How good is the alarm response? How is the emergency response organised? Are the employees trained and prepared? Are (almost all) incidents reported? Etc.

Figure 13. Systematic inspection of the layers in risk identification

the pathways and barriers (see also the introduction 'Agents of Deterioration and Scenario Schemes'). Figure 13 provides an example of a systematic inspection.

- **Collection survey**: check what the collection, objects or their parts say about the influences to which they have been exposed thus far. Are there traces of wear-and-tear or fading, damage through use or handling, or signs of leakage in the building? Is there any information in the condition reports?
- **Incident analysis**: if a situation remains unchanged, incidents tend to repeat themselves. Therefore, incident analysis forms an important basis for risk scenarios. Make maximum use of information on incidents in the past. What can you find, for example, in incident logs, in the organisation's incident registration system, or in a national Incidents Database (see for example RCE, 2015)? What do staff remember?

The outcome of this step is a so-called 'longlist' of risk scenarios in the form of sentences with a source–pathway–effect structure, such as those shown in Figure 4 (Introduction). Based on a rough estimation of the likelihood and consequence, a first, albeit imprecise, magnitude of risk can be determined. Likelihood and consequence can be scored using, for instance, a three- or five-point scale and placed in a risk matrix. Below, an example of a three-point scale is provided in which more than 10% loss of total collection value is considered a large loss. Large could also be defined as beginning at 50% (also see Introduction, Figure 5).

- **Likelihood**
  1 = seldom – loss of collection value expected in more than 100 years
  2 = occasionally – loss of collection value expected in ten to 100 years
  3 = regularly/continuous – loss in collection value expected within ten years
- **Consequence**
  1 = small – less than 1% of the total collection value lost
  2 = medium – between 1–10% of the total collection value lost
  3 = large – more than 10% of the total collection value lost

Risk matrix

A risk matrix (likelihood–consequence matrix) offers a quick way to arrange qualitative or semi-quantitative assessments of likelihood and consequence according to their magnitude. The size and division of the matrix depend on the context in which it is used and the level of detail in the available data. The classification can be made using a scale of 0–1 (does not matter – does matter). This forms a 2 x 2 matrix with four cells. A scale of 1–2–3 (small–medium–large), forms a 3 x 3 matrix with nine cells.

If the accuracy of the data permits, the matrix can be expanded to 5 x 5 for a greater distinction between risks. Other variations are also possible. However, it is important to work with a clearly defined scale, so that what constitutes 'small' to one person also means 'small' to another. Numbers provide a solid basis, for example a likelihood of 1, 10 or 100%. The scales for likelihood and consequence should always cover the full range of possibilities and be divided in balanced classes. These can be linear (0–25–50–75–100) or logarithmic (order of magnitude: 1–10–100).

A risk matrix is effectively a visualisation of the equation 'Risk is Likelihood times Consequence' (R = L x C). When using numeric scales, the value of the cells corresponds to the multiplication of the scores for probability and effect. A matrix can be used to arrange risk scenarios, but it can also simply arrange sources, pathways, effects or measures based on the probability of a certain outcome.

A risk matrix is a powerful communication tool. When, after consultation, acceptable risk levels have been identified, it is immediately apparent which risks fall within that safe range and which do not. A risk matrix is relatively easy to draw up and supplies a quick overview of the risks. That overview is, however, rather general, and everyone must bear in mind that awarding scores can be very intuitive and subjective.

Aggregating or disaggregating scenarios

When identifying risks and describing specific risk scenarios, there is always the question of how far one should go in dividing events into separate scenarios (zooming-in or disaggregating), or whether it is better to describe them as a complex set of similar or correlated events (zooming-out or aggregating).

Dividing the risks helps to make the situation manageable, better describe the consequences and determine a probability. When using a risk matrix or the ABC method, the individually-described risks cannot be aggregated or combined and their scores totalled. The more that specific risks are described in separate scenarios, the smaller their probability will be. Disaggregating risks can thus lead to underestimation of the total risk of a certain threat. The key is, therefore, to find the right level of aggregation, whereby the situation can still be described and analysed easily, but has not been simplified so much that a misleading picture is created.

Communication and consultation

Assessing likelihood and consequences requires gathering information and data. Here communication and consultation play an important role. Information needs to be collected about the day-to-day business of the organisation. Employees should be interviewed and experts consulted. As risk identification is about gaining a better understanding of the weaknesses in the organisation and everyone's working practice, there is a chance that staff get the feeling they are to blame for everything that goes wrong. Commitment and trust are crucial, so that all are willing to contribute to improving practice and organisation. Accordingly, the strengths and successes of the organisation should also be mentioned when identifying and analysing risks. Consulting colleagues with different expertise ensures a broader overview when identifying risks. Creative, 'out-of-the-box' thinking, imagining yourself to be an agent of deterioration and how you could cause damage, also inspires the identification process.

Monitoring and review

Discuss the results of the identification with all those involved and check whether everybody is satisfied with the results. Verify, for example by using the checklist, if all the gaps and blind spots have been filled. It is perfectly possible that new or more relevant risks emerge during the risk analysis; these can always be added to the longlist as insight and knowledge improve.

Step 4 ABC track – Analyse risks

If the risk matrix has been created objectively, based on sound knowledge with acceptable uncertainty, then it can be used in the decision-making process. However, when it is based on limited information and greater uncertainty, rough estimation and intuition, it is better to carry out a more in-depth analysis of the risks, including consultation with colleagues and experts.

It is also possible that many risks end up in the 'high' category and further prioritisation is needed before the correct decisions can be made. In this step, a scenario is developed for each specific risk in which the arguments for the magnitude of this risk are made explicit. The magnitude of risk is determined based on scores, and those scores need to be substantiated by data that can be verified and understood by others in the future. It is important to break away from prejudices and biases, think beyond favourites, and separate facts from fiction. The risk scenarios should be developed as comprehensively and factually as possible. The scenario form in appendix 2 can be used to compile all arguments and scores for a specific risk scenario.

ABC scores

The ABC method uses three scores: A, B and C. The A-score expresses the period in which a loss of value due to a change is expected; put simply, 'how soon do we expect damage?' Subsequently, the question is, 'how bad is the damage?' This question is split into two parts, 'what material change will a susceptible object undergo when exposed to this particular risk?'

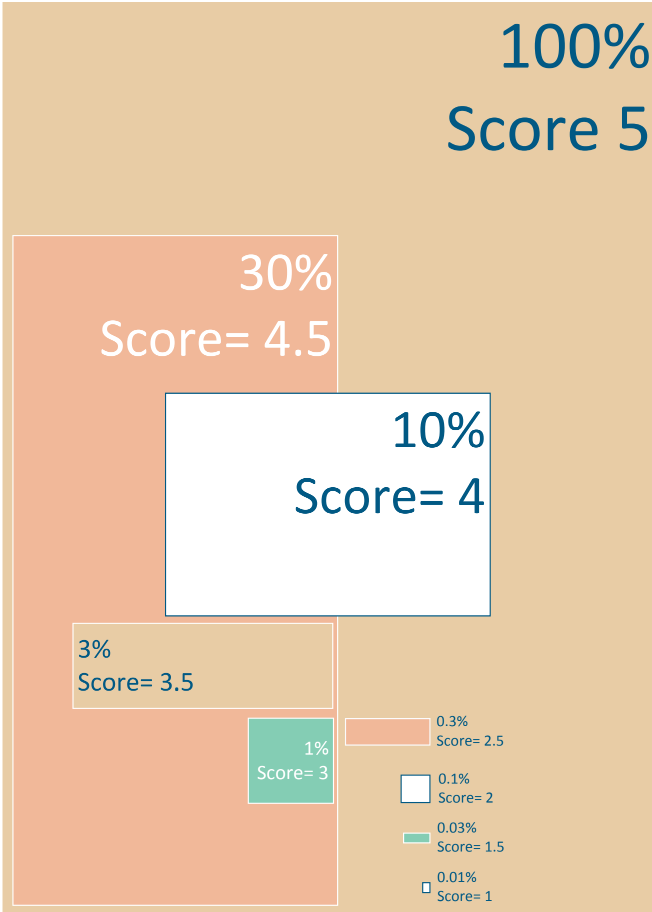


Figure 14. A representation of a logarithmic scale for the A-, B- and C-scores by ratio of surface area

and 'how much value does it lose as a result of this change?'. If several objects are exposed to the same risk, an average loss of value should be determined. This loss of value for each affected object is the B-score.

Finally, the question is how many objects will lose value and how much value do they represent within the entire collection? If all the objects are of the same value, it is simply a matter of counting the number of objects that will be damaged and dividing this by the total number of objects in the collection. However, damage to masterpieces will have a larger impact on the total collection value than damage to core or reserve objects. In that case, the value distribution has to be taken into account and the question becomes, 'how big a piece will be taken out of the value pie?' This gives the C-score.

Since predictions are never certain, the expected score is always flanked by a highest and a lowest possible score. The range

A. How often?? The probability or frequency with which an event takes place and leads to a loss of value	**A. How soon?** The rate with which a process leads to a loss of value. The loss of value from the B-score will occur in:	**A-score**
Once every year	Approximately 1 year	5
Once every 3 years	Approximately 3 years	4½
Once every 10 years	Approximately 10 years	4
Once every 30 years	Approximately 30 years	3½
Once every 100 years	Approximately 100 years	3
Once every 300 years	Approximately 300 years	2½
Once every 1,000 years	Approximately 1,000 years	2
Once every 3,000 years	Approximately 3,000 years	1½
Once every 10,000 years	Approximately 10,000 years	1

Table 6. Possibilities for the A-score for events and processes

B. How bad? Loss of value to each affected object		**B-score**
100%	Total loss of value to each affected object	5
30%		4½
10%	Significant loss of value to each affected object	4
3%		3½
1%	Small loss of value to each affected object	3
0.3%		2½
0.1%	Very small loss of value to each affected object	2
0.03%		1½
0.01%	Just noticeable change, but barely a loss of value	1

Table 7. Possibilities for the B-score

indicates the level of uncertainty, which plays a role in the evaluation of the risk assessment.

The ABC scores each range from 0 to 5. They are not linear but logarithmic and count, as it were, the zeros in a number. A score of 4 is not, therefore, twice as big as a score of 2, but 100 times as large. Figure 14 gives an impression of how the scores relate to each other.

A-score

For events, the A-score is the answer to the question, 'once in how many years does the event cause damage?'. One can also consider the frequency with which events occur, 'how often per century does the event cause damage?', or the average time between repeated events, 'what is the time between events?' For processes, the question is, 'how long does it take before a certain loss of value has occurred?' The possibilities for the A-score for events and processes are presented in Table 6.

B-score

How much value will be lost for each exposed object as a result of the expected material change? We are trained in the observation of visual changes to objects. We can see a crack in a panel painting or tarnishing of silver. But how does one translate those changes into loss of value, and does the change in value evolve in the same way as the physical change? The possibilities for the B-score are given in Table 7.

There are two states of an object for which it is easy to determine how loss of value and condition relate to each other. When undamaged or pristine the object has its full value and there is no loss of value (the B-score would be 0). If the object is completely destroyed or lost, it is a total loss (its B-score is 5). But what about changes of condition that result in partial loss of value? Figure 15 shows three different situations that lead to a loss of value. There are many more, often derived from the situations shown, but these three are discussed as illustrations. The possibility of an increase of value over time is disregarded for now.

The first damage causes the biggest loss of value

The red line in Figure 15 shows a steep decline of value at the beginning. The first damage to the object causes a large loss of value, but subsequently the rate at which value is lost decreases. Typical examples of such a situation are the first scratch on a pristine surface, graffiti on a clean object and fading of coloured reference materials.

Loss of value takes place after a certain damage level has been reached

The green line in Figure 15 shows a gradual loss of value until it reaches a certain point, after which the loss suddenly increases.

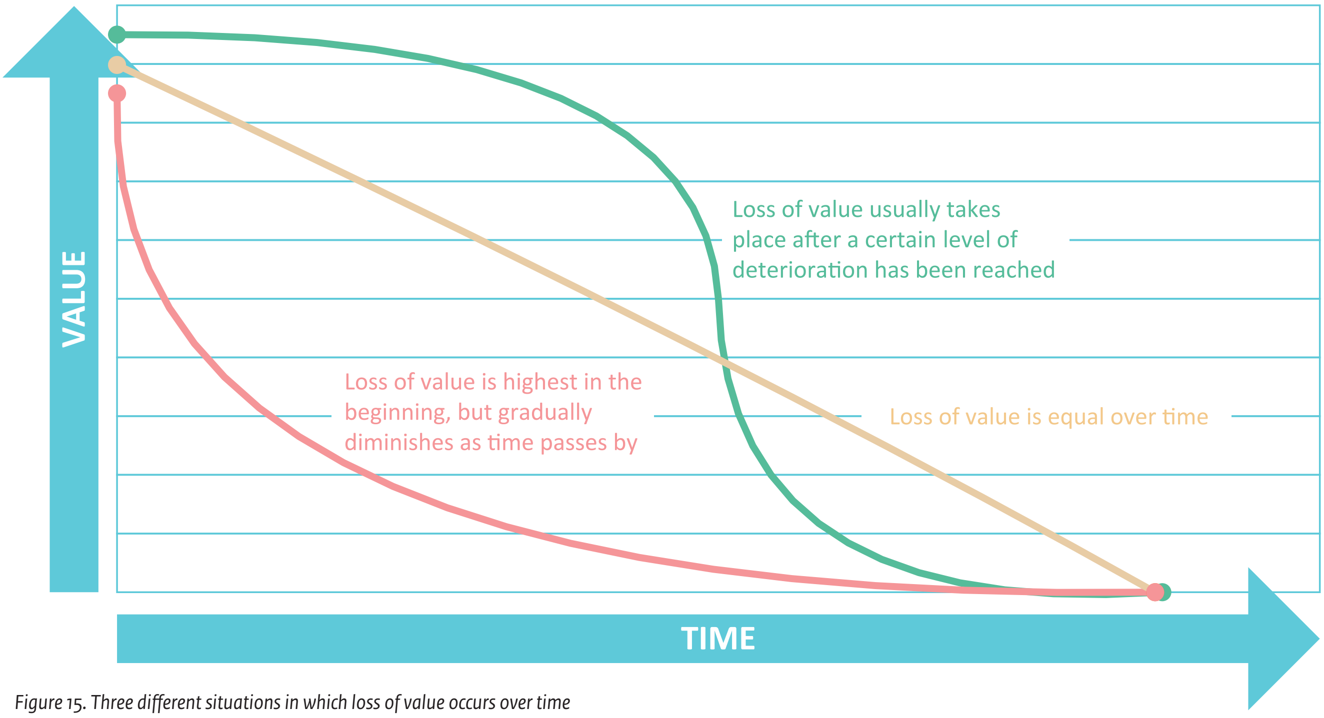


Figure 15. Three different situations in which loss of value occurs over time

Figure 16. Detail of the silver plaque The Resurrection of Christ by Paulus Willemsz van Vianen, 1605 (BK-1959-14), showing significant abrasion of the head to the right (Photo: Rijksmuseum, Amsterdam).

The first damage is barely visible but at some point it becomes obvious and is considered a significant loss of value. Typical examples of such a situation are the continuous polishing of silverware, which gradually wears off raised or incised decorations until they are illegible and lose their meaning, or where a silver or gilded surface is polished off. In these cases, the value of the object may never be lost completely.

Other examples are the cracking of oil paint under the influence of fluctuating relative humidity, which eventually leads to paint loss, or the acidification of paper, which is hardly noticeable at first but becomes apparent when the paper tears upon handling. Wear-and-tear of a floor is barely noticed for a long time, until the boards lose their strength and need to be replaced. In addition, chemical processes with an inhibition phase, such as degradation of stabilised plastics, can show such a pattern.

Loss of value increases linearly over time

The straight yellow line in Figure 15 represents a linear loss of value over time; as time passes, damage and loss of value increase. Clothes moths could cause such a linear process. Fading of tapestries and watercolours, which becomes more noticeable with time is another example. Although most damage processes are not linear, we often use this pattern to give an average over time. It shows the importance of the time horizon; the further in the future the time horizon moves, the more likely it is that the situation shown by the red line could be missed, failing to notice its urgency. If only a short time horizon is considered, the pattern represented by the green line may be missed.

Determining the loss of value is the most subjective part of the risk analysis and can best be objectified by discussing it with colleagues. It helps to define first why something is valued, and how highly. For this, the cultural value should be assessed and the character-determining features defined. If those features change, the value decreases. See for example Brokerhof et al. (2008).

Processes

Information about the rate of degradation processes can be found in the collection itself. Comparing the front and back of an object can give a good impression of the rate of colour

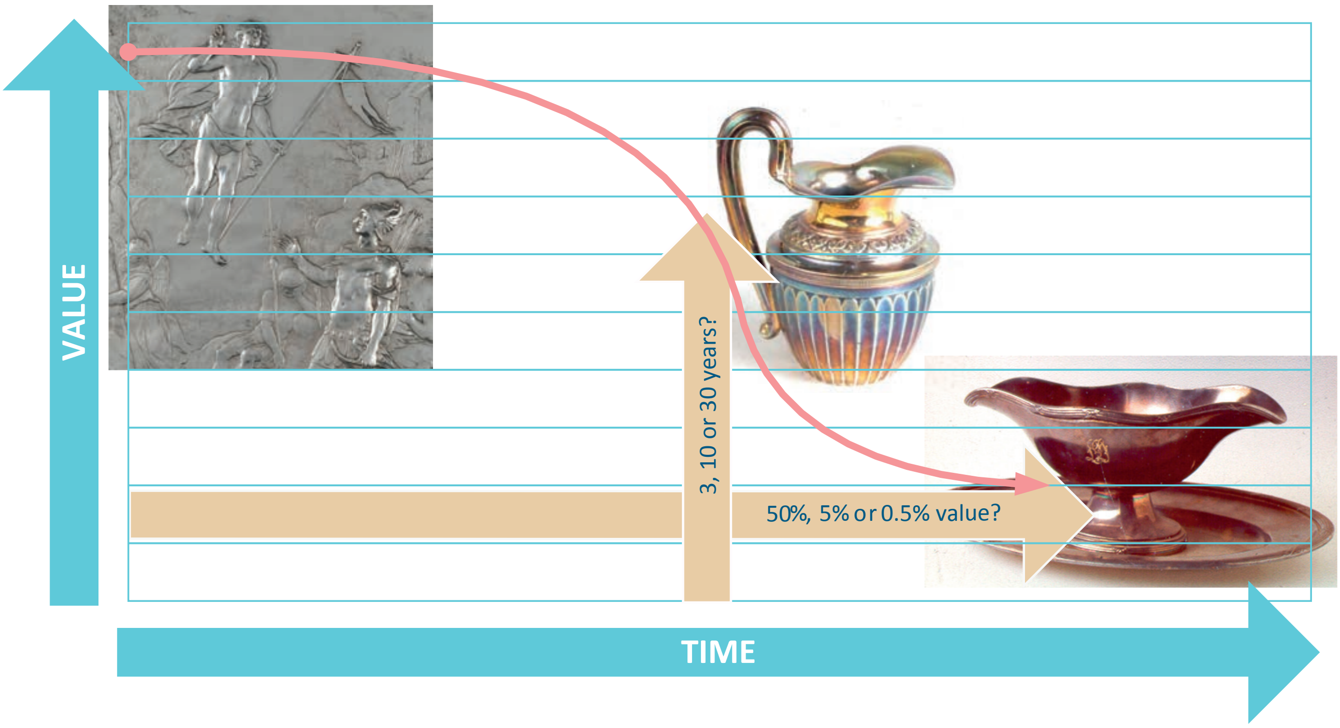


Figure 17. A well-known degradation process in museum collections is the tarnishing of silver. Many heritage institutions want to exhibit clean, shiny silverware. Sulphur-containing gases in the air (H2S and OCS) can turn silver yellow to light brown within just a year. The clean, shiny silverware has 100% of its cultural value. A slight discolouration of the object will only cause a small loss of value. Once the object has become completely black, it has suffered a larger loss of value, but its value will not be lost completely. To some institutions, the blackened objects may have only 75% or 50% value left, while for others the loss of value will be minimal. Once it is heavily tarnished, further discolouration will hardly lead to any additional loss of value.


11de JAARGANG
AVONDBLAD
ALGEMEEN HANDELSBLAD
Vrijdag 10 Mei 1940
Nederland in oorlog met Duitschland
België, dat ook door Duitschland is aangevallen, en ons land hebben een beroep gedaan op de Geallieerden, die hebben toegezegd alle mogelijke hulp te zullen verleenen
Grenstroepen bieden verbitterd weerstand aan IJssel en Maas
PROCLAMATIE VAN H. M. DE KONINGIN
Mijn Volk,

Figure 18. An example of a slow process is the degradation of newspapers. The Algemeen Handelsblad of 10 May 1940 is a chemically unstable object that has a limited lifespan. Based on models, it is estimated that it takes about 100 years at a temperature of 20°C and a relative humidity of 50% for the acid paper to degrade. At that moment, the newspaper can no longer be handled as the paper is too brittle and will break when the pages are turned, resulting in loss of material. A frequently requested newspaper will lose its value quickly. When a newspaper is too fragile to read it will have lost most of its information and use values. Thus the B-score is set at minimum 4 and maximum 5. The A-score corresponding to that large loss of value can be calculated by subtracting the age of the newspaper (2017-1940 = 77 years) from the expected lifespan (100-77 = 23 years). We expect to reach a fragile condition in approximately another 20 years. However, there is uncertainty in these figures and the rate of degradation may be twice as fast (or half as slow), giving an A-score between 3.4 (40 years) and 4 (10 years).

C. How much of the total collection value is involved? If all the objects are of equal value: how many objects are actually damaged? If there is a value pie chart: which segment will be affected?		**C-score**
100%	All the collection value	5
30%		4½
10%	A significant part of the collection value	4
3%		3½
1%	A small part of the collection value	3
0.3%		2½
0.1%	A very small part of the collection value	2
0.03%		1½
0.01%	A minute part of the collection value	1

Table 8. Possibilities for the C-score.

change. Another source of information is the conservation research literature (see the chapters on the Ten Agents of Deterioration). It is to be expected that watercolours exposed to daylight will fade significantly over the course of ten years. This is known from experience and from published research. Other processes take place very slowly, which makes it difficult to assess exactly how much damage occurs during an average staff member's career.

The A- and B-scores are connected. For slow degradation processes it is practical, therefore, to choose either a particular period (fix the A-score) and consider what the effect and loss of value in that period will be, or to consider a certain effect (and attribute a loss of value to it: i.e. fix the B-score) and then determine how long it will take before the object reaches that state.

Events

Statistics, logbooks, incident reports and institutional memory provide information about events. How often has something been stolen in the past? How many objects were damaged due to handling in the past ten years? How many times did the roof leak? How often does this happen in other institutions? Are we better or worse than the average? More information to substantiate the A-score can be found in the chapters on the Ten Agents of Deterioration.

C-score

Which part of the total collection value is at risk? In other words, how many objects from the collection or how many parts of the whole will experience the loss of value described by the B-score, and what percentage of the total collection value do they represent? To answer these questions, the collection anatomy and 'value pie' need to be consulted. Figure 19 explains the concept, based on a coin collection. The possibilities for a C-score are shown in Table 8.

Magnitude of risk

The Magnitude of Risk (MR) for a specific risk is the sum of the three scores: MR = A + B + C. The maximum score is 15. This score implies that the total collection value will be lost within one year. Table 9 provides a description of the scores for different magnitudes of risk.

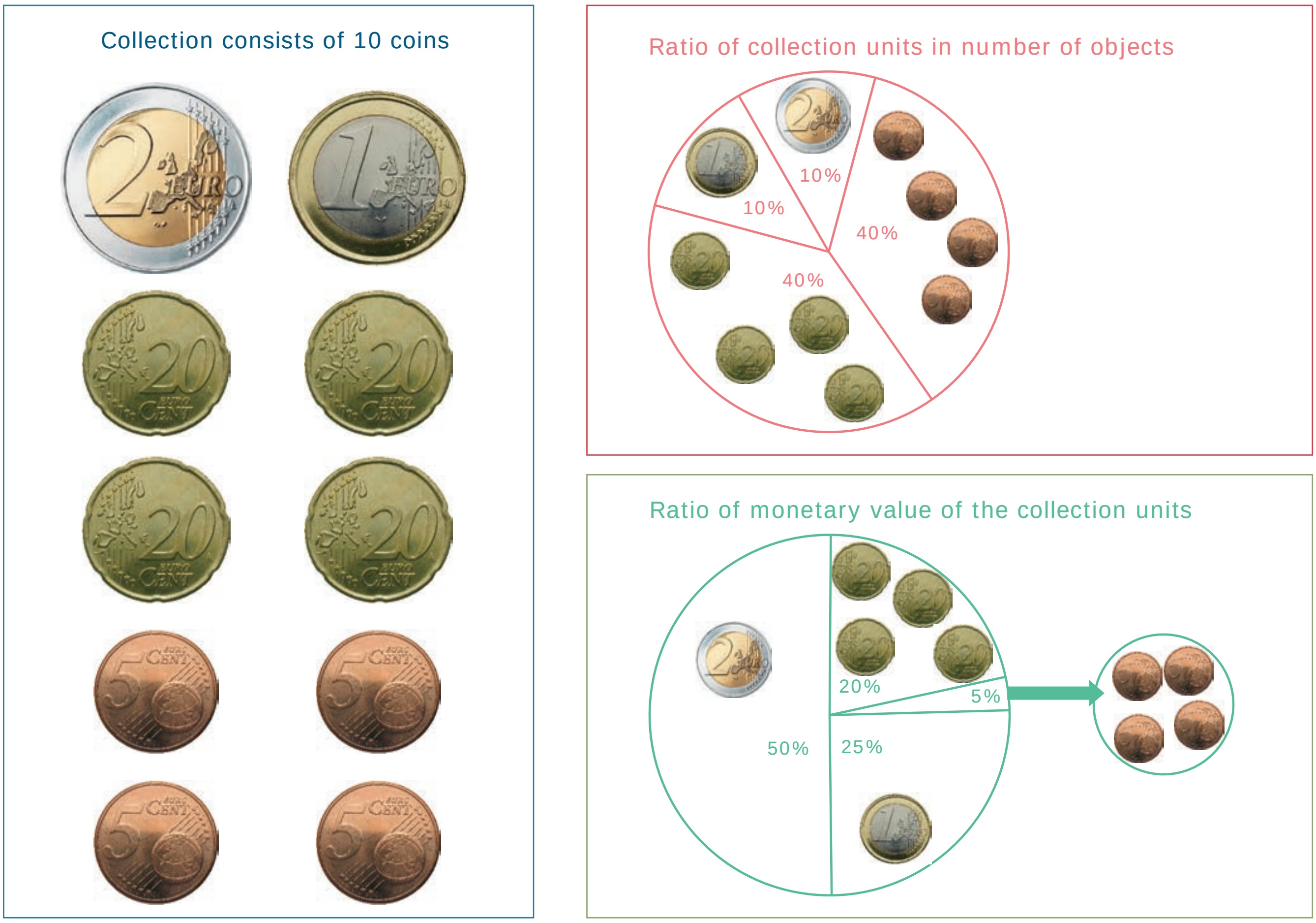


Figure 19. Division of a coin collection into units corresponding to copper, bronze, silver and gold. The red pie chart shows the distribution based on the number of objects, assuming that all objects are of equal value. In that case, the whole collection loses 10% if any one coin is lost. The green pie chart represents the monetary value distribution. Losing a copper coin yields a loss of 1.25% of the total collection value. Loss of a gold coin would represent a 50% loss of the total collection value.

MR score	State	Description
15-13½	Catastrophe	All or most of the total collection value is in danger of being lost within a few years. Only possible if a collection has come to be in a very dangerous situation, such as a completely unsuitable building or in an area prone to natural disasters or human crises.
13-11½	Top priority	Significant loss of total collection value or total loss of value of a large part of the collection in a decade or less. Often the case with fire and security risks, or with fast degradation processes such as exposure to high doses of light and UV radiation or to moist conditions that cause extensive mould growth.
11-9½	High priority	Moderate loss of value to a number of objects in a few years, or significant loss of value in a few decades. This happens in, for example, institutions where preventive conservation receives little attention or where a number of valuable objects are sensitive to theft or another risk that causes total loss of value.
9-7½	Average priority	Moderate loss of value of the collection over a number of decades. These scores are normal when measures have been taken to improve high priority risks.
<7	Low priority	The collection loses a small part of its value over a few centuries. On the whole, this describes risks that are kept low through regular maintenance. If there are higher-priority risks, it may be that the relative value of the objects subject to these risks has been assessed as very low.

Table 9. Description of the magnitude of risk scores

Step 5 ABC track – Evaluate risks

After the A-, B- and C-scores for the different risk scenarios have been determined, the team can compare the magnitude of the risks, categorise and rank them. The risk magnitude calculated in this way can be visualised in a vertical or horizontal bar chart (Figure 20). For each scenario, the A-, B- and C-scores can be stacked so that the height or length of the bar represents the total magnitude of risk for that scenario, while the individual contributions of the A, B and C scores are also visible.

Indicating the 'lowest possible' and 'highest possible' scores provides an indication of the uncertainty of the assessment. The most pragmatic way to get the highest possible MR is to sum the highest possible A-, B- and C-scores (likewise, for the lowest possible MR, the lowest possible A-, B-, and C-scores are summed). The distance between the highest and lowest possibility gives a measure of the uncertainty. Appendix 3 provides an evaluation form.

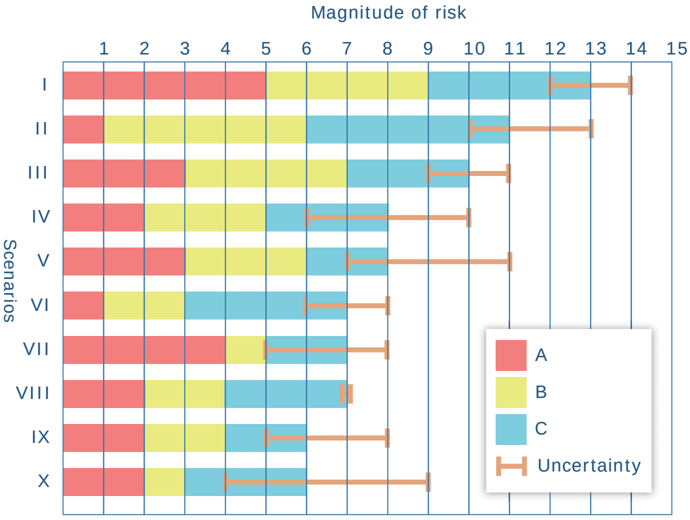


Figure 20. Example of a stacked horizontal bar graph ranked according to the total magnitude of risk and showing the individual contributions of the A-, B- and C-scores and the uncertainty.

Interpretation of the results and risk graphics

The result of the risk assessment can now be interpreted and evaluated. For this one has to consider the magnitude of risk, urgency, impact and uncertainty. Together they determine the priorities and the type of action to be taken.

Magnitude of risk

The first thing to look at when interpreting the result is the magnitude of the risks that have been identified and their ranking compared to each other. The magnitude of risk can be associated with a typical priority for reduction, as shown in Table 9.

Urgency

The A-score indicates how soon a certain loss of value is to be expected and therefore determines the urgency with which action is required. A process that leads to loss in about 100 years has lower priority than one through which value is lost in the short term. For events it is trickier. Although a risk with a probability of recurrence every 100 years is less likely than an event with a probability of recurrence every 10 years, both could happen tomorrow. Although likelihood will influence urgency, for events consequence is equally important. Risks with a low probability and a large impact are comparable to those with a high probability and a small impact.

Impact

The B- and C-scores together indicate how great is the expected impact for the collection. A risk with a low probability but a large impact will have a relatively high magnitude of risk. When contemplating measures to reduce the risk, it is most likely that little can be done to lower the probability, so it is best to focus on limiting the impact. These risks include those for which planning and practising an emergency response is important.

Uncertainty

The uncertainty in the assessment determines if action needs to be taken and the type of action required. A high risk with a small uncertainty needs to be reduced in the short term. For an average risk with great uncertainty, more certainty is needed before reducing the magnitude of risk. In that case, it is worthwhile first to invest time and money into research or to gathering more information and data. Figure 21 shows the most efficient approach for different combinations of magnitude of risk and uncertainty.

Clustering risks

When it is apparent which are the greatest and most relevant risks, it is useful to investigate whether there are risks that have their origin in the same source, or whether they reach the collection through the same weak spot in the pathway. In that case, taking away the source or improving the weak link in the pathway can reduce these risks simultaneously, which will make it a (cost) effective measure. It can also make sense to look at which risks have the same effect. In that case, it can be more effective to take measures near the object or collection instead of dealing with everything at the sources.

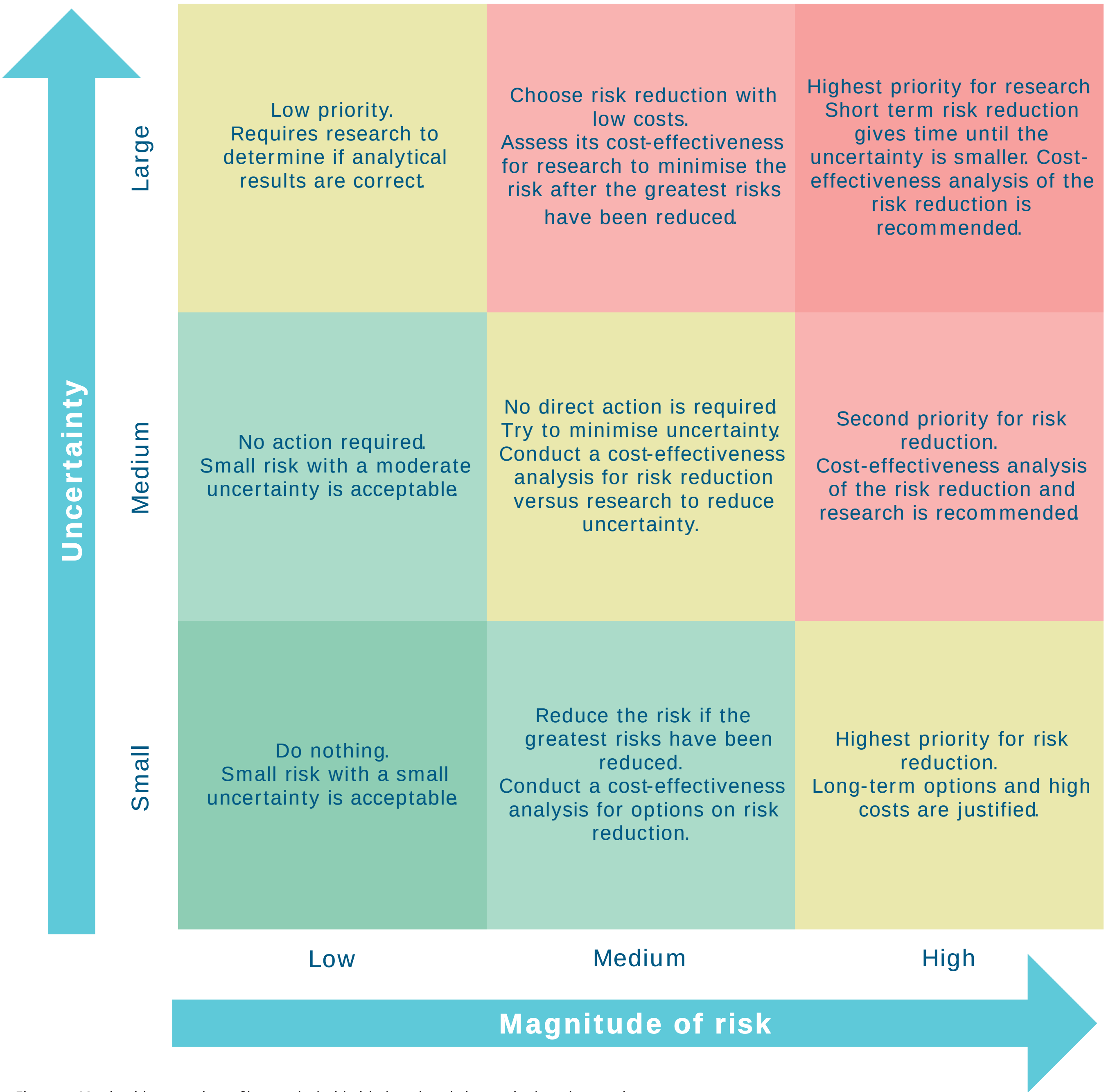


Figure 21. Matrix with suggestions of how to deal with risks based on their magnitude and uncertainty.

Communication and monitoring

Discuss the outcome of the risk assessment with all those involved. Working *together* to decide what the most important risks are, to cluster risks and to think about options for risk mitigation, creates a wider understanding and builds support for further actions. Make sure that risks that are low because of mitigation measures that are functioning well are recognised, as they prove the usefulness of these measures. Also consider if measures were taken in the past that have become outdated or ineffective. Check whether measures have been implemented in the past based on an overestimation of the risk or simply to meet best practice and which, with current knowledge, may be unnecessary, allowing savings to be made.

Do a 'reality check'. Does the outcome correspond with everyone's gut feeling and professional experience? If not, what is the reason for this? Has this rational approach to risk assessment given a better understanding or do the results not match reality? Was an incorrect score added somewhere by accident?

Do a 'consistency check'. Are the results in agreement with each other? Are the results consistent and are they correctly ranked with each other? Remember that the risk graph has a logarithmic scale and that a one-point difference between two risks means that one is ten times greater than the other. If the ratios do not feel right, then go back to the analysis of the risk scenarios and see if the scores are justified. It is perfectly possible that opinions have changed in the course of the process, which might not have been applied consistently throughout the scenarios. Similar damage with equivalent loss of value should have a similar B-score in all related scenarios. Maybe somewhere along the line something went wrong with the logic?

Do a 'matrix check'. Compare the final bar chart with the rough estimates in the risk matrix made earlier. Do both outcomes show a similar pattern, or is there a shift due to a thorough analysis of the risk scenarios? Are those shifts justifiable and do they lead to new ideas about what works or does not work well within the organisation?

Do an 'uncertainty check'. How big are the bars that indicate the uncertainty? Remember that every full point of uncertainty implies that a risk can be ten times larger or smaller. When the uncertainty of all the risks is high, then the risk matrix might give a better impression of the outcome than the pseudo-accuracy of the risk graph.

Finally, do an 'application check'. Relate the outcome of the risk assessment with the purpose and questions formulated at the start. Do the conclusions from the risk assessment answer the questions? Have the right risks been considered? Has anything been overlooked?

Done or continue?

The risk assessment is now completed and the results have been interpreted. This is the starting point for thinking about options for reducing the relevant risks. Celebrate your success! At this point the team can take a break if required. The risk graph and the conclusions drawn need to be discussed with others in the organisation, such as management and decision-makers. The advantage of the risk bar chart is that it 'speaks a language' that business-minded partners in the discussion will understand.

Step 6 – Reduce risks

This last step of the risk management process deals with the control of risks identified by both the ABC and the QuiskScan tracks. Different strategies can be chosen. There are options that reduce the likelihood or probability of an event or slow down the rate of deterioration processes; e.g., by removing or reducing sources or blocking the pathway. Alternatively, there are options that limit the impact or consequences by minimising the effect on the object or collection, e.g. by blocking the pathway or by ensuring a fast response when an event takes place.

With risks that have a source over which you have control, that source can be dealt with directly. However, when the source of the risk lies outside one's control (e.g. natural disasters), the source cannot be removed and everybody needs to be prepared for adequate response. Here, preventive conservation, safety and security, facilities management and emergency response go hand in hand.

Options for risk reduction for the different agents of deterioration are described in the chapters that follow. When considering options, the customary principles for the different disciplines have been used, such as the safety chain for fire, the OBE-approach for protection against theft and the Canadian Conservation Institute's *Framework for the Preservation of Museum Collections* (Michalski, 1994). Several levels are distinguished at which measures can be implemented, as well as different steps in the chain where intervention is an option (see the introduction 'Agents of Deterioration and Scenario Schemes').

Effectiveness and costs

Many factors play a role in deciding whether or not to implement a certain option or measure. The effectiveness (degree of risk reduction) and the cost are always important. The cost effectiveness looks at the reduction of a risk as a result of an investment. It can be expressed as the risk reduction per monetary unit, the cost for each percentage point of risk reduction, or the retained value per monetary unit.

Generally, high effectiveness is preferred over low cost. A small reduction of a risk or the reduction of a small risk at low cost has little meaning if there are bigger or more urgent risks. Picking 'low-hanging fruit' can, however, give a satisfying feeling and produce energy to take care of the greater risks. In practice, the costs are usually the limiting or driving force.

Rules of thumb

The following rules of thumb can give some guidance when making decisions.

- Inexpensive measures – large risk reduction = do immediately
- Expensive measures – large risk reduction = make an investment plan, spread costs over a period of time, look for sponsors
- Inexpensive measures – small risk reduction = give a good feeling, but ask yourself if it is really worth it
- Expensive measures – small risk reduction = do not do it

Time horizon, priority and cost effectiveness

The choice of the time horizon (planning period) has an influence on the priority of the risks and their reduction. The choice of the time horizon also has an influence on the cost effectiveness. The longer the time period for the measures you consider, the more the costs are spread over time and the longer it may take before the investment pays off. On the other hand, less expensive options may become available in the future. With a slowly-progressing loss of value, it might be worth waiting. With investments in installations and equipment, one has to account not only for the one-off purchase costs, but also for the annual running costs for energy, maintenance and replacement.

Measures can also introduce risks

Measures that reduce one risk can affect other risks or introduce new risks. They can have a synergistic effect, reducing other risks, but can also have an adverse effect, leading to a (temporary) increase in other risks. Repairing a roof to prevent leakage and reduce water damage brings with it a temporary risk of theft because outsiders need access to the building. At the end of each chapter on the agents of deterioration is a table with examples of relationships between that particular agent and the other agents.

The conclusion – Recommendation, decision, conclusion

The purpose and questions that set the risk assessment in motion require a decision or an answer. The outcome of the risk assessment contributes significantly to this as it helps to identify areas for improvement, to find options for improvement, and to set priorities.

But there are more factors that ultimately determine the decision that is made. Available capacity and resources determine if something will or will not happen. There may be a preference to earmark funding for low-priority options. Political circumstances and personal interests may shift, and not everything follows the path of rationality. The conclusions and recommendations derived from the risk assessment and the options for risk reduction should, therefore, not be seen as golden truths, but rather as goals and arguments in the discussions and negotiations with others.

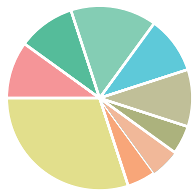
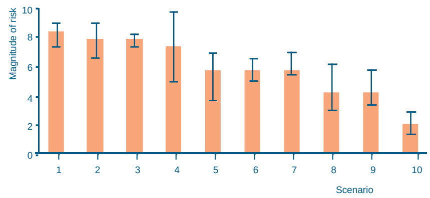
Communication and monitoring

The conclusions and recommendations from the risk assessment form the core for communication with clients, stakeholders, funders and other decision-makers. They must provide the arguments and persuasive power to convince others in making decisions. They should give an answer to the questions and provide a solution to the problems that were the reasons to undertake the risk assessment project. They should enable sound decisions to be made that find support among stakeholders.
Monitoring and review consists of checking if the conclusions and recommendations truly answer the questions and meet the purpose. Evaluate the conclusions and the recommendations with the clients, stakeholders, colleagues and experts who participated in the process. See if they come to any additional conclusions. Have all the questions been answered thoroughly? Does the outcome meet their expectations?
After implementing risk reduction measures, they also need to be monitored for correct implementation and desired effect.

Final report

The final report contains the full description of the process with arguments and results. It documents all thoughts and deliberations for the future. The report also serves as a communication tool with the client and others to underpin the recommendations. It can be very useful to emphasise what currently works well and which risks are small because appropriate measures were taken in the past. This credit can encourage the implementation of further improvements.

Although the outcome of the risk analysis with its colourful graphs, numbers and priorities is a very useful product, the most important aspect of a risk assessment is that the team has worked through the process together. Whether one choses a broad-brush or a more in-depth approach, the fact that everyone has the same understanding of the situation, shares a better insight into the collection, its values and risks, and speaks the same language, contributes greatly to the shared realisation of objectives. Furthermore, the outcomes from the risk assessment are supported by the team.

The process	What to do	The result
Define Context	In this first step the framework is drawn up. Why is a risk analysis conducted? What do we want to achieve? What does it cover and what is the scope? Who are the stakeholders? How far do we want to look into the future? The collection anatomy is mapped out and a value distribution of the collection is made.	A descriptive document describing why the risk analysis is performed, what the goal is and for which collection the risks are determined. A value distribution of the collection. 
Risk Identifi-cation	Draft a list with all risks that are expected to be relevant to your (decision-making) context. This list, separated into manageable units of risks, forms the basis of the subsequent risk management process. Information about incidents in the past as well as other information sources, such as people, situations and literature are used further to develop the risks.	A list with short sentences describing the pathway. Examples (also see Table 1): - (**PF1**) Catering during weekly events leads to damage on door frames and doors. - (**W1**) Filling of mobile humidifiers leads to moisture stains on historical floors. - (**D1**) Misplacement of an object in storage makes it untraceable.
Risk Analysis	After a first rough estimate of the risks, often based on experience and an gut feeling, the rational analysis follows of those risks that are relevant. These are developed further and the probability and effect are quantified. This requires information on - how often and how fast a certain threat occurs, - the susceptibility of the collection, - studying the condition of the collection (with colleagues): do we see anything damaged and when did that happen? - How do we rate the loss in value?	Risks can be calculated by giving a score based on probability and effect (see Figure 3: Rarely = 1, regularly = 2, etc.). The numbers can be totalled and the results of the summation can be compared to each other. 
Risk Evaluation	The magnitudes of risks are visualised in a graph and compared with each other.	An understanding of which risks are the biggest; which have the most effect and which occur most often and quickest. Which are urgent or have a large uncertainty and require more research? An understanding of the priorities.
Risk Mitigation	After the risk evaluation and the interpretation of the results, it is determined how the unacceptable risks can be reduced. In this step, risk reduction strategies are developed for individual risks or clusters of risks. The effectiveness of the measures to reduce risks and the costs are taken into account. In this way, the cost-effectiveness of the options can be determined.	An understanding of effectiveness and costs of possible measures. **PF1** 1. Contract with (new?) caterer, who works with a regular staff and is responsible for the damage done. Costs: ± € 1,000; Great reduction of the risk. 2. Cover exposed/susceptible surfaces with plexiglass. Costs: ± € 1,000; Great reduction of the risk, but also deterioration of historical materials (loss of historical value). 3. Organise vewer events. Costs: ± € 10,000 per year (income shortfall); Moderate reduction of the risk.

Final result
Well-substantiated conclusions and recommendations for measures that can be discussed with stakeholders.

Figure 22. Summary of the risk management process according to the ABC method.

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We have applied the QuiskScan method to find a balance between preparing objects for exhibition and caring for the collection in storage. In order to do so, curators and conservators have determined which are the most valuable and which are the most vulnerable objects in the collection, respectively. For the collection of prints and drawings we defined three vulnerability classes. First, are the works fit for storage? If they remain in storage unused, will their condition stay the same or will it deteriorate? Second, are they fit for handling? Can a researcher use, study and handle them? Are the objects strong enough? Thirdly, are they fit for display?

The value of each item could be high, medium or low, while the vulnerability could be 'fit', 'maybe' or 'not fit'. Simply determining the value of an item, and to which class it belonged, led to interesting discussions within the team, as everyone has their favourite objects in the museum. Arguments regarding the artistic value, historical value, ensemble value and social value had to be agreed upon. By weighing up all the arguments, we were able to set priorities for conservation. First, we addressed the group in which we had placed the most valuable and vulnerable objects. For example, this year we will make our Dutch and Flemish drawings fit for storage by re-housing them into better quality material. Next year we will work on making a collection of ephemera fit for display. Additionally, and unexpectedly, this approach proved of interest to our sponsors – a not insignificant outcome. Some find it special to support the restoration of Rembrandt's work, while others prefer another artist or genre. Sponsors of the British Museum find this direct support more appealing than simply handing over a sum of money. Now, they can link their name to a specific project in a way that most find more recognisable.

Indoor climate control often requires technical installations that take up much space and use much energy

Agents of deterioration and scenario schemes

Agents of deterioration

Practice shows that almost all risks to the preservation of collections can be connected to one of the ten agents of deterioration (see Figure 23). The agents of deterioration were formulated in the late 1980s by Stefan Michalski of the Canadian Conservation Institute in connection with the *Framework for Preservation of Museum Collections* (Michalski, 1990, 1994; CCI, 1994). He distinguished nine material, tangible agents of deterioration: 'Direct physical forces', 'Thieves, vandals and displacers', 'Fire', 'Water', 'Pests', 'Contaminants' (later renamed 'Pollutants'), 'Radiation', 'Incorrect temperature', and 'Incorrect relative humidity (RH)'. In the 1990s Robert Waller of the Canadian Museum of Nature, while developing his Cultural Property Risk Analysis Method (CPRAM), added the tenth, non-material, intangible agent of deterioration: 'Loss' (which was later renamed 'Custodial neglect' and finally 'Dissociation') (Waller, 1994, 2003). Table 10 lists the ten agents of deterioration with the names used in this publication and a brief description of each.

In recent years, experience gained from risk assessment for contemporary art installations has led to the consideration of agents of deterioration that do not fall directly under the existing ten, such as computer viruses and the failure of electronic systems, 'loss of value due to incorrect interpretation during reinstallation' or 'incorrect functioning of an artwork resulting in a visitor experience that differs from the artist's intention'. Sound can be too loud or too soft or tuned incorrectly, monitors and lights can be too bright or too dim, or something can rotate at the wrong speed. These could be considered as dissociation of presentation from original intent.

The ten agents of deterioration provide guidance when thinking of risks, but nothing stops the user from adding other agents when this proves necessary or useful. Classifying the agents of deterioration should help to identify all possible risks and the causes of 'all the things that could go wrong', and offers a structure to facilitate discussion and team working. It is not about placing the risks in the right box, but the boxes and their inter-relationships should inspire the process of thinking of a comprehensive and broad range of risk scenarios.

In the chapters that follow, the agents of deterioration will be discussed individually. The most common sources, pathways and effects are described, and information is given on probability and frequency of events, rates of processes, and material changes

Agent of Deterioration	Description
Physical forces	All forces that act on objects, such as gravity, wear-and-tear, abrasion, vibrations, handling, shock, falling trees, collapsing buildings and earthquakes, and that lead to physical or mechanical damage of objects.
Water	Water in liquid form, which makes objects wet by spillage, leakage, rising damp, condensation or floods.
Fire	The process by which a few or many objects, a room or a building with collections are (partially) burned or damaged by fire, smoke and soot.
Thieves & vandals	People, known or unknown, who intentionally damage or remove one or more objects without authorisation, during or outside opening hours.
Pests & plants	Soiling and material loss in objects due to excrement or feeding by birds, rodents and insects, or by the growth of roots or tendrils.
Light, ultraviolet and infrared	Radiation from sunlight or electric light sources, such as direct sunlight, incoming daylight, lamps for object, background, work or emergency lighting, which are used regularly or occasionally, such as for filming or photography. These can cause discolouring, yellowing, fading, embrittlement or disintegration.
Contaminants	Gases, vapours, liquids and solids, varying from external air pollution to spilt coffee and yellowing adhesive tape.
Incorrect temperature	Temperature that is too low, too high, or that fluctuates too greatly, causing materials to become glasslike and brittle, deform and melt, expand and shrink, or undergo accelerated chemical degradation (oxidation and hydrolysis).
Incorrect relative humidity (RH)	RH that is too low, too high, or that fluctuates too greatly, causing materials to dehydrate and crack, suffer mould growth, expand and shrink, or undergo accelerated chemical degradation (particularly hydrolysis).
Dissociation	Disconnection between the object and knowledge and information about it, between an object and its recorded location, or separation of the parts of composite objects. Caused, for instance, by detached labels, lost documentation or employees leaving without recording their knowledge.

Table 10. The ten agents of deterioration and their descriptions. In this publication Incorrect temperature and Incorrect relative humidity are discussed together as Incorrect indoor climate.

that can occur. In addition, entries are provided that help when thinking about measures to reduce risk. More information and further details can be found in the references to important publications on the subject. Fifield *et al*. (2013) offer a very useful overview of sources of information on preventive conservation and risk management, which is accessible online.

From complex to structured

Events and processes that lead to damage usually take place in a chain of causes and effects. Behind each cause lies another cause. A collection getting wet due to flooding is considered as a 'water' risk. The direct cause of damage is the incoming flood water, but an underlying cause of the flood could be heavy rainfall that causes rivers to overflow, which may in turn be a result of climate change due to global warming because of human activities. Many of the underlying causes are beyond our control. The ten agents of deterioration structure these complex chains of cause and effect at a level we can influence. They help connect risks to causes that we can mitigate (Figure 23).

Scenario schemes

In this publication the agents of deterioration are described separately in a way that best supports the identification, analysis and reduction of the risks. The chapters on each agent start with a scheme in which risk scenarios are structured according to generic sources, pathways and effects, the so-called 'scenario scheme'. The scenario schemes zoom in on the right-hand part of Figure 23 and focus on those parts of the risk scenarios that collection managers can influence (Figure 24).

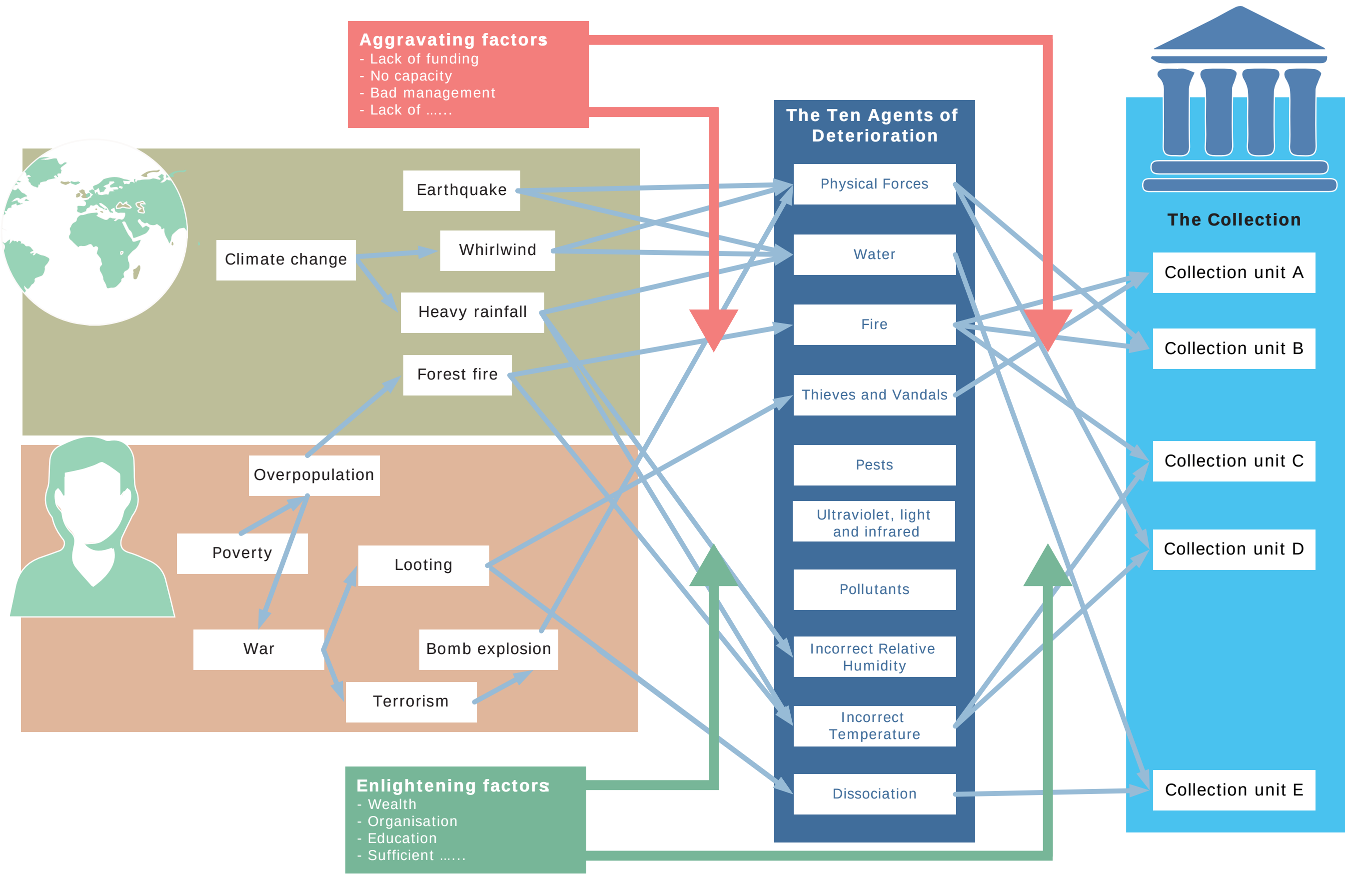

Figure 23. Representation of the complexity of risks with examples of chains of cause and effect that eventually lead to damage to the collection. Almost all the chains pass through one or more of the ten agents of deterioration.

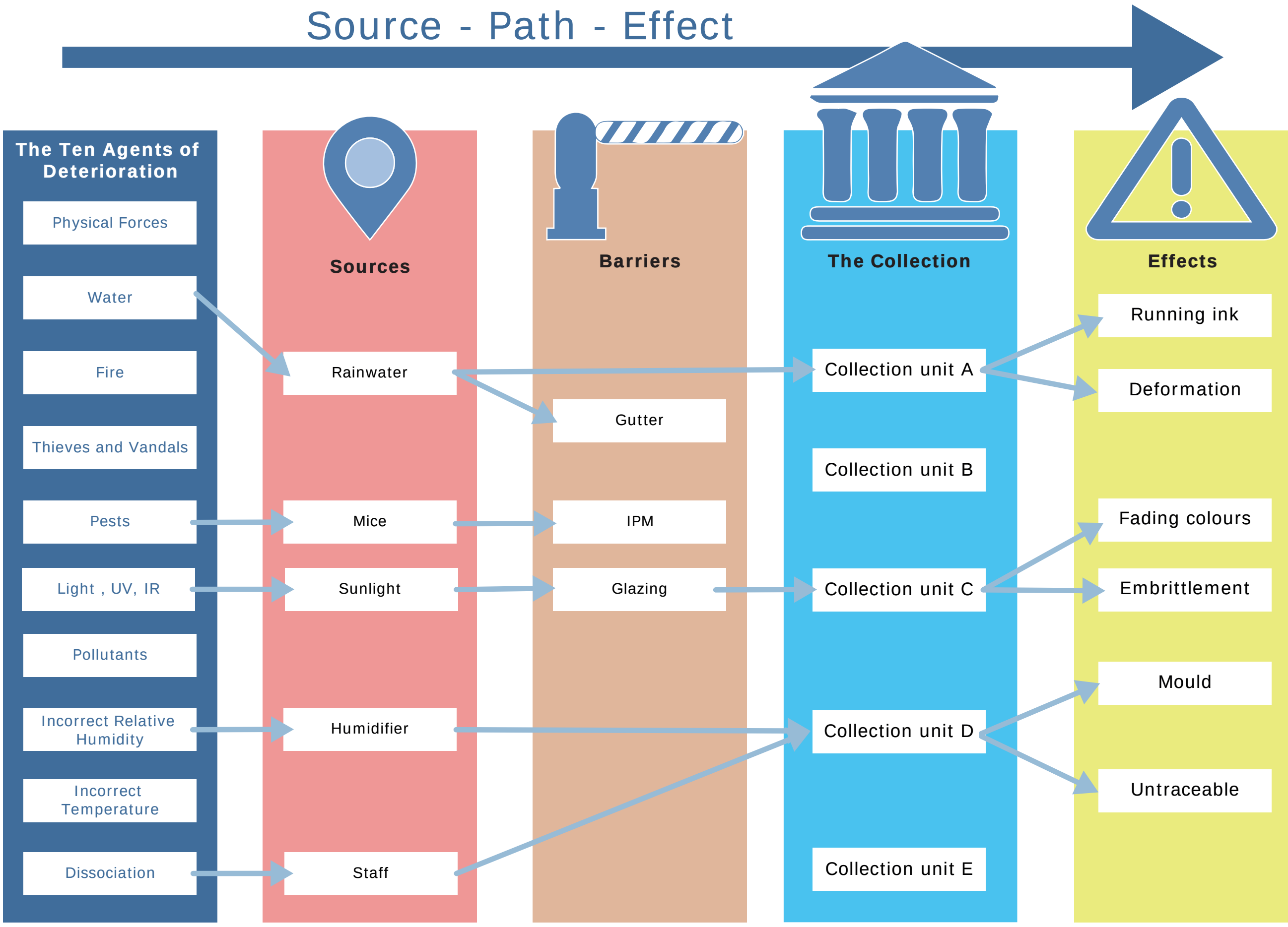

Figure 24. The scenario schemes focus on the sources, pathways and effects that collection managers can influence; the right-hand part of Figure 23.

Layers around the object

Threats always exist in the surroundings in which an object or collection is located. Those surroundings consist of one or more layers around the object. From outside to inside these can be: outside world, museum grounds, building, rooms within the building, storage and exhibition furniture, packaging and coating on the object itself (Figure 25). Instead of 'layers' we speak of the 'levels' at which we can take measures.

The outside world is generally beyond our control, but from the perimeter of our own grounds inwards we can take control. An object placed outdoors may have only a small space surrounding it, bounded by, for example, a fence, base or plinth, while a collection in storage may be surrounded by all the layers listed above. The layers or levels relate to the 'control levels' of the *Framework for Preservation of Museum Collections* (Michalski, 1994). The concept of a 'zone' is also often used. The zone includes all the connected areas or spaces in which the exposure to, and effect of, an agent of deterioration may be similar.

From source to object

The scenario schemes represent the collection in its surroundings in a schematic manner (Figure 26). These schemes correspond to slices through the layers in Figure 25. Instead of the abstract scheme shown in Figure 26, the scenarios can also be drawn on a floor plan or a cross-section of the building. The most important thing is that they help to visualise the possible risk scenarios by mapping or plotting the sources, pathways and effects.

Sources may be found in every layer; for instance, fire due to a short-circuit in a room, theft by a burglar who must first cross the grounds and then enter the building, or fading of an object due to lighting in a showcase. In the scenario schemes, the sources are indicated as red boxes. For each agent of deterioration the most common sources are grouped systematically. Every box represents a number of specific causes.

The pathways from the different sources to the object or collection are represented by arrows. The arrows visualise, for example, the path taken by external air pollution that enters the building and makes its way to the object, the manner in which sunlight enters and falls on the object, how leaking water flows to an object, or the route taken by a thief to enter and subsequently escape with an object.
The most common effects of the material and non-material changes that can be caused by an agent of deterioration are described in the orange boxes. Those changes and the resulting loss of value will depend on the level of exposure to the hazard. In turn, that exposure depends on the pathway, the various layers that need to be crossed and the barriers that need to be passed. Sunlight that enters through windows with UV-filters and screens will cause less fading than when it can enter unobstructed.
The barriers are usually the separations between the layers, which (depending on the specific situation) are either impenetrable or partially penetrable, so that they reduce the effect of the hazard. The barriers can be physical – part of the building's construction, such as roofs, walls, doors and windows, or containers for the object, such as showcases, cabinets and boxes. But these barriers can also be installations or electrical equipment, such as air handling and climate control systems, fire and water detectors, or security cameras. Finally, there are organisational or procedural (non-physical) barriers, such as inspection procedures, quarantine for pests and moulds, security inspections, alarm response, cleaning, and emergency preparedness and response.

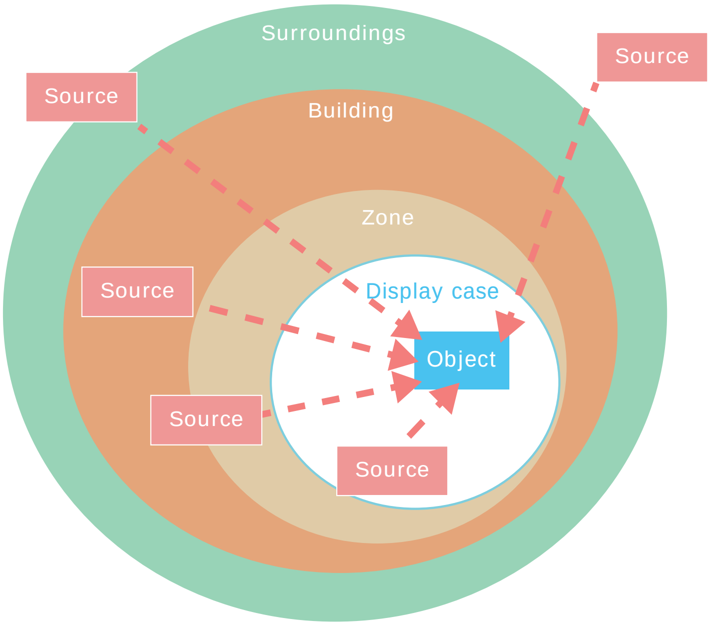

Figure 25. The different layers around the object or collection: grounds, building, room or zone, storage and exhibition furniture, and (packaged) object.

Identifying risks

A risk scenario answers the following questions: from which source does this risk come?; how does the agent of deterioration reach the object?; and what happens to the object? There are three ways to develop scenarios. In practice, all three are used simultaneously when identifying risks.

- **From source to effect:** the agent of deterioration is followed from the source to the object and the changes that take place.
- **From effect to source:** starting with an unwanted effect in mind, and taking the object's vulnerability to the agent into account, possible sources are considered and the pathways are followed back to those sources.
- **Via weak barriers:** taking the weaknesses of barriers as a starting point, pathways are analysed to see where an agent is insufficiently blocked. In this way, it is possible to determine if a combination of individual measures forms a well-considered package. For example, fire detection measures are only effective when they are combined with good response to alarms.

Reducing risks: six levels, five steps

In a manner analogous to that used in the *Framework for Preservation of Museum Collections* (CCI, 1994), various protective measures can be taken at each layer or level. They can be arranged according to five steps in an integrated approach.

- **Avoid:** remove source or control at the source.
- **Block:** create physical or organisational barriers.
- **Detect:** inspection and monitoring to see if the two preventive steps above are effective and if a threat can be detected at an early stage.
- **React:** when the risk becomes reality, act fast to confine the threat and limit the damage.
- **Treat:** intervene, control the agents, recover and treat the objects; for instance, extinguishing fire, pumping away water, drying the collection, controlling insects.

In the chapters on the agents of deterioration, measures to reduce risks are discussed using these five steps. A number of agents of deterioration have their own approach and jargon, and this guide has attempted to align with these. The security profession, for instance, uses security zones as levels, and measures are classified

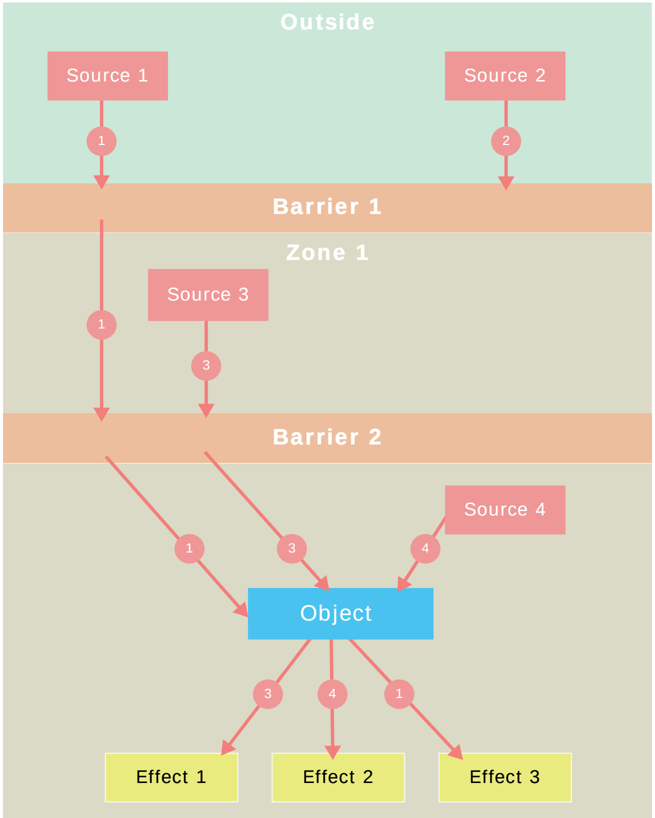

Figure 26. Abstract scenario scheme in which three layers are shown with two barriers separating the layers. The arrows that link a source to a particular effect, via the object, sketch a risk scenario. Pathways 1, 3 and 4 pose a risk; pathway 2 is blocked by the first barrier and does not pose a risk.

as: organisation, building physics, electronics and measures to avoid objects being carried off (OBE). They can all be applied using the five steps.

Fire departments use the 'fire safety chain' in which five steps are distinguished that correspond, to a certain extent, to those in the framework: pro-action, prevention, preparation, repression, salvage, aftercare. They also use a level classification: organisation, building, installations, response, extinguishing (OBI).

Working with scenario schemes

First, the scenario schemes can be used in risk identification. They make users aware of the possible sources, pathways and effects, and are the starting point for developing risk scenarios. They also help identify barriers that are present or absent. That makes them very useful in the further analysis of risk scenarios, at the stage when they need to be developed in more detail and it is necessary to determine the effectiveness of barriers clearly. Eventually, they support the risk reduction step, when it comes to taking protective measures and considering which barriers can be erected at each level to reduce the likelihood and consequences of a specific risk.

For a number of agents of deterioration an abstract scenario scheme is provided that is applicable to all situations (e.g. 'Light, ultraviolet and infrared'). For other agents of deterioration, a more detailed scheme has been designed, showing a general floor plan or cross-section of a building that can be adjusted to one's own situation (e.g. 'Thieves & vandals' and 'Incorrect indoor climate').

Designing a scenario scheme for one's own situation

Based on the methodology of scenario schemes one can make an abstract scheme or a tailor-made map for one's own situation. Use the generic schemes presented in the chapters on the agents of deterioration as examples and inspiration.

1. Use a separate floor plan or cross-section of your building for each agent of deterioration.
2. For each agent of deterioration determine which rooms, zones or layers can be identified.
3. Indicate where the objects or collections are located.
4. Draw the sources in the different layers.
5. Sketch the pathways that the agents of deterioration will take from the sources to the objects or collection.
6. Consider what will happen to the objects when exposed to the agent of deterioration.
7. Indicate for each room, zone or barrier which measures have already been taken.
8. Determine how effective these measures are.

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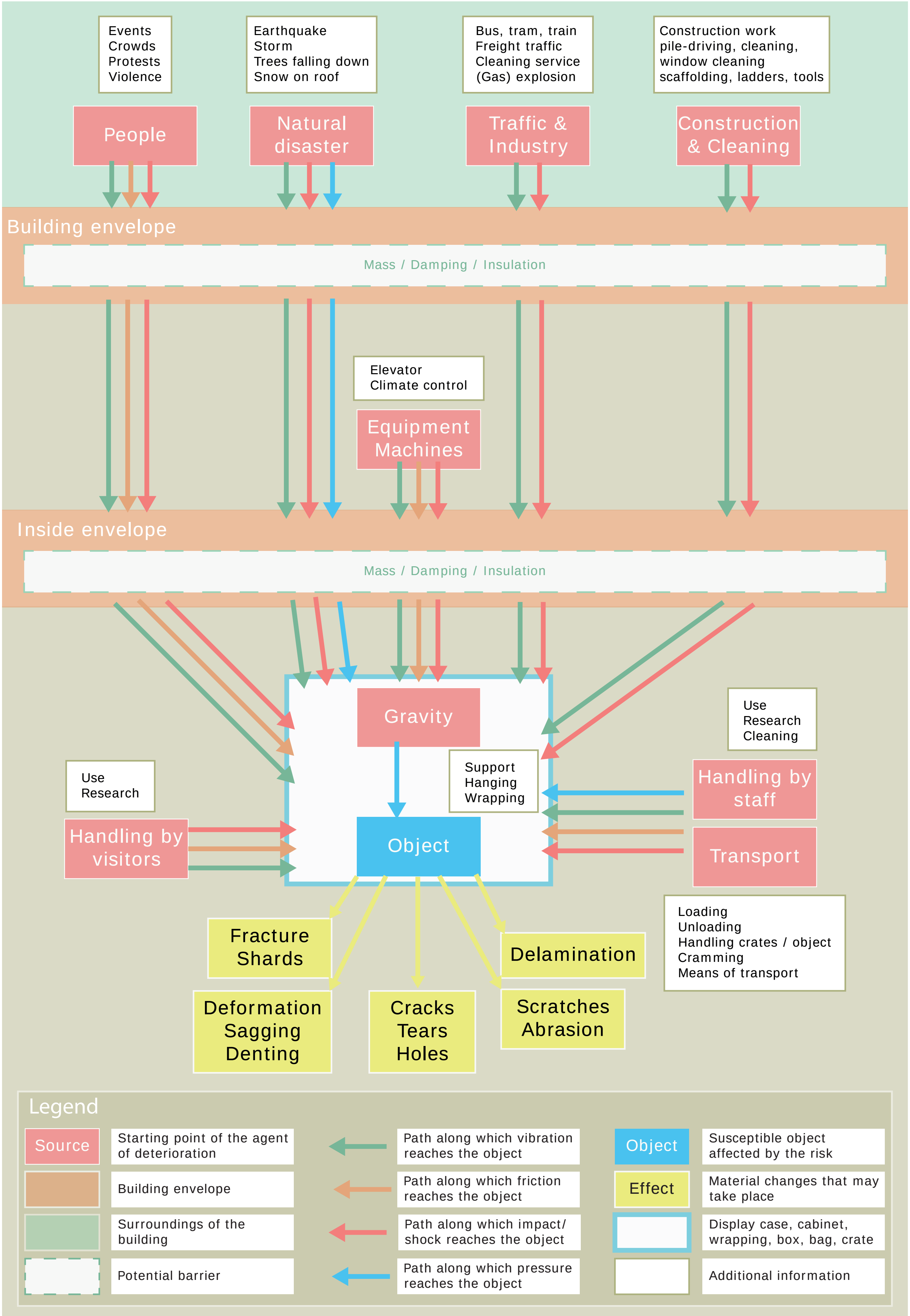
Because the climate control system in the old building of the KB in The Hague needed replacing, we considered adding chemical filters to the new system that supplies the old store rooms. These would remove harmful gases from the air 24 hours per day. The air handling system in our new storage areas had already been fitted with such filters; in many paper-based collections air filtration has been common since the 1990s. But at a time when more attention is paid to environmental impact and to cutting costs we asked ourselves: what exactly will be the effect of these costly filters and are they really necessary for paper conservation? Besides, could one put the money we might spend on air filtration to more effective use for other measures to protect the collection?

Accordingly, a meeting was organised at the KB for all the stakeholders: collection care, building maintenance, facility management and representatives from the Government Real Estate Agency, because the building itself is not owned by the KB. Scientists from the Pollution Pathway Project, which was financed by the Dutch 'Metamorfoze' conservation programme, were also invited. The results, calculations and models from that research project played a decisive role in the meeting, as it had shown that volatile air pollutants have a minimal effect on the durability of paper collections. The main causes of paper degradation are present in the material itself: as a result of their production process, many papers are very acidic and it is this acidity that accelerates ageing. Chemical absorption of pollutant gases by the air handling system is not very effective and does not justify the huge expense. It was decided, therefore, not to place air filters in the system for the old stores. The filters will be retained in the new stores and we will monitor the situation closely. In that way, we can compare the condition of the paper in the stores with and without filtration, and determine whether we made the right decision.



Scenario scheme for the agent of deterioration 'Physical forces'

Physical forces

Scenarios for physical forces

This scenario scheme sketches the most common scenarios for physical forces. It can be presented on an abstract floor plan of a building, which in the context of this publication can be a museum, historic house, storage facility or archaeological site. At the top of the diagram is the outside world and at the bottom the object or collection, which is probably indoors, within a room, and perhaps in a showcase, cabinet or box. The scheme is a cross-section through the layers around the object.

The red boxes represent the sources for physical forces, classified according to the most common causes, such as 'Humans' and 'Nature'. The sources can be found both outside and inside the building.

The grey and orange bars represent the barriers that physical forces meet on their way from source to object. These include building elements of a certain mass and isolating effect, but also measures or procedures that can intercept physical forces such as absorption, suspension, packaging and training in how to handle objects. If the object is outside, there are probably fewer or no barriers.

The coloured arrows indicate the pathways that physical forces take to reach the object. They have four different colours and shapes, representing four different types of physical forces: static load (mechanical stress), shock load or impact (discrete load events), cyclic load (vibrations) and friction (wear-and-tear).

The blue box indicates an object with a specific vulnerability to physical forces; one object might be fragile, while another is not.

The orange boxes at the bottom indicate the different types of effect that may be caused by physical forces, such as scratches, cracks and breakage. Each line drawn from a source to an object via one or more barriers, and its effect, represents the scenario for one specific risk.

Introduction

The agent of deterioration 'Physical forces' describes all mechanical loads that can lead to damage of materials and structures. These range from the smallest deformation (indentation) in a part of the object and barely visible cracking, to material loss, breakage, permanent distortion of the whole object (crushing) and total loss due to a major accident or the collapse of part of a building.

There are different types of physical force and, in practice, more than one can affect objects simultaneously. The four most common are: static load (mechanical, stress), shock load or impact (discrete load events), cyclic load (vibrations) and friction (wear-and-tear).

Figure 27. Deformation of a book due to the influence of gravity and the lack of support (creep)

Static load

Mechanical stresses are the forces that build up slowly and continue to act on the object. These can be tensile stress, pressure or bending stress, whose sources include:

- the object's own weight (pressure exerted by a large sculpture on its base or tensile stress on the upper edge of a hanging tapestry),
- handling objects (pressure from packaging or the method of display),
- piling or stacking objects (pressure on the lower objects), and
- internal stresses in canvases and panels because of a temperature or humidity that is too high or too low (tensile or pressure load).

This type of load distorts, tears or even breaks objects. The extent of damage depends on the magnitude of the force, the duration of the load, the properties of the component materials and the construction of the object (e.g. strength and stiffness of materials and connections).

Usually, the effect of static load is noticeable immediately; as soon as stress is applied, the object changes, for instance, stretching a canvas on its frame. But there are also materials and objects that change shape slowly under constant pressure, such as

Figure 28. Broken teapot after a fall

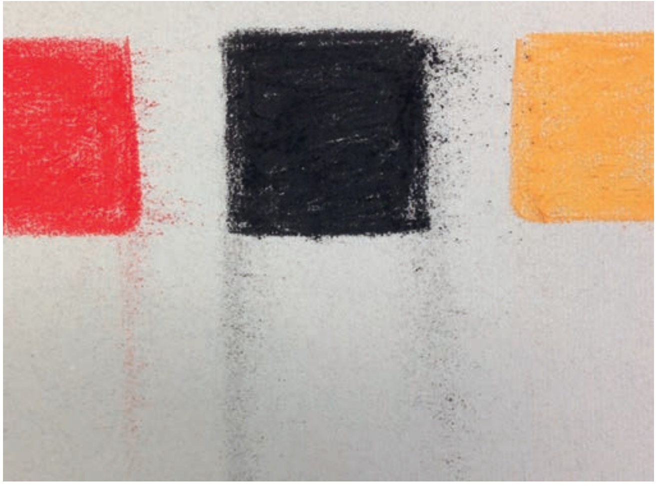


Figure 29. Loss of pastel particles due to vibrations during transportation (photograph: L. Sauvage, Rijksmuseum/TU Delft)

the gradually sagging book that is supported poorly, or the steady deformation of lead organ pipes. This time-dependent change due to permanent mechanical stress is called 'creep' or 'cold flow'.

Shock load

A shock load is a strong force striking in a split-second event. These events might be somebody bumping into an object or letting it drop out of their hands (see Figure 28). During transportation they might result from a rough landing or a bump in the road. While pile-driving can produce shock loads, repeated cyclic pile driving can be considered as an extreme vibration.

The consequences of shock are directly noticeable and depend on the magnitude of the force or the amount of kinetic energy acting upon the object (e.g. the velocity with which the object collides or falls). This energy or shock intensity is often related to the 'g-force', the acceleration due to gravity. The way in which an object succumbs under shock load differs from that under static load as the entire force acts instantaneously. The effects are deformation, indentation, cracking, splitting or fracture, depending on the strength or fragility of the object and its component materials.

Cyclic load

Cyclic or dynamic loads are forces that change over time and repeat themselves. They can be irregular, such as vibrations during transportation (Figure 29), or the result of a heavy rock concert. Footfall from passing visitors can cause objects to 'walk' across shelves or to topple over (Figure 30). The load can also be regular, such as pile-driving (an example of cyclic shock). Dynamic heritage objects, including millwheels, boats, vintage cars and clocks, all have parts that are exposed to (rotating) cyclic load and vibrations,

Figure 30. Fallen object in a display case due to vibrations caused by visitors walking by

while many pieces of installation art also contain moving parts. A cyclic load can also be induced by fluctuating temperature or humidity causing materials to swell and shrink.

Vibrations may cause damage to the objects but, unlike in the case of static load or shock, damage occurs cumulatively and depends on the number of cycles and their amplitude. At first, changes may go unnoticed, but the longer the repeated load lasts the more the material or object weakens, until the fatigue limit is reached and damage occurs.

Another effect of vibration is 'walking' of unfixed objects, sometimes followed by shock when the object reaches the edge of a shelf and falls.

Figure 31. Friction between skin and metal causes a 'polishing effect'; here the cage construction is designed to protect the sculpture

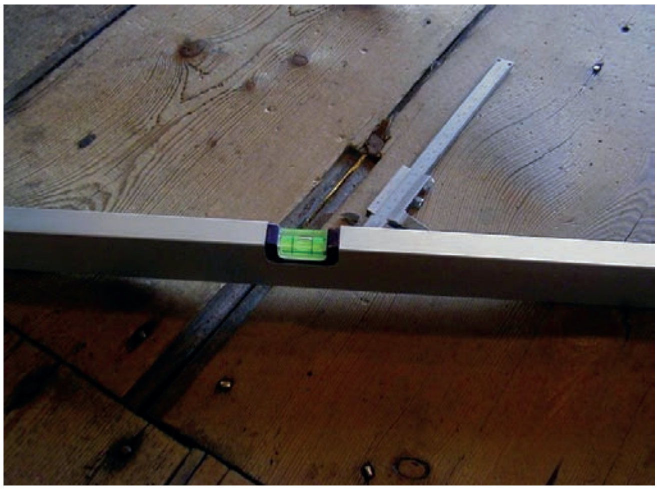


Figure 32. Worn down floorboards at the top of the stairs where visitors turn a corner

Figure 33. Pigment loss due to touching a mask with a powdery paint surface

A particularly dangerous form of vibration is 'resonance'. When the frequency of an external vibration is the same as the so-called natural frequency of the object, vibrations are absorbed and amplified, making the effect much greater. A notorious example is that of the Tacoma Narrows Bridge in the USA, which collapsed soon after its opening in 1940 due to resonance (Tacoma Bridge Collapse, 2013). More information on vibration is discussed under 'Sources'.

Friction

Friction is a force that is generated when there is movement between two touching surfaces. This may damage one or both surfaces, generally the surface of the softest material. The damage is referred to as abrasion or 'wear-and-tear'. Examples of damage due to friction are threadbare carpets, staircase steps worn down by the many visitors to a historic house, alteration of surfaces due to touching (which often has a polishing effect), abrasion of silver upon polishing, scratches from dusting, or wear-and-tear to moving parts in clocks or engines. As with cyclic loads, the damage due to friction is cumulative. The final damage depends on the duration, the extent of load, the roughness and resistance of the two surfaces, and the properties of the materials that move against each other.

Sources – probability and impact

To get a grip on the wide variety of scenarios that can be developed for physical forces, a distinction is made based on the likelihood and impact of their occurrence. There are:

- events that take place rarely with a huge impact (catastrophes),
- events that take place regularly with a moderate to significant impact (incidents), and
- processes that take place continually with little impact in the short term but which, due to their cumulative nature, can ultimately cause great damage.

To make an educated guess about the probability of incidents that occur regularly, the incident log or register of the institution is very important. Supplemented by 'institutional memory' (from employees who have worked for the institution for a long time), it is possible to check how often something has happened in the past. If there is no reason to believe that circumstances have changed, then *this* is the starting point for forecasting how often a similar incident might happen in the future. Obviously, results from the past offer no guarantee for the future.

For events that occur rarely, such as natural disasters or major accidents, the organisation's incident log offers insufficient data. In that case, national or even international data need to be consulted. Examples are the Dutch national incident register (Database Incidenten Cultureel Erfgoed, DICE; RCE, 2015) and the websites of one's own country's national bureau of statistics or meteorological service; these often contain information on large-scale accidents, weather phenomena and earthquakes.

With cumulative processes the question is 'how long before a particular change or damage occurs or becomes visible?' Data to answer these questions come from experiments and research. Several specific sources for physical forces are discussed below, with information on probability and impact of the events and processes that could lead to damage: human interaction, earthquakes, transport, and vibrations due to construction work and festivals.

Human interaction

All actions with and near to objects, bear a risk of physical damage. But since not all physical contact leads to damage, people tend to forget this. The organisation's incident log should register damages and their causes. These records provide information on the frequency of such incidents, their sources and their impact. Centralised data gathering and the anonymous processing of data could generate statistics that can be used by

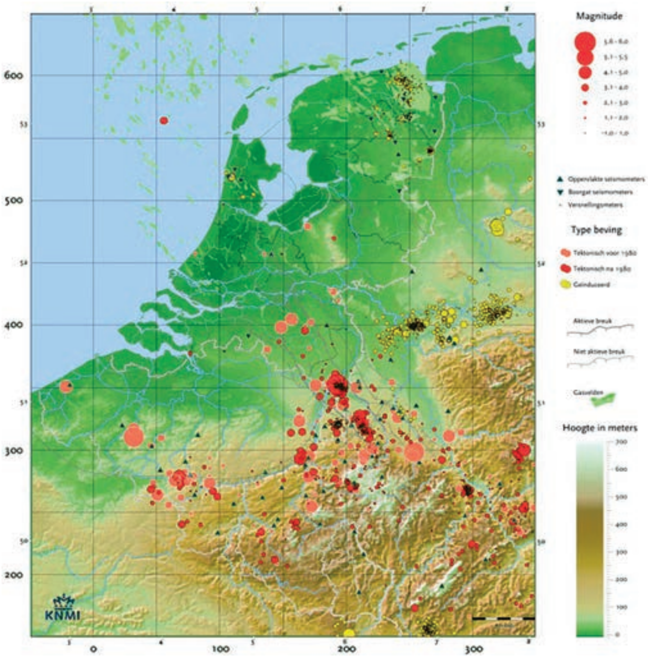


Figure 34. Earthquakes in the Netherlands between 1904 and 2004 (source: KNMI).

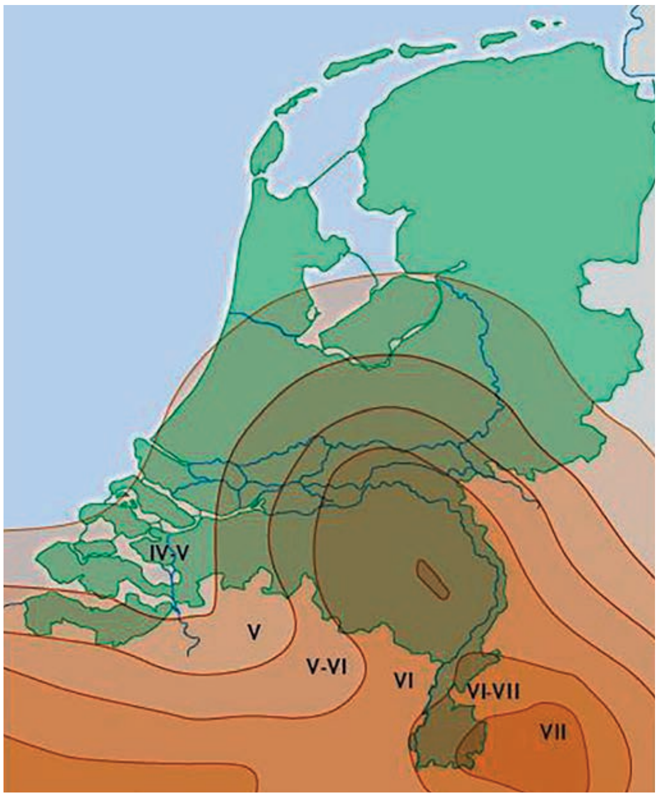


Figure 35. Map of the Netherlands showing the maximum intensity tectonic earthquake that is expected over the course of each 475-year period (source: Haak and Goutbeek, 2005).

Class	Intensity of vibration detected	Damage to building and collections	Equivalent shock on the Richter scale
I	Instrumental	No damage, detected only by seismographs	1-2
II	Feeble	No damage, vibration barely felt, only by sensitive people	2-3
III	Slight	No damage, vibration similar to passing traffic	3-4
IV	Moderate	No damage, vibration similar to heavy traffic, felt by people, rattling of windows and doors, rocking of free standing objects	4
V	Rather strong	Generally felt, sleeping people wake, pendulum clocks stop, suspended objects swing, light objects 'walk', no damage	4-5
VI	Strong Light damage	Trees sway, objects fall, windows break, splits in masonry, damage to unstable and vulnerable buildings	5-6
VII	Very strong Damage	Waves in surface water, church bells ring, cabinets fall over, chimneys break, cracks in walls, damage to many buildings	6
VIII	Destructive Heavy damage	General damage to buildings, weak buildings partially destroyed or collapse, objects are buried	6-7
IX	Ruinous	Damage to foundations, underground pipes break, many buildings are heavily damaged, buildings collapse, objects are buried	7
X	Disastrous	Ground cracks, landslides, damage to dykes and dams, many buildings destroyed, tsunamis	7-8
XI	Catastrophic	Most buildings and bridges destroyed, railway tracks bent, tsunamis	8
XII	Extremely catastrophic	Total destruction, change of landscape, earth cracked	>8

Table 11. Mercalli intensity scale, detailing perceived intensity and expected damage to buildings and collections, with a comparison to the force measured using the Richter scale (after Haak and Goutbeek, 2005; Risicokaart.nl; geography-site.co.uk).

everyone, or serve as a reference point for one's own situation – 'benchmarking'.

The Dutch national incident register shows that the most recorded incidents in museums in the period 2008–2014 were caused by water (63) and accidents (67) (RCE, 2016). The collection suffered damage in 57 of these 67 incidents. The causes of accidents included technical failure (11), bumping against an object (16) and dropping an object (10). Technical failures included the failure of hanging systems, metal fatigue or weak construction of display cases. Another source of damage is people-related accidents, 50 of which were registered in 2013–2104, including tripping (15 incidents) and visitor or staff illness.

Natural disasters – earthquakes

Catastrophic physical forces are often associated with earthquakes. The Netherlands experiences small earthquakes regularly; in the north these result from drilling for gas (with an intensity of 1–3 on the Richter scale) and in the south because of a tectonic fault line (intensities up to 6 on the Richter scale). The earthquake map of the Netherlands (KNMI, 2015a; Faculty of Earth and Life Sciences, 2015) shows past earthquakes and their magnitude. Similar maps exist on a global and national scale, for example IRIS's seismic monitor (IRIS, 2016) and the Munich RE website (Munich RE, 2016).

The website of the Faculty of Earth and Life Sciences at the University of Amsterdam (FALW, 2015) and the Dutch publication *Aardbevingen. Wat beweegt de aarde?* (Haak and Goutbeek, 2005) both contain much useful information, including a map of the Netherlands showing the maximum intensity earthquake expected over the course of each 475-year period, classified using the Mercalli scale, which categorises local impact. In the Netherlands, the maximum intensity expected from tectonic activity is VII to VIII on the Mercalli index. For earthquakes that result from gas production in the north, the expected maximum Mercalli intensity is VI in a small area around the epicentre. Table 11 describes the extent of damage typically associated with each Mercalli intensity. There are many websites with useful information on earthquakes in various languages.

Websites such as the Dutch *Risk Guide in Groningen* provide information on what to do in preparation for, during, and after

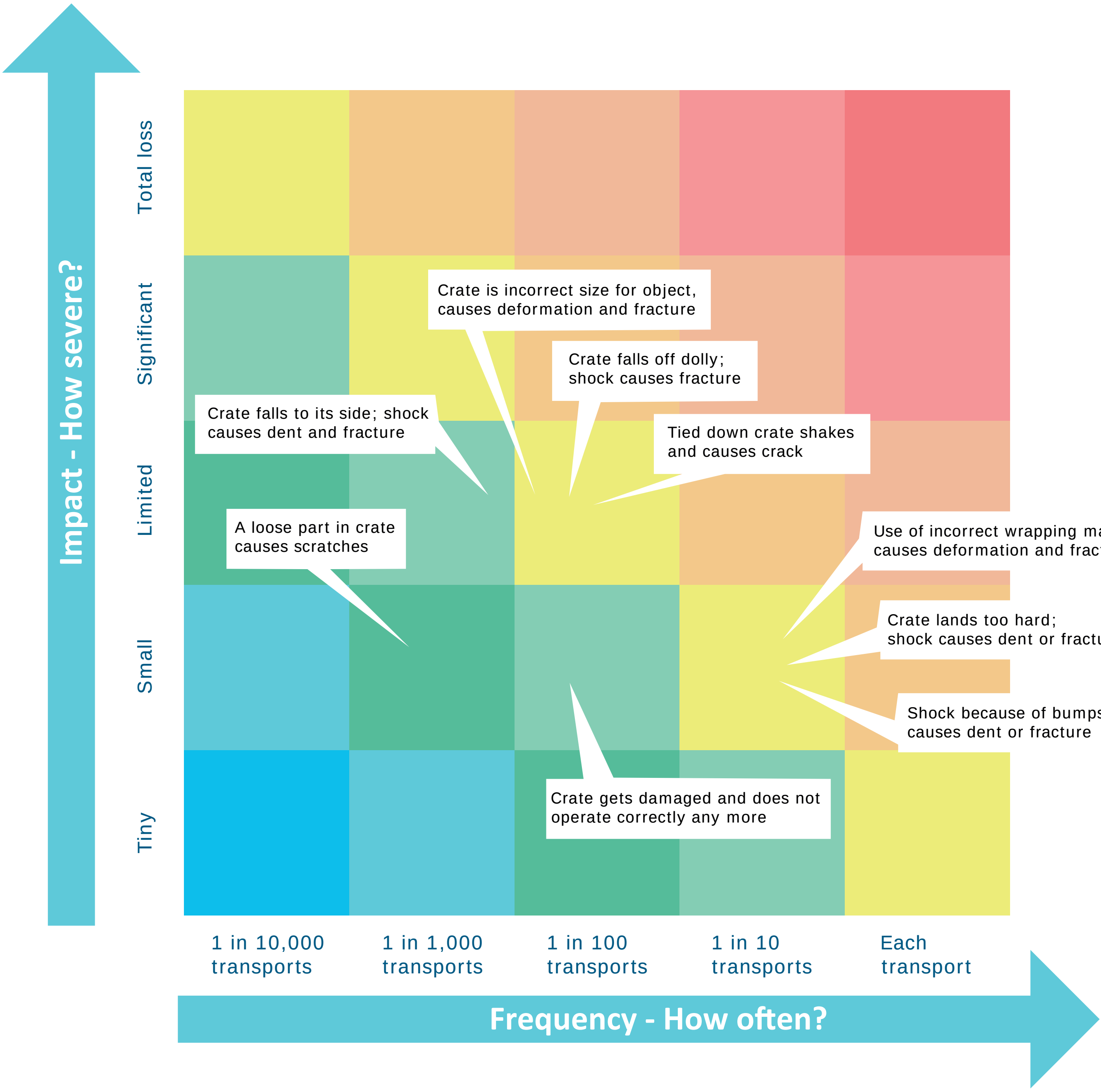


Figure 36. Risk matrix for transportation – indicating how often each different scenario leads to damage and how severe that damage will be. The data are derived from the experiences of logistics employees in various Dutch museums contained in a study into packing crates lead by Marc Bongaarts of the Stedelijk Museum, Amsterdam in 2010–2011.

an earthquake (Risicowijzer Groningen, 2015). The Federal Emergency Management Agency in the USA produces a highly informative publication on assessing and managing earthquake risks (FEMA, 2001). The 'Earthquake Risk Project' of the German Centre for Disaster Management and Risk Reduction Technology has investigated the vulnerability to earthquakes of different types of building and gives an overview of this information on their website (CEDIM, 2009).

Weight of package (kg)	Largest dimension (cm)	Probable drop height (cm)	Mode of dropping	Mode of handling
<10	120	100	On side or corner	A person throws
10-20	90	90	On side or corner	A person carries
20-45	120	60	On side or corner	Two people carry, dolly or forklift
45-70	150	50	On side or corner	Two people carry, dolly or forklift
70-90	150	45	On side or corner	Two people carry, dolly or forklift
90-270	180	60	Roll, topple or fall	Hoist or forklift
<1,360	>180	45	Roll, topple or fall	Hoist or forklift
>1,360	>180	30	Roll, topple or fall	Hoist or forklift

Table 12. Typical drop heights for handling packages and goods depending on their weight and size (after Brandenburg, 1991; Marcon, 2016).

In countries that often experience earthquakes, museums generally have specialised measures to protect their objects against natural disasters. Mitigation measures start with the foundations and construction of the building and continue through to securing objects against shaking, moving and falling. More information can be found in, for instance, Erdik, *et al*. (2010) and Ertürk (2012).

Transportation

Transportation is a process in which many types of risk can be encountered. Experience has shown that when handling or moving objects, physical forces are responsible for the greatest risks. With every phase in the transportation process, a number of different scenarios can be envisaged: de-installing the object, packing, loading, internal and external transportation, transit and transfer, unloading, unpacking, and installing the object are operations that may involve physical forces of all four types. From dropping an object, bumping it against something, vibrating it on a trolley, or over-compressing it in a crate, everything is possible.

Figure 36 brings together in a risk matrix the experiences from those with packing expertise in major Dutch museums. The frequency with which damaging events take place is given on the horizontal axis, expressed as 'once in the number of transportations'. The average impact or extent of loss of value for the affected object is given on the vertical axis. The different scenarios are placed in the matrix according to the pooled scores of the experts. It is worth noting that the data are based on the practical experience of employees with adequate training in professional institutions. As a result, their level of awareness of potential threats and the possibilities for protective measures is probably above average.

The transportation risk matrix shows that shock and impact are generally greater risks than vibration. Paul Marcon at the Canadian Conservation Institute has conducted much research on the most effective methods of packing objects for transport (Marcon, 2015). In summary, he concludes that the best protection against shock is provided by a crate-in-crate system. The object is secured within the inner crate, which is then placed into the outer crate with the appropriate cushioning. The minimum quantity of shock-absorbing material (e.g. polyurethane foam) that is required can be calculated based on the weight and expected drop height of the crate by using cushioning curves, for example those provided by QualityFoam (2016). The Canadian Conservation Institute has developed the PadCAD software that helps simplify protective package design for fragile objects (CCI, 2014). The expected drop height is usually based on a table derived from military practice, which has been adapted and is presented as Table 12. In general, the larger and heavier a box or crate, the smaller the expected drop height, because people do not usually lift heavy crates very high. However, above a certain weight specialised lifting equipment will be used, which increases the drop height. To reduce the risk of dropping small and light objects, they can be packed in larger crates (even if they are oversized), or together with other objects in a large crate.

Vibrations during events, transportation and construction

There is some confusion about measuring vibrations and the interpretation of data. This arises because people in the heritage world often use the words 'shock' and 'vibration' as synonyms, whereas the two are different types of loads. The method of measurement also contributes to the confusion. A vibration logger measures the velocity (m/s) or acceleration (m/s2) to which objects are exposed and records these values over a certain period. A shock meter measures or registers single acceleration events (in m/s2, but usually expressed as a multiple of the acceleration due to gravity (g) – 9.8 m/s2). In the older conservation literature, vibrations were measured with shock loggers that only registered shock events above a particular threshold value. This meant that those vibrations with an acceleration below the threshold were ignored, even though they contributed to the total vibration dosage that would eventually lead to damage. This literature also fails to mention the length of time for which objects were exposed to particular levels of vibration. As a result, no information is available concerning vibration dose. For instance, although Thickett (2002) measured vibration levels, any attempt to relate these to damage and vulnerability of materials is not possible as he did not investigate the cumulative cyclic load acting on the objects themselves.

Although measurements made during transportation reported in the literature provide useful information, especially about shock and impact (Saunders, 1998; Kamba *et al*. 2008), they cannot be used to draw any conclusions about exposure to vibrations. In instances where the acceleration levels were measured on or in crates, they do not indicate to which vibrations the objects *themselves* were exposed, or the cumulative exposure dose. None of the measurements shed light on the types of deformations that resulted or the type of damage these produced. Although Saunders (1998) reported that none of the paintings showed any visible signs of damage after transportation. What one can deduce from these studies is that the greatest acceleration takes place during loading and unloading, and that the acceleration levels of vibrations during air transportation are lower than those that characterise road transportation.

Lasyk *et al*. (2008) measured the movement of painting canvases during transportation, which yielded more pertinent data on the impact of vibrations on objects. Although there are questions surrounding the design of the measuring system, it seems that the canvas moves the most during packing and unpacking, while there is relatively little canvas movement once ‘on the road’. Michalski (1991) studied the effect of vibrations on fresh canvas paintings to determine the level at which they initiated cracks in the paint. Wei *et al*. (2005) studied crack elongation and paint loss in aged, brittle and already-cracked paintings. They exposed paintings on canvas that were in poor condition to music with heavy bass beats and observed after how many beats paint flakes came loose from the canvas. They concluded that one should not stipulate maximum vibration levels during a concert or transportation, but determine *how many* concerts or transportations can take place before the acceptable vibration dosage has been exceeded.

Just as with light, damage due to vibrations is cumulative and depends on intensity and length of exposure. Based on further laboratory studies and measurements made during construction projects in museums and historic houses, a correlation has been made between vibration levels, length of exposure and damage observed. The results indicate that short-term exposure, such as during transportation, handling, building projects of a few months, or a loud concert near the collection, produces a minimal risk if the vibration level remains below 2 mm/s1 (Wei *et al*., 2014).

Pathways and barriers

Physical forces can be transferred directly from the source to the object by direct contact: if someone knocks against an object, holds it or walks over it. The only effective barriers against such contact are display cases, plinths, cords to keep visitors at a distance, containers and trolleys for handling and carrying objects, rugs on the floor, and slippers against wear-and-tear. If physical barriers are impossible, it is necessary to pay more attention to procedures that regulate the number of visitors or improve the handling of objects. Such procedures must obviously be applied and respected.

Vibrations can also be transmitted through materials. Sound vibrations from the outside can be transmitted through a wall and affect a painting hung on that wall. Vibration and shock can be absorbed or attenuated by suitable cushioning and absorptive material, such as suspension systems to hang objects, trucks with air-suspension and cushioning foam in transport crates.

As a result of a single force or a series of small forces, objects can shift, move or ‘walk’ from one place to another. Whether this occurs depends on the friction between the object and the surface; the load must exceed the frictional resistance. The resistance depends on the weight of the object, the size of the ‘footprint’ between the object and surface, and the roughness of the object and surface at their interface.

Objects and their vulnerability

The vulnerability of objects depends on the properties of the materials from which they are made and the geometry and construction of the object. The vulnerability, in combination with the magnitude and the duration of the load, determine the material changes that occur. The level of exposure depends on the extent and effectiveness of any protective measures.

Plaster and marble are strong under pressure, but could break easily after a fall because they are brittle. Paper can easily tear and is sensitive to sharp impact, but it is also very flexible and less sensitive to vibrations. A single sheet of paper has a different behaviour to a sheaf of papers or a book.

The most important features of the construction of an object,

Type of object	**Static load** Long-term force, which is smaller than the strength of material or object: stacking, hanging, sagging	**Shock load** Discrete force acting with high velocity: falling, collision. A drop of 1 m onto a hard floor will cause the object to:	**Cyclic load** Cyclic force that accumulate with time: vibration, handling, oscillating climate	**Friction** Movement between surfaces in contact with each other: abrasion, walking, wear-and-tear
Thin glass, crystal or ceramic (glass, vase, window, sculpture, tableware) Thin, brittle, hollow	Breaks when pressure is greater than material strength	Crack or break	Can resonate and 'walk' or shift on smooth surfaces	Will scratch in contact with materials of Mohs hardness > 6–7
Thick glass or ceramic (solid object, tile) Thick, brittle, solid	Breaks when pressure is greater than material strength	Chip or crack	Can 'walk' or shift on smooth surfaces	Will scratch in contact with materials of Mohs hardness > 6–7
Cannonball Regular, closed form, solid, flexible		Flat dent in ball, dent in floor	Can roll away	Will scratch in contact with materials of Mohs hardness > 4
Metal sculptures Irregular open form, protrusions, solid, flexible	Protruding parts can break off when force exceeds strength of construction	Permanent deformation or fractures	Fatigue in protruding parts, 'wobble' of parts or whole object	Surface polished by soft materials, scratched by hard materials
Organ pipe Hollow objects made of flexible, thin metals	Deformation with time (creep) especially in heated spaces	Dent upon impact of pointed or blunt object		Lead is scratched by materials of Mohs hardness > 1.5
Relatively fresh paint on support Flexible materials, well-adhered layers	Flattening of impasto	Deformation or cracks upon impact with pointed object		
Old paint layers in good condition (paintings, furniture) Brittle, well-adhered layers		Craquelure upon impact with pointed or blunt object		
Old paint layers in poor condition (loose, flakes) Brittle, poorly-adhered layers		Paint loss upon impact with pointed or blunt object	Paint loss due to vibrations	Paint loss due to friction
Pastels, lean paint Poor adhesion to support		Loss of pigment particles	Loss of pigment particles due to vibrations	Loss of pigment particles due to friction
Books (upright, flat) Bound construction, thin layers, flexible	Deformation with time (creep) when poorly supported	Deformation and possible torn binding		
Brittle paper (acidic, ink corrosion) Single sheet, thin, brittle	In time folds will crack	Folded parts may break if force is large enough	Tears upon handling if sheets or pages turned regularly	Breaks under friction
Plant fibres (basketry, thin wood, ethno-graphic objects) Construction, woven or plaited, flexible	Deformation with time (creep) when stacked or filled with heavy load	Deformation		Material loss under friction, wear-and-tear
Textile (tapestry, carpet, clothing, upholstery) Construction, woven, knotted, flexible	Deformation with time (creep) under own weight if insufficiently supported	Can tear if knocked when stretched on frame		Eventually wears down
Hard plastic Brittle	Breaks when pressure is greater than material strength	Chip or crack	Crazing upon cycling of moisture or heat (primary cause is incorrect climate)	Scratches in contact with harder material, can wear down

Type of object	**Static load** Long-term force, which is smaller than the strength of material or object: stacking, hanging, sagging	**Shock load** Discrete force acting with high velocity: falling, collision. A drop of 1 m onto a hard floor will cause the object to:	**Cyclic load** Cyclic force that accumulate with time: vibration, handling, oscillating climate	**Friction** Movement between surfaces in contact with each other: abrasion, walking, wear-and-tear
Soft plastic Flexible	Deforms with time under pressure	Dent		Scratches in contact with harder material, can wear down
Rubber ball Solid, flexible	Deformation while under pressure	Bounces		
Constrained wood (panel, furniture, marquetry) Mechanical construction of swelling parts	Breaks when pressure is greater than material strength	Deformation of construction, cracking or chipping (especially corners)	Cracks in response to large RH fluctuations (primary cause is incorrect climate)	Abrasion under friction
Good adhesive bond Strong construction, flexible	Deformation or failure when force is greater than adhesive strength	Cracking if the adhesive bond is stronger than the object itself		

Table 13. Examples of objects and their vulnerability to the different physical forces

are the connections between materials, protruding parts and whether it is solid or hollow. Objects with weak connections are particularly sensitive to all types of forces, for instance pastels and painted surfaces with matt, dry or loose paint. In addition, large objects that seem to be heavy and solid can have protruding parts with weak connections, as is often the case with skeletons and contemporary art installations. Table 13 shows the vulnerability to different loads of a number of types of objects and materials.

Options for risk reduction

The different situations in which physical forces can lead to damage have specific solutions that cannot all be discussed here. The basic strategies are appropriate support to reduce the damaging effects of static load; cushioning and absorption of shock and vibration; and soft contact surfaces or greasing to alleviate friction. Physical forces that result from human interaction – such as handling objects, maintenance works and object treatment – require, above all, procedures that state clearly how to handle objects responsibly and training in appropriate handling. Physical forces resulting from building works require procedures that are agreed with external partners and based on acceptable levels of shock and vibration. At the same time, as a precaution, vulnerable objects should be moved temporarily to a safer place. As discussed above, there are many options for cushioning shock and vibration during transportation (Figure 37). To avoid objects moving across shelves or plinths, rough surfaces, 'museum wax', 'museum putty' and slip-resistant underlays can be used (Figure 38). To secure objects to protect them in earthquake regions, various fixings have been devised (Figure 39). The general approach that is used to reduce the risks from physical forces is based on their division into the five types of mitigation measures used in the integrated approach, and the steps in the *Framework for Preservation of Museum Collections* (CCI, 1994). This format can be used to brainstorm solutions for specific scenarios and situations, see Table 14.

Rules of thumb for determining the magnitude of risk for specific risk scenarios

Because there is currently insufficient quantitative information on the impact of physical forces on museum objects it is difficult to make an accurate assessment of the magnitude of these diverse risks. Good dose-effect studies for vibration have only been published quite recently and the impact of static load and shock load on objects is based mainly on experiential rather than experimental data.

To predict the degradation processes resulting from physical forces such as pressure, friction and vibration, experiences with one's own collection are often the best starting point. Comparing condition reports at different times may reveal changes. If the level of protection has not changed then the simplest approach is

to assume that degradation will continue at the same rate. A floor that has worn down by 1 cm over the last century will probably lose another 1 cm in the next 100 years if the exposure remains the same. An organ pipe that has sagged somewhat over the last century will continue to do so in the following century.

For discrete incidents that cause a shock (a fall or collision) it is necessary to look at how often these occur within the organisation and the average effect they have. Accidents that involve only one or a few objects generally lead to a small loss of value across the entire collection, but they could have a great impact on the reputation of the organisation. Even if their likelihood is small, incidents that involve a large part of the collection (disasters such as earthquakes, building collapse or an explosion) may lead to a great loss of value for the entire collection and thus have a huge impact.

Figuur 37a (top) and b. When appropriately packed in a box with cushioning foam, a raw egg in a glass survives a drop from a height of 1m

Figure 38. 'Museum putty' used to stick objects to a shelf (source: Preservation equipment)

Figure 39. Objects secured to protect them against the impact of earthquakes

Relationship with other agents of deterioration

Measures that reduce one risk can have side effects on other risks. They can have a positive synergistic effect, reducing the effect of other risks, but they can also have a negative effect leading to a (temporary) increase of other risks. Installing a security system involves handling objects, tools and equipment, which can result in objects being knocked over. Keeping visitors at a distance to avoid contact with the objects also reduces the risks of contamination, theft and vandalism.

Agents of deterioration may also act consecutively. Infestation by woodborers may weaken an object causing it to collapse under physical forces. When a space is evacuated during a fire, objects may be damaged physically.

Examples of the relationships between 'Physical forces' and other agents of deterioration are listed in Table 15.

Step	Static load	Shock load	Cyclic load	Friction
Avoid	Do not stack objects on top of each other. Support objects appropriately. Use appropriate hanging construction and support.	Train staff in handling objects. Avoid contact with visitors. Provide enough room to manoeuvre. Secure objects from falling.	Agree on maximum allowed vibration levels. Move objects (temporarily) to a low vibration area. Ensure a stable climate.	Avoid contact with harder surfaces. Maintain moving parts regularly.
Block	Place objects in separate packaging that can be stacked. Support hanging objects.	Create good shock absorption, use appropriate packaging materials and suspension systems. Place objects in showcases. Keep visitors at a distance.	Create appropriate vibration absorption, use appropriate packaging materials and suspension systems. Place slip-resistant material under, or barrier in front of, objects to stop them from 'walking'.	Cover or protect surfaces. Place objects in showcases. Keep visitors at a distance.
Detect	Check objects in storage regularly. Write condition reports and follow changes over time.	Measure shock levels to check quality of handling objects. Write condition reports and follow changes over time. Use a security guard or IR sensors to warn when visitors come too close.	Measure the number of changes and their amplitude over time using a vibration logger to check if agreements are met. Write condition reports and follow changes over time.	Measure wear-and-tear. Write condition reports and follow changes over time.
React	Respond to risky situations or damage to avoid additional damage.	Move vulnerable objects that are still in the danger zone.	Move vulnerable objects that are still in the danger zone.	Regulate or spread the number of visitors. Find alternative routes.
Treat	Change the situation and restore the object if possible.	Act in accordance with the emergency plan. Collect loose parts of the object.	Intervene when agreed vibration levels are exceeded.	Replace worn parts if possible.

Table 14. A general division of the approaches used to reduce damage due to physical forces, based on the five steps in the Framework for Preservation of Museum Collections (CCI, 1994), with examples of mitigation measures

Agent of deterioration	Interaction
Fire	Using plastic foam to support objects in storage increases the fire load. Evacuation during a fire can cause physical damage due to inappropriate handling.
Water	Evacuation due to flooding increases the risk of physical damage due to inappropriate handling.
Thieves and vandals	A large crate makes a small object less vulnerable to theft. Illegally substituting a packing crate is less noticeable than substituting an unpackaged object. Showcases also reduce risks of shock and friction.
Pests and plants	Vermin can easily 'hitch a ride' with packaging material. Wooden crates or pallets can be infested with wood borers. Cardboard boxes are an ideal hiding place for silverfish and mice.
Contaminants	Packaging materials – such as MDF or bubble wrap – may emit harmful gases that can cause corrosion. Polishing and dusting can cause scratches and damage due to friction. Earthquakes or collapse of constructions cause dust and debris.
Light, UV and IR radiation	When objects are placed in protective showcases, appropriate lighting is needed to avoid cyclic climate changes. When replacing lamps and fittings tools can fall on objects.
Incorrect temperature	When objects are placed in showcases, the heat from lights can cause cyclic loads from heating and cooling.
Incorrect relative humidity (RH)	Boxes and cabinets buffer fluctuations in RH. When objects are packed under moist conditions, temperature changes may cause local high RH, resulting in mould growth.
Dissociation	When object parts are transported in separate boxes, some can get lost. Labels can detach, dissociating the object from its information. Inappropriate labelling of the contents of crates may lead to the loss of objects.

Table 15. Examples of the relationships between 'Physical forces' and the other agents of deterioration

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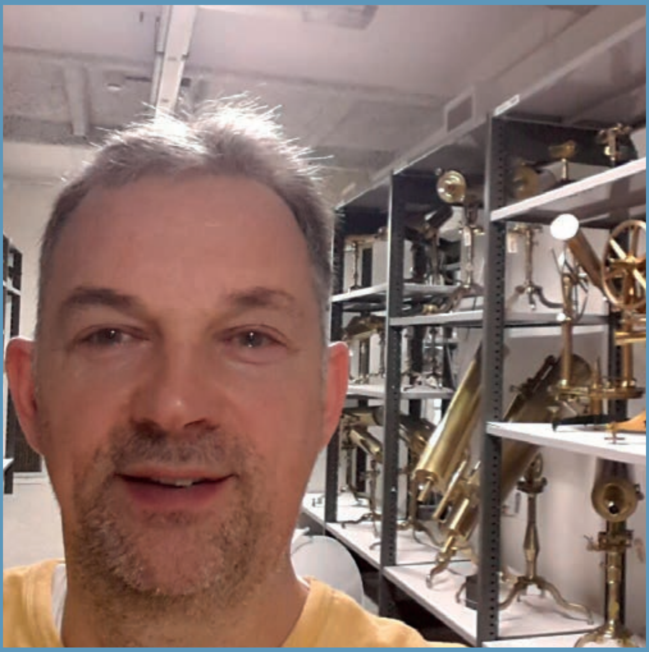
Sometimes, moving objects into the building requires major construction work.



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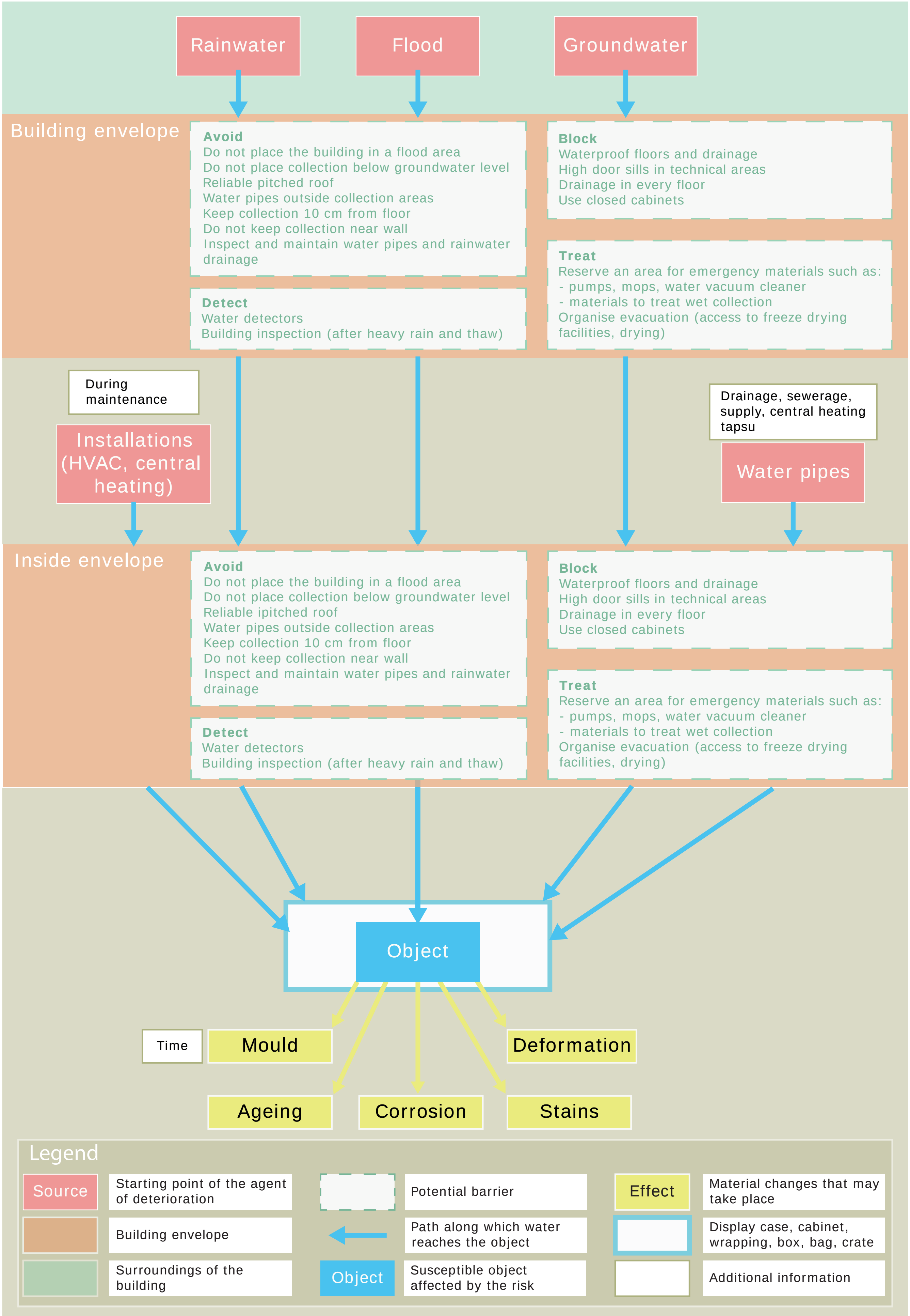
Head of Collections, Boerhaave Museum,
Leiden, the Netherlands

Objects from our collection, such as microscopes, globes, astronomical rings, lenses and medical instruments, are regularly loaned to museums and non-museum locations. They are displayed, for instance, in office buildings, in the reception of a hotel in Noordwijk, in the Boerhaave Medical Centre in Amsterdam or in ministry buildings. The utmost care was obviously always taken with the packaging and transportation of these sometimes very vulnerable objects, usually based on experience and instinct. We always thought the greatest risk for the objects would be when they were handled at the borrowing institution. Upon packing and unpacking parts could break off, small pieces could get lost or drop to the ground. With a small group of Boerhaave Museum staff we decided to look at this more closely during a risk assessment. What exactly are the greatest threats? Then we weighed the agents of deterioration against each other. We realised that an earthquake would cause much damage to our collection, but the probability of such a disaster occurring in Leyden or anywhere nearby, is very small. Packing and unpacking, however, happen much more often, and even though they may cause only slight damage, the chances of such damage are much greater than that of an earthquake. It is good to create this awareness. Furthermore, it turned out that drops and breakages of loaned objects do not necessarily occur during installation or de-installation, but rather while the objects are being transported between the borrower and our museum. That is why we have built new transportation cases that are easier to handle and stack, and are sometimes made to fit a specific object, reducing the risk of damage due to transportation to a minimum.



Scenario scheme for the agent of deterioration 'Water'

Water

Scenarios for water

This scenario scheme outlines the most common scenarios for water. It presents an abstract floor plan of a building. At the top is the outside world and at the bottom is the object or collection, probably inside, in a room, and perhaps in a showcase, cabinet or box. The scheme is a cross-section through the layers around the object and shows how water flows from its sources, via different pathways, towards objects, where it can have a number of different effects.

The red boxes represent the sources for water, which can be found outside as well as inside the building. The white boxes give additional information about some of these sources.

The brown bars outlined in grey are the barriers that water may encounter on its way from source to object. In this scheme two barriers are shown, the building envelope and an indoor barrier, for example an inner wall, case or box. The texts in the barrier layers provide suggestions for improving their performance. If the object is placed outdoors, there are probably no barriers except, perhaps, a protective coating.

The blue box represents an object or collection that has a specific sensitivity to water. The orange boxes describe the most common effects.

The blue arrows represent the water flow. Each line drawn from a source, via one or more barrier, towards the object and an effect, represents the scenario for one specific risk.

The alternative scenario scheme shows the same relationships, but superimposed on a cross-section of a building.

Introduction

Incidents related to water were the most frequently-reported events registered by museums, archives and libraries in the Netherlands between 2008 and 2014. This conclusion can be reached from the data included in the Database of Cultural Heritage Incidents (Database Incidenten Cultureel Erfgoed, DICE) published by the Heritage Monitor (Erfgoed Monitor, RCE, 2015a and 2015b). This is perhaps not such a surprise in the Netherlands, given that more than half of the country is situated in a flood-prone area, a third is below sea level and the country lies in a climatic zone with a high level of precipitation (Figures 40, 41). Although exposure to water is virtually inevitable, most water damage is caused by local incidents: burst water pipes, leaks, overflowing gutters, negligence during construction work, careless use of water in and around the building, and water used to extinguish fires. Insurance companies pay out almost as much for water damage as for fire damage on their domestic policies.

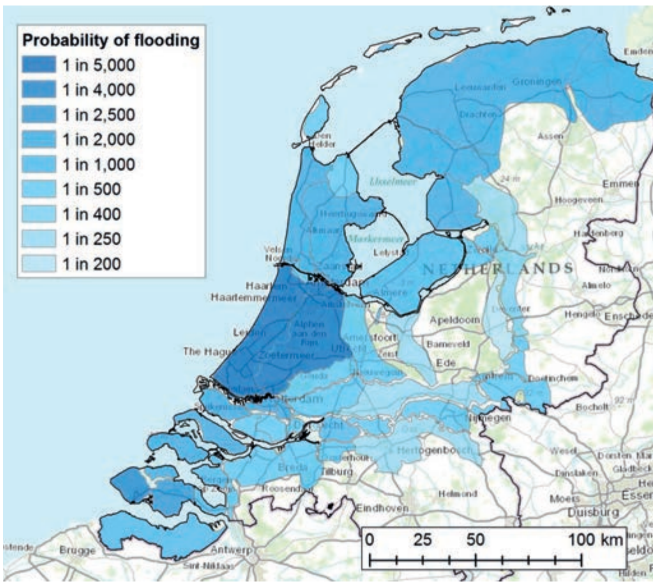
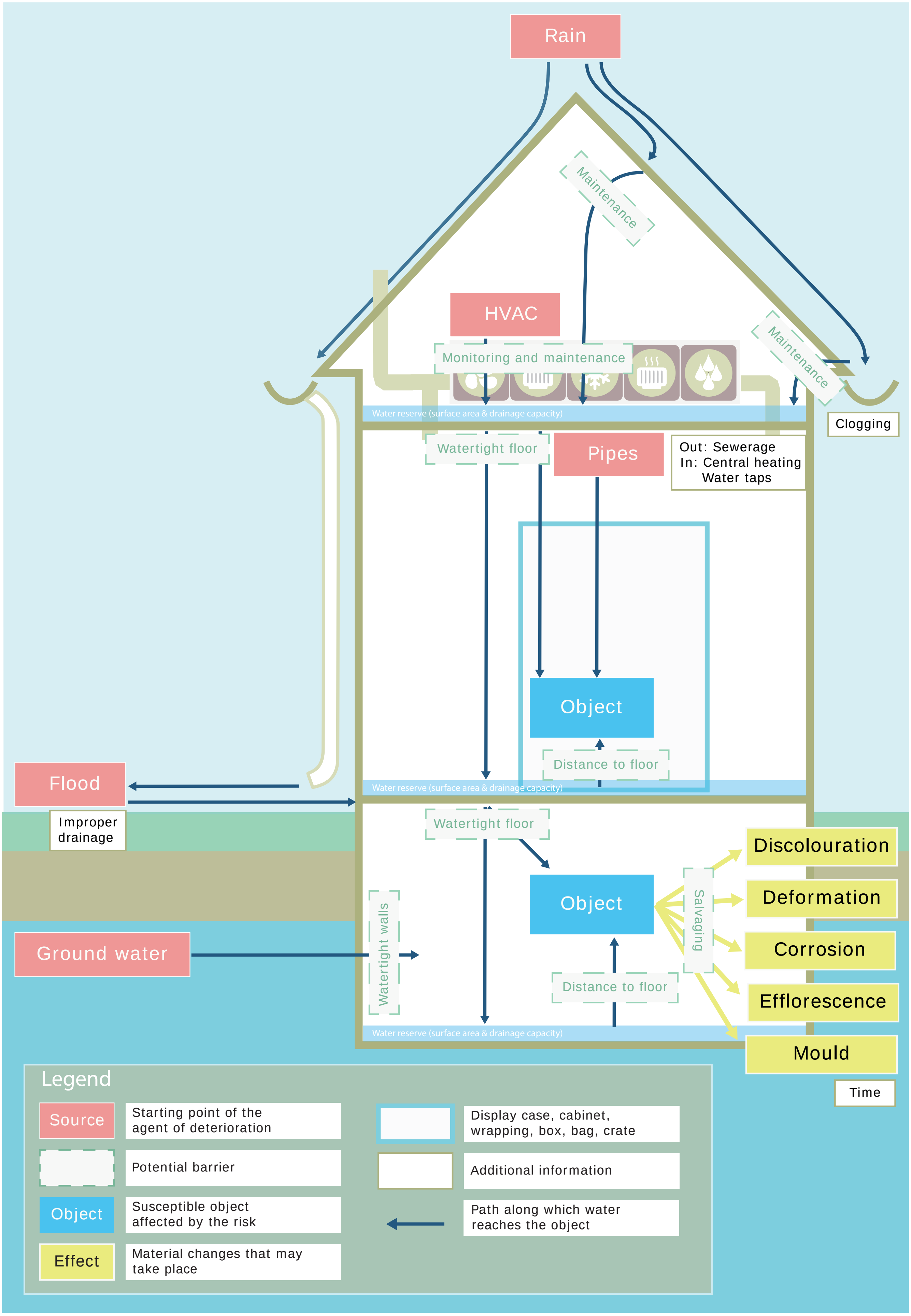


Figure 40. Maps of the Netherlands showing the probability of flooding (left – Source: AON, 2013) and the maximum water height in metres in the event of a flood (right – Source: Mijnoverstromingsrisico-HKV, 2015).



Scenario scheme for the agent of deterioration 'Water' (alternative)

The scenario scheme shows three 'flows' of water:

- From above – rainwater or leaking water that flows down via the roof, pipes or upper floors.
- From the side – water from a flood, an accumulation of rainwater or nearby reservoirs.
- From below – water rising from the ground or coming up under high pressure through the sewerage system.

Sources

Water comes from a number of external and internal sources. Heritage organisations have little influence on the natural, external sources; all they can do is protect themselves with appropriate measures in their grounds and buildings. Internal sources, however, are within their sphere of influence and lower levels of risk depend on good maintenance and well-considered handling of water.

External sources

There are four external sources for water incidents in heritage institutions:

- Flooding from surface water
- Heavy or extreme rainfall
- External water mains, pipes and equipment
- Ground water

Figure 42 illustrates these different water sources (Kok, 2005). Rainfall comes directly from above (1). If the soil saturates (2) or the sewers become overloaded (3), water can come from below. Flooding from nearby reservoirs, ditches and canals (4) can cause water to enter from the side. In low-lying areas such as the Netherlands, defective flood defences on canals (5) and coastal dykes (6) may also allow water to come from the side. In combination with storms, (spring) tides and high water levels, the water can overwhelm the dykes (7). Heritage sites that lie outside the flood defences are particularly vulnerable.

Floods from surface water

In the Netherlands, flood risks that originate from failed flood defences on major bodies of surface water (the North Sea, the IJsselmeer and the chief rivers) are controlled at a national level

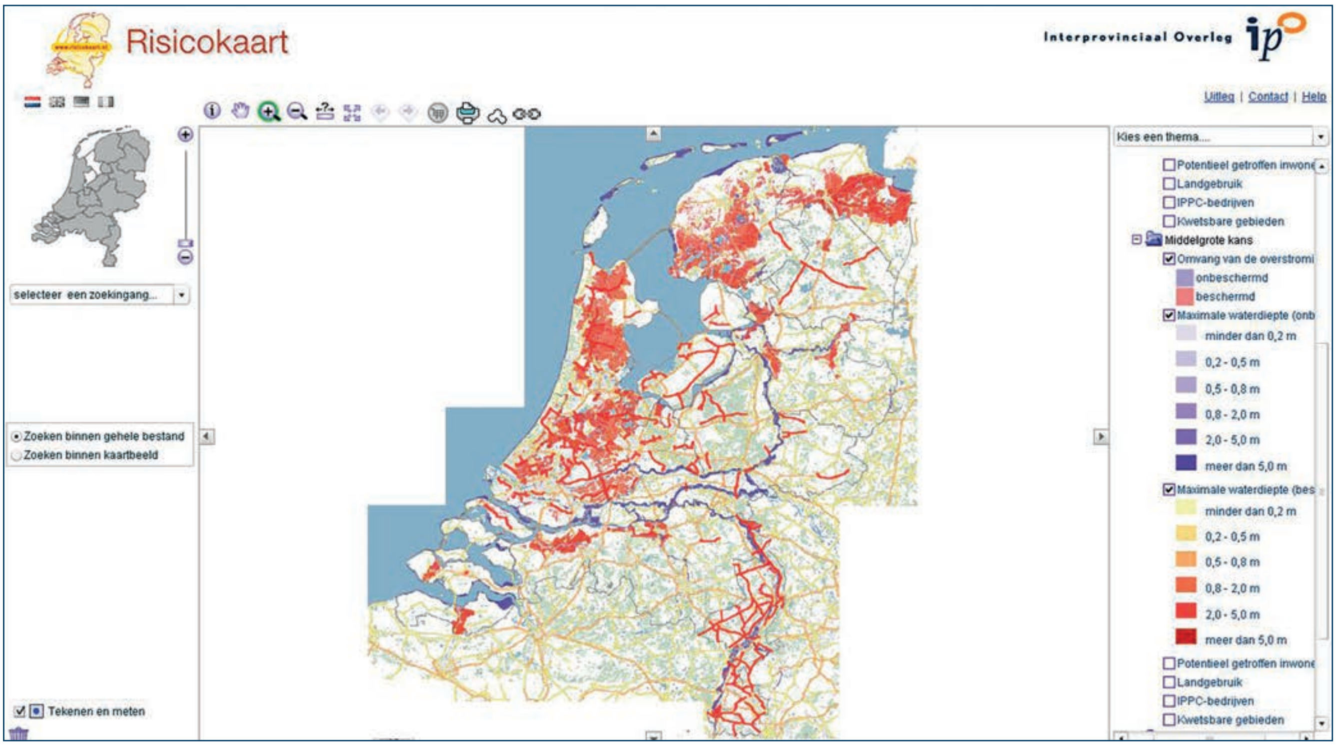


Figure 41. Screenshot from the website 'Risicokaart van Nederland' (Risk map of the Netherlands), showing the maximum water depth during a flood of moderate probability. A set of menus allows the user to select which data they wish to view.

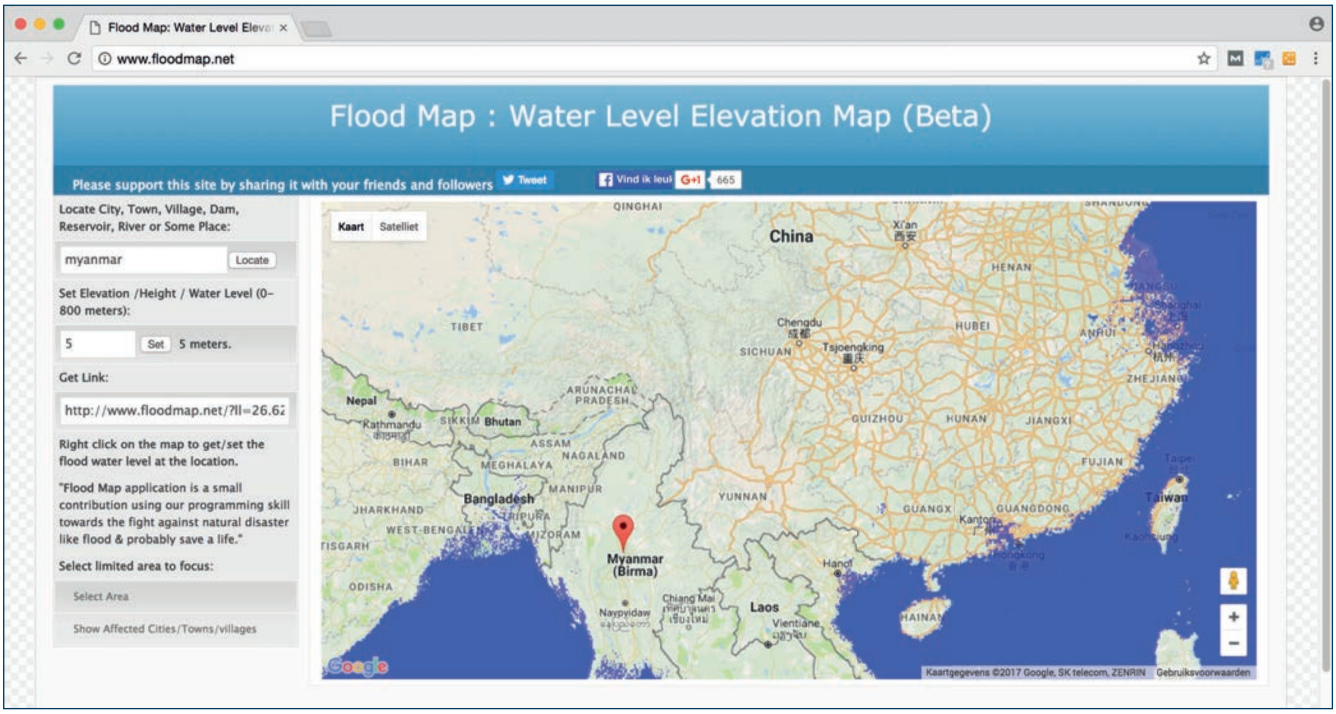


Figure 43. Screenshot of the website 'Floodmap.net' showing those areas in South East Asia that would flood if the sea level were to rise five metres (source: http://www.floodmap.net/)

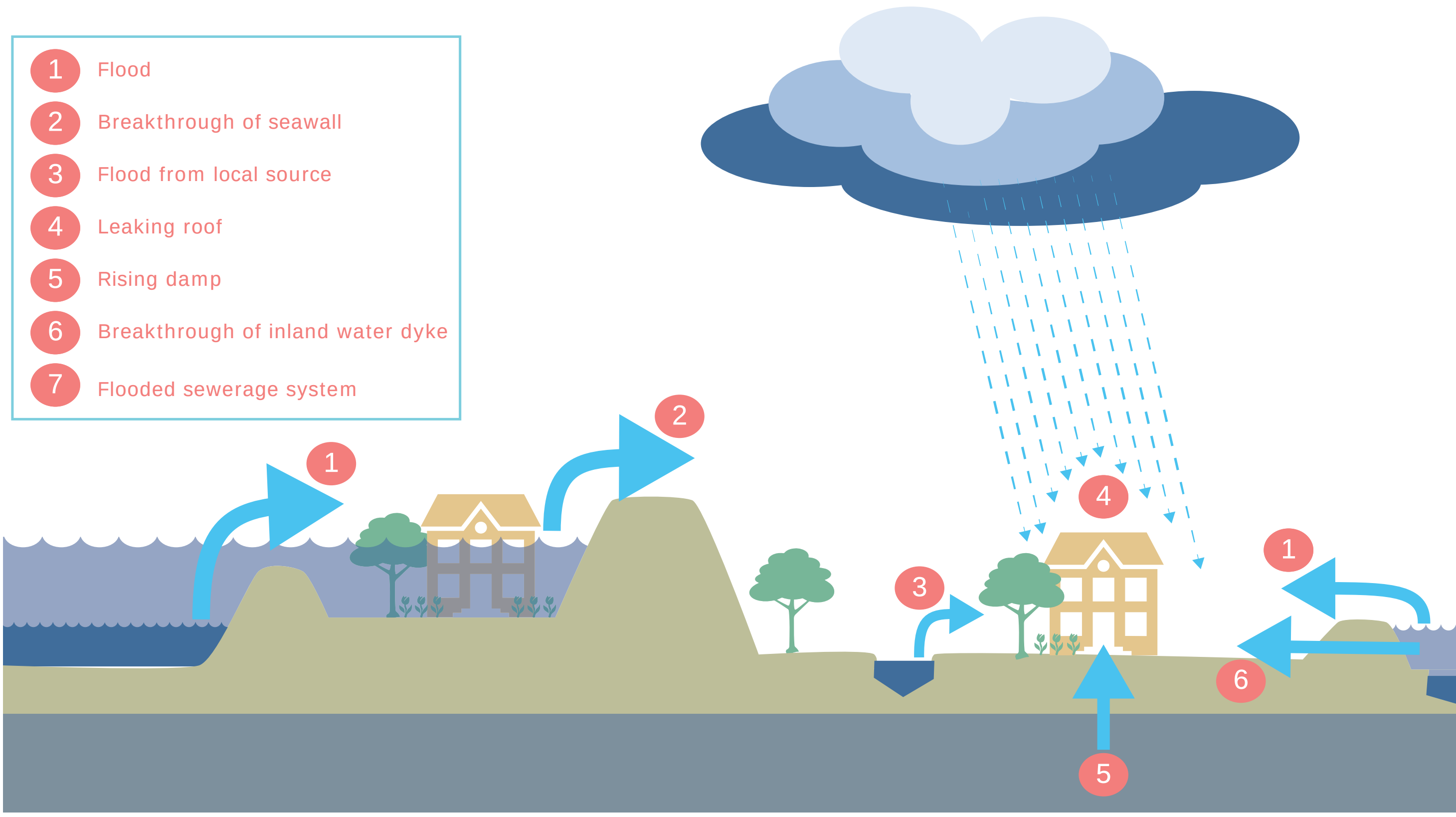


Figure 42. Overview of seven causes of water incidents in low-lying and higher parts of the Netherlands (Kok, 2005).

by the Ministry of Infrastructure and the water authorities. They strive to reduce the probability of a catastrophic flood, such as the North Sea Flood of 1953. Nevertheless, there are regular floods that affect historical buildings and heritage organisations. These occur in the river floodplains, along river banks or in local dips in the terrain. The two maps of the Netherlands in Figure 40 indicate the type of information that is available at a national level. They show the probability of flooding (left) and the maximum water height when flooding occurs (right). The likelihood that a historical building, museum, archive or library will be exposed to water can also be determined using the national risk map of the Netherlands (Figure 41). Similar maps are available on the internet for other countries and regions of the world, for example the UK Environment Agency (2016), FEMA (2016) and Floodmap.net (Figure 43).

Heavy and extreme rainfall

The annual rainfall in the Netherlands is about 800 mm (average 1981–2010). This rainfall is spread quite evenly throughout the year, but there are regional differences in the seasonal pattern (Figure 44). In spring, coastal areas are colder and drier than the warmer inland region due to the presence of cold sea water.

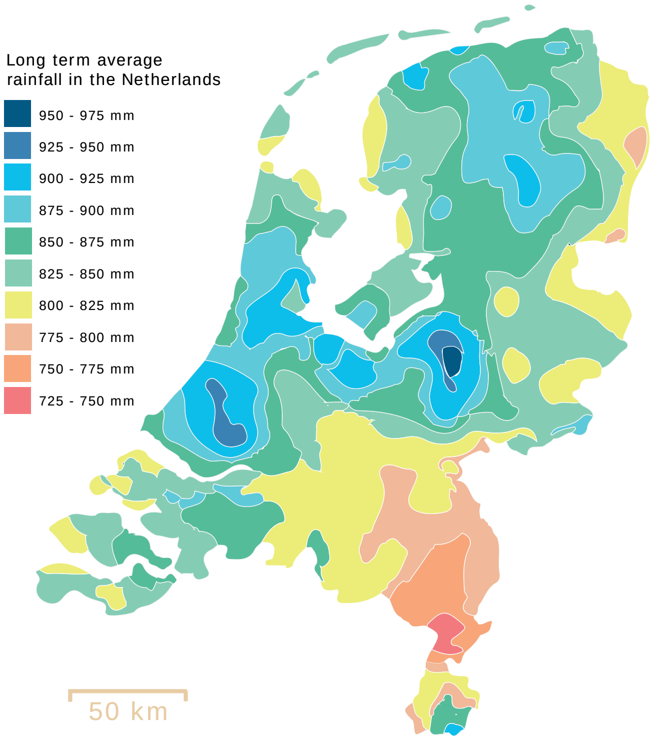


Figure 44. Long-term average annual rainfall in the Netherlands 1981–2010 (Source: KNMI)

In summer, heavy storms build over the warmer inland areas. In autumn, the air over the warm sea is hotter than that over the cooler inland area, with the result that the coastal area experiences more rain. In winter the differences are smaller (KNMI, 2015a, 2015b). Similar maps are available on internet for other countries, for example at Climate-Charts.com (2016). Heavy and extreme rainfall causes flooding when the water cannot be drained sufficiently quickly. It collects in lower areas and creates flooded streets, saturation of the soil and flooding from drains, gutters and sewers. Statistics from the Dutch Meteorological Service (KNMI) show that, at any given location in the country, at least 73–90 mm of rain falls within 24 hours and 86–105 mm during 48 hours once in every 100 years. The frequency has also been determined for lighter rainfall; on average, 20–24 mm of rain falls during 24 hours five times per year, a daily precipitation of at least 26–32 mm occurs about twice a year, and once a year at least 50–62 mm falls in one day.

The Dutch Meteorological Service uses the concept of a *cloudburst* to describe short-term heavy rainfall, when 25 or more millimetres of rain fall in an hour, or a minimum of 10 mm in five minutes. During a cloudburst visibility can be reduced to less than 200 m. On average, any given location in the Netherlands is

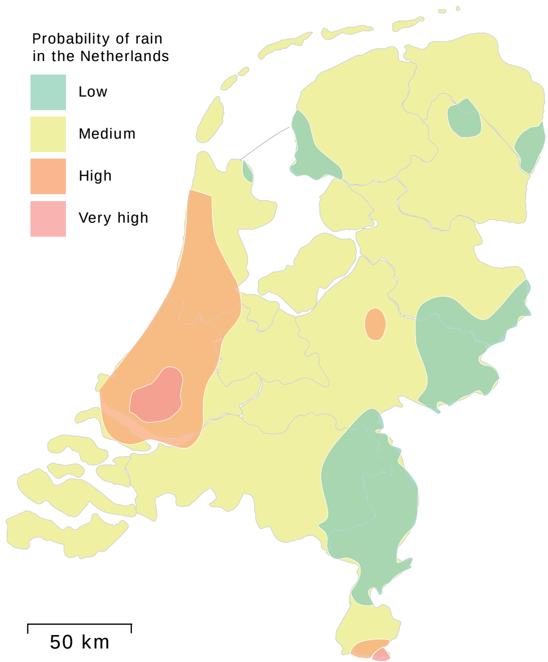


Figure 45. Rainfall fluctuations in the Netherlands, according to Buishand, Jilderda and Wijngaard, 2009 (source: KNMI, 2014).

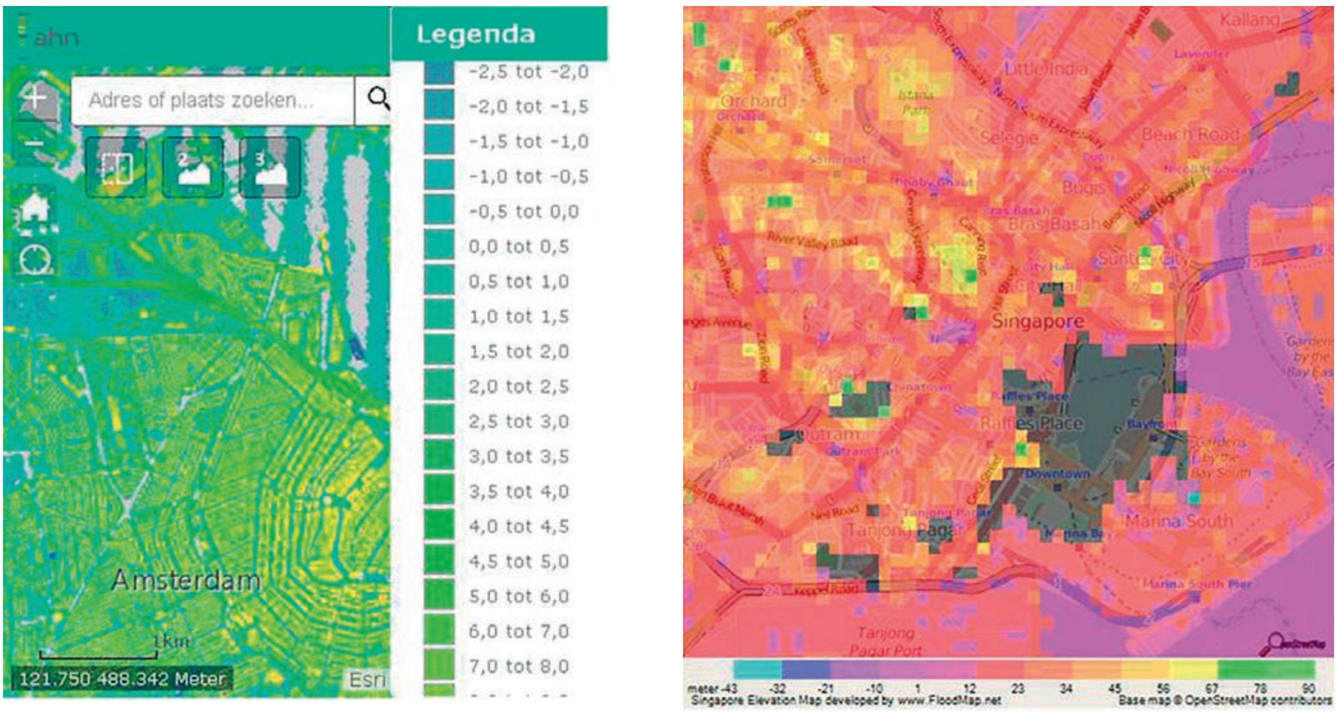


Figure 46. High resolution elevation map of the Netherlands, zoomed in on Amsterdam; water will flow from the yellow to the green and blue areas (left – AHN, 2015) and of Singapore where water will flow from the green and yellow zones towards those shown in orange and purple (right – FloodMap.net, Base map© OpenStreetMap contributors; http://www.floodmap.net/Elevation/ElevationMap/?gi=1880252)

Figure 47. Flooded street during construction work.

exposed to a cloudburst once every ten years (KNMI, 2015b).

The Netherlands is divided into four precipitation regions. In the areas with lower than average precipitation, at least 31 mm can fall in a day once a year. In areas with higher than average rainfall a daily level of at least 38 mm is expected once a year.

Whether streets are flooded depends strongly on local differences in elevation, the capacity of the soil to absorb water and the drainage capacity of the sewerage systems. Information about one's own situation can be gathered from water authorities, the sewerage board and the local council. High resolution elevation maps may give an indication of where rain water will collect and help to determine if one's own location lies below the surrounding area, in a hollow into which excess water will flow (see for example FloodMap.net).

External pipes and equipment

In addition to extreme rainfall, flooded streets can also result from technical failures that cause the release of water from systems such as water mains and temporary pumping equipment used in construction work (Figure 47). Building or excavation work in one's surroundings is a serious risk that requires alertness and communication with all the parties involved. In this case, the best information comes from direct observations, eyewitness statements and incident reports. A typical example of this kind of incident is the flooding of the basements of the archives of Wijk bij Duurstede in the Netherlands after a human error during pumping (Nimwegen, 2006).

Ground water

Unwanted groundwater flow causes problems if the water enters basements or when it forms a continuous source for rising damp. The construction and the quality of the basement floors and walls and the dilation joints play important roles. Some stone and concrete constructions are porous or contain irregularities making them unsuitable to keep groundwater out. Thorough inspections, and asking the right questions, usually reveal these problematic aspects. A groundwater level that is too low can also be harmful as it may, for example, weaken pile foundations and the roots of very large trees.

Irregularities in the groundwater level have important consequences, not only for heritage but for the economy and agriculture in general. Accordingly, there is much information available on this topic in the Netherlands. Groundwater levels are monitored through an extensive network of measuring tubes and regulated by the water authorities using a complex network of pumps and pumping stations. Whether regulated or not, the groundwater level at a particular location can be affected by activities a few kilometres distant. The main cause of anomalously low groundwater levels, which could cause the ground to sink and piles to rot, is the local disappearance of groundwater into leaking sewers (KCAF, 2012).

Rising damp or moisture in building elements moves slowly and sometimes becomes apparent only after many years. Effects such as salt efflorescence may also persist for many years.

Internal sources

In practice, much water damage is caused by leaks from internal water-bearing pipes and equipment. Data from the Database of Cultural Heritage Incidents over the period 2008–2014 show that external and internal sources are equally prevalent causes of flooding (RCE, 2015a). Of the 63 reported water incidents, leaks due to (faulty) roof construction were reported 12 times, and rainwater or leaking gutters five times. Of the eight registered incidents in 2014, six were caused by heavy rainfall on one particular day. The internal sources – ruptured pipes (5), leaking equipment such as the air conditioning, climate control, cooling or (de)humidification systems (10), and leaking fire hose reels (3) – are just as common. Everything that contains or can contain water is, therefore, to be treated with suspicion. To assess the risk from these internal sources, it is necessary to know the water pressure in the pipes and systems, how much water can be released and their location relative to the collection areas.

Equipment

Inside the building, water can be released from air handling or heating systems and from fire extinguishing equipment. Unless it is released accidently, the water in firefighting systems is desirable and the water risk is linked to a primary risk from fire. In all other cases, the water is unwanted and the underlying cause is technical failure, human error or deliberate actions. In the last case, the primary cause is vandalism. For many years, a fear of water damage was the reason that sprinkler systems were not installed. Modern sprinkler systems are technically robust, extinguish fires locally and use a limited amount of water. The fear is no longer justified and when assessing risks, one should consider which is the worse risk – part of the collection getting wet or the possibility that a larger portion is burned or covered with soot.

Pipes

Water can be released from pipes carrying clean or waste water, as well as from taps or pieces of equipment that are connected to the water supply, such as washing machines, coffee machines or drinks dispensers. The leaks may be caused by, for example, frost, technical failure or negligence. It is often difficult to establish where pipes run or to assess their condition, as they are hidden within or behind walls and ceilings. Accordingly, a rapid response to the detection of any leaks is of great importance to limit its consequences. Incident registration and subsequent improvements form an important part of the strategy to reduce risks.

Some organisations follow up incidents more effectively than others, which creates considerable differences in the probability of water risk scenarios. The pathway that water takes as it spreads through a building is often difficult to predict and can often only be inferred by observing the patterns that become evident during incidents. Therefore, incident analysis forms the basis for improvement.

Spillage

Water can be released during unskilled use of water or because of accidents during cleaning, watering plants and flowers, refilling humidifiers or emptying dehumidifiers. Although visitors increasingly bring water bottles into buildings and exhibitions, these fortunately contain only a limited amount of water.

Pathways and barriers

Almost everybody has some experience with the way water spreads and is aware that it always flows to the lowest point, but the pathway it takes can be erratic and unexpected. It is relatively simple to create a first impression of the different pathways by which water can reach collections and objects, and of the damage processes that occur in consequence. At the same time, individual experiences of water incidents are limited. Based on dozens of incident analyses and the information derived from them, such as guidelines for emergency response, an overview can be produced of common measures to reduce water risks. These separate reduction measures, barriers and procedures are described for the most part in the scenario scheme and are discussed further under 'Options for risk reduction'.jese e to reduce water risks. s and emergency response plans, an overview can be made of the he lowest point, but the path it t

When considering barriers, one should think of flood defences and watertight, physical obstacles. Around the building, barriers such as ramparts and dykes can be raised to block the water

Source	Description of event
Groundwater in a basement due to error when using a pump	A pump used to drain a construction site near an archive building was improperly connected. Out of hours the basement that contained the collection filled with water. A complication was that the electric lock refused to operate, making it difficult to open the door. Although the final loss of value of the archive material after restoration was estimated to be 2%, other consequences of the material becoming wet were that the archive was inaccessible for a long time and that the recovery and legal costs were very high. Secondary damage from mould growth was minimal thanks to professional support and recovery, and cold storage. Early detection of water entering the building would probably have confined the damage. Subsequently, new archive regulations have made water detectors mandatory and a new waterproof door has been installed.
Groundwater in a basement due to a drill hole	While installing a new pipe for the city heating system, which passed through an exterior wall of the basement, a hole was drilled below the groundwater level. When the drainage pumps in the construction pit near the outer wall were switched off overnight, water flowed into the basement because the cement around the pipe was not yet dry. The result was several centimetres of water in the two basement floors. The collection materials in the basement remained dry because they were placed on shelves above the floor and because the water had only dripped into the lower basement along cable ducts, beneath which – by coincidence – no collections had been placed. Drying the floors afterwards proved more complicated than expected, because the narrow spaces under and between the racking were difficult to reach. Although this event was reported in the incident register, reconstructing the cause was difficult because of a division of tasks and limited communication between people. There is every reason to believe similar incidents will recur if internal communications do not improve.
Groundwater leak at a ground anchor saturates the building structure	In the concrete foundations of a building, so-called ground anchors had been installed. Over time, the basements had increasingly been used for archival storage. A double floor covered the underlying concrete construction. Due to a leak near an anchor groundwater gradually penetrated and the double floor construction became saturated. The archival material suffered no water damage, but the basement needed to be cleared in order to replace the double floor.
High river level after heavy rainfall	The Chemung River in New York State burst its banks after heavy rains and many parts of the city of Corning were flooded. The emergency services were overwhelmed. Muddy river water caused considerable damage to objects in showcases and to the museum library. The books were caked in mud and the metal cabinets were distorted by the expansion of the wet paper. During the subsequent freeze-drying process some high-gloss pages stuck together. The details of this incident are described thoroughly in Martin (1977).
Basement floors under water after heavy rainfall	During severe weather, groundwater levels rose and the sewerage network overflowed into the low-lying grounds of the museum. Groundwater penetrated the porous floor and dirty water entered from the sewerage system. The damage and repair costs were considerable. It was not clear to what extent such high groundwater levels were to be expected. It is known, however, that a decline in industrial activity and consequent reduced water use have led to the city experiencing problems with higher groundwater levels over recent years, for which adjustments to the water drainage system needed to be made.
Roofers take their lunch during a cloudburst	Controlling construction work is difficult. At a critical moment, just after folding back the lead coverings during the renovation of a roof, a cloudburst coincided with the period during which the roofers were at lunch. The rainwater ran down the walls and damaged a number of paintings. While some museums enforce strict contractual procedures to avert fire hazards during construction work, these should perhaps also be introduced for work that creates water hazards.
Snow clogs gutters	When there are small leaks, it is not always easy to take effective measures to address the issue. Following earlier leaks of the gutters during snowfall, a museum took additional measures, including placing salt in the drainpipe hoppers. Despite this, meltwater caused a leak at an unexpected location, damaging prints, photographs and old manuscripts. In retrospect, it would have been advisable to take more measures at object level as an extra precaution. If necessary, a plastic cover could be placed over cabinets before the snow starts melting.
Storm damages roof	The roof of a library store was blown away in a hurricane, causing a great number of books to become damp. With much effort, it was eventually possible to pack many of the books and freeze-dry them, thereby limiting the damage.
Ruptured water main	The area around a building had been affected by many years of intensive building activity and the location of major water mains and pipes was unclear. During digging, a drinking water pipe was hit and thousands of litres of water flooded the area. Fortunately, the basements remained dry as the water flowed into the parking garage opposite the museum.
High pressure hose in steam humidifier disconnected after maintenance work	In an archive, the central steam humidifier, with its high-pressure water supply, was situated in a separate plant room with waterproof floors, thresholds and a drainage system. During the night, after maintenance work, a hose clamp came loose from a high-pressure hose and a much water was released. The capacity of the drain proved insufficient and the water flowed past the water detector, through the door opening and down the stairs into the archive room. The archive material remained dry because the waterproof floor and walls in the plant room above functioned well and all the archival documents were on shelves at least 10 cm above the floor. After the incident, the drain was enlarged and a second water detector installed.

Source	Description of event
Technician forgets to turn off a tap in a fire extinguishing system	During adjustments to fire hose reels on different floors of a building a technician forgot to turn off a tap. When another person turned on the main valve, water flowed through pipe outlet holes in the floor into an archive space below. The floor was not water resistant, because the space was not originally built as an archive area. Several linear metres of important documents became wet but, thanks to a rapid freezing and freeze-drying, the damage was limited to bleeding of ink, water stains and tide lines.
Central heating equipment leaks through a rust hole	Over the years, a dripping cap led to corrosion of the central heating pipes in a floor duct in an archive. Because of the high pressure in the pipe, a hole suddenly formed and water spouted from the pipe under force. The water poured through the pipe outlets in the floor into the archive below. The floor was not water resistant, because the space was not originally built as an archive area. Several linear metres of important documents became wet but, thanks to a rapid freezing and freeze-drying, the damage was limited to bleeding of ink, water stains and tide lines.
Ruptured pipes due to frost	A frost-damaged water pipe in the central heating system ruptured, producing a flood in the museum. The cause was traced to mistakes that were made when the systems were installed. The collection remained undamaged because it was stored sufficiently high above the floor.
Leaking pipes	A leak occurred in an ageing water pipe in the sanitary water system, which was concealed and difficult to inspect. This caused disfiguring stains on the historical interior of the building. When such water systems are installed in historical buildings, this risk should be anticipated and measures taken to ensure easy inspection and maintenance.

Table 16. Anonymised examples of water-related incidents in heritage institutions with an analysis of the source, pathway and effect, and the effectiveness of mitigation measures

flow, or culverts and gullies dug to lead the water elsewhere. The building envelope or outer layer (roof, walls, floor) form the most important barrier against external sources. The construction method and the materials used determine the water resistance. Weak spots in the envelope increase the risk considerably. Defects, such as shifted roof tiles, cracks in the walls or floor, broken windows and damaged connections in the gutters, can allow water to penetrate the outer layer. Water may also enter inadvertently through essential openings, such as doors, windows, cable ducts and pipe outlets.

A recurring problem is water that enters because the capacity for rainwater drainage has been exceeded; gutters and hoppers overflow, drains from the roof fill and connections leak. The probability increases as roofs get steeper and more complex, such as in neo-Gothic churches, the gutters of which easily become clogged.

There are also physical barriers inside the building: walls, floors and ceilings. For these, the rule is the same as for the building envelope: depending on the construction and materials they offer different degrees of resistance to water, and weak spots reduce their resistance. Finally, physical barriers can be found at object level, such as cabinets, boxes, bags and showcases.

An assessment of the performance of these barriers, and of the effectiveness of different precautionary measures, requires experience and specific technical knowledge. For this reason, it is important for an institution to have experienced facilities and technical staff, who know the building and the surrounding area well and who understand the importance of risk management. Although every situation is different, much can be learnt from other water-related incidents in heritage institutions. In some cases incident descriptions are directly applicable to one's own situation and they can be turned into a risk scenario quite easily. In other instances, the details of the incident give a better understanding of a specific risk mechanism. A Table 16 lists a number of water incidents in heritage institutions and gives a description of each real-life scenario. The examples have been selected based on the quality of the descriptions and are not statistically representative. An attempt has been made to identify source, pathway and effect, and to indicate the effectiveness of the most important mitigation measures. Furthermore, it needs to be stressed that available incident reports vary greatly in quality and undoubtedly contain errors of interpretation, even in situations where eyewitness statements are included. One should assess for oneself which aspects of these incidents best relate to one's own situation.

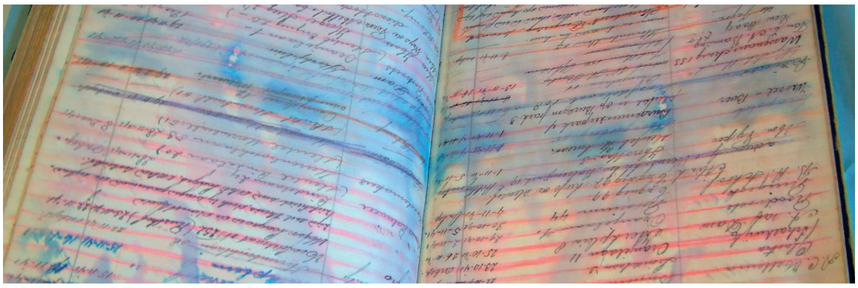
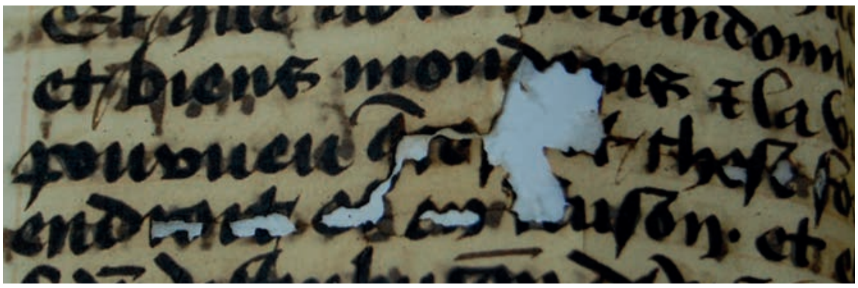
Example	Description
	*Figure 48.* **Disintegration and displacement due to water movement** A collection of microfiches was crushed under the weight of the wet boxes in which they were stored. After salvaging they needed to be dried and flattened.
	*Figure 49.* **Deformation, cracks and loss of flexibility** Books can swell and change shape due to the absorption of water. Parchment covers become rigid upon drying.
	*Figure 50.* **Migration of water-soluble components** Bleeding of ink.
	*Figure 51.* **Acceleration of chemical degradation** The corrosion of iron-gall ink is a chemical process that is accelerated by water.
	*Figure 52.* **Biodegradation** When the surfaces of organic materials remain moist for some time, there is a greater risk of mould growth.

Table 17. Examples of the five mechanisms that lead to water damage in paper collections

Objects and their vulnerability

Exposure of objects to water can lead to damage in different ways. Five mechanisms can be distinguished (see Table 17):

- Disintegration and displacement by the movement, weight or force of large quantities of water. Strictly, the objects are affected by physical forces, but water is the primary cause.
- Deformation, cracks and loss of flexibility due to the swelling and shrinking of water-absorbing materials.
- Migration of water-soluble components, colourants or salts, and the deposition of dirt.
- Acceleration of chemical degradation, such as the corrosion of metals or ink.
- Biodegradation of wet or moist organic materials by mould, bacteria and insects.

Whether an object sustains damage when it becomes wet depends on its component materials and its construction. On wetting, materials react differently; for example, the various components in layered structures may expand differently, causing delamination or warping. The length of exposure to water and the response rate of the materials determine whether the water has enough time to wet the materials and be absorbed. The thickness and surface finish influence this greatly.

The initial exposure to water and the way in which the incident is handled can cause changes to the object that may affect its function. The type and extent of damage, and the associated loss of value, are related to the material composition and construction of the objects as well as to their function and meaning. For example, a water stain on an object whose function is primarily aesthetic (e.g. a watercolour painting on paper) can result in a significant loss of value, while the same water stain may be insignificant on an object that functions primarily as a support for textual information (a paper document). When classifying collections by their vulnerability to water, the following categorisation can be used:

Not vulnerable: material and object do not interact with water. Form and function remain intact.
Vulnerable: material and object interact with water, which causes the form to change, but leaves the function intact.
Highly vulnerable: material and object interact with water. Both form and function are affected.

Table 18 offers an overview of the vulnerability to water of different materials and types of objects, describing the physical changes to materials and construction when they become wet. Whether this results in a loss of value depends on the meaning and function of the object.

To gain a better understanding of the risk, and to assess the severity of the consequences of a certain risk scenario, it is necessary to have a clear idea of the damage that might be expected when objects become wet. Once a collection is wet, there are usually additional measures to take to limit further damage, such as rinsing, freezing and freeze-drying. Experience shows that many water-damaged objects can be restored, but often at great expense. Although the final loss of value to an object may not be that large, the cost and effort associated with recovering any lost value should be considered when determining the consequences of a risk. Risk analysis for a particular scenario assesses the loss of value to the objects before restoration; conservation and restoration treatments are thus investments to regain lost value. In these terms, the risks associated with water are usually very expensive risks.

Options for risk reduction

When taking measures to reduce water risks, the five steps in the integrated approach can offer guidance. Below each step is discussed and a number of possible measures are considered. For more information see, for example, Tremain (2016), FEMA (2014), Environment Canada (2013) and Boylan (2004).

Avoid

When planning and designing a (new) building, a location can be chosen with as few water sources as possible and a low risk of flooding. Avoid flood plains and low-lying areas where water may flow or collect (consult flood maps). Make sure the area around the building is well drained, using for instance, trenches, gullies, ditches, gravel and local wells. Ensure the building envelope is strong, waterproof and functioning well. Buildings, roofs, drainpipes and water systems should be inspected and maintained regularly (see Figure 53). The roof should ideally be pitched at an angle that avoids water collecting and promotes good run off. Ideally, the building should be designed in such a way that it is easy to inspect.

The technical specifications for the design should include water systems and pipework. Water pipes should be kept outside the collection areas and drainage systems should be fitted with non-return valves. Place the collections above the groundwater and flood levels, especially vulnerable masterpieces. Make sure that all shelving and cabinets are sturdy and that the distance between the floor and bottom shelf is at least 10 cm. Keep space between the cabinets or objects and the walls so that water running down the wall will not be in contact with the objects. This also reduces the likelihood of creating micro-climates and condensation. Catching water from short-term leaks and directing it away (using buckets, trays or temporary gutters) will prevent the collection from getting wet.

When flooding occurs, it is likely that the power will fail, which will have consequences for access, security and recovery. If construction work takes place near the building it is advisable to have clear agreements with the contractor and to monitor compliance.

An example of taking action at a community level is 'Amsterdam Rainproof'; a project that aimed to make Amsterdam more resilient to increasingly frequent heavy downpours (Amsterdam Rainproof, 2015). On the (web)platform, ideas, initiatives and information are gathered that allow the community to put the rainfall to good use for the city and to limit the damage it causes.

Other strategies for preventing exposure to water are to move the collection to a drier place in good time (preventive evacuation) or to a higher part of the building (vertical evacuation).

Block

The watercourses in the area can be dammed using permanent barriers such as ramparts, dykes and walls. In the event of high water levels or heavy rainfall, temporary barriers can also be installed using bulkheads, sandbags or tarpaulins, and temporary ditches or overflow tanks can be created.

The building blocks water from external sources, but the outer envelope can fail under the force of floods or extreme rainfall, allowing water to enter via the roof, gutters, windows, doors and other openings. During heavy downpours, the capacity of some gutters and downpipes is simply insufficient, or the drains are blocked by leaves, snow or rubbish. Roofing and gutters are subject to deterioration, for example through corrosion, and eventually lose their protective function.

To minimise the chances of a leak, the outside envelope should be inspected and maintained regularly. Fresh or old water stains and incident descriptions give clues to the location of weak spots. Some roof constructions are prone to leaks; gable roofs are vulnerable and there is no such thing as a glass roof that never leaks. In some countries, it is possible to have regular inspections carried out by specialised companies.

When water enters, or is released inside the building, a physical barrier can be used to block its route to the collection (Figure 54). Since many internal water incidents start in plant rooms, it is good practice to block the spread of water by installing high thresholds and waterproof floors and walls. If the floor has drains the water can be transported away to prevent other rooms from flooding.

Water can also be blocked at object level, for example by storing objects in waterproof packaging or placing them in closed cabinets. Experience shows that a simple cardboard box provides considerable protection. Shelves and open cabinets can be fitted with a waterproof cover or protected by plastic sheeting. When

Figure 53. Inspection reveals that leaves clog the rainwater downpipes

Figure 54. Protecting objects against leaking water by placing a cover on top of cabinets

Type of object	Materials	Changes caused by water
Documents, prints, drawings, works on paper	Paper Ink Colourant	Paper becomes soft, deforms, bulges and loses strength. Weight of paper increases because of water absorption Inks and colourants bleed Stains from water and dirt, tide lines upon drying Mould growth
Books	Leather Parchment Paper Ink Colourant	Bindings soften and deform, then harden after drying Paper becomes soft, deforms and bulges Inks and colourants bleed Stains from water and dirt, tide lines upon drying Mould growth
Hide, fur, leather	Processed and unprocessed skin	Becomes soft and stretches when wet, shrinks upon drying and deforms Stains and bleeding of coloured components Degradation of collagen
Feather, fur, hair	Keratin	Becomes soft when wet, curls upon drying Mould growth
Skeletal	Bone Ivory Horn	Possible fracture and deformation upon drying Softening and degradation of collagen Teeth in skulls loosen Ivory splits Stains, dirt penetrates porous parts during drying Mould growth
Photographic prints	Coated paper Polyethylene Emulsion layer Gelatine	Paper softens and deforms, then curls upon drying Gelatine swells, emulsion layer expands Colourants bleed Mould growth
Glass	Glass	Any existing glass disease is re-initiated
Furniture (wood)	Wood Veneer Varnish Wood stain Paint Glue Metalwork	Swelling and shrinking of wood, deformation, with cracking if the movement of panels is restricted Stains White bloom on varnish Corrosion of metal parts Mould growth
Ceramics	Clay Pottery Porcelain	Porous surfaces stain Patina and salts lost from of archaeological objects Cracks (in glazing) become visible Unfired clay disintegrates
Basketry	Plant fibres Colourant	Softens, deformation, loss of strength, shrinks upon drying Stains Colourants bleed Mould growth
Shells	Calcium carbonate	Porous surfaces stain Salt crystallisation, efflorescence
Panel paintings	Wood Board Ground layer Paint Varnish Frame	Panel swells, shrinks, deforms and cracks Delamination of ground and paint layers White bloom on varnish Frame joints move and crack Mould growth

Type of object	Materials	Changes caused by water
Canvas paintings	Linen Cotton Ground layer Paint Varnish Frame	Canvas swells, shrinks, deforms and sags Delamination of ground and paint layers Water solvent linings may detach White bloom on varnish Frame and stretcher joints move and crack Mould growth
Plastics	Polyethylene Polypropylene Polystyrene Polycarbonate Polyester Plexiglas/Perspex	Porous surfaces stain
Rubbers	Natural rubber Synthetic rubber	Porous surfaces stain
Stone Stone-like materials	Stone Brick Plaster	Dirt accumulates in porous surfaces and forms stains Salt crystallisation, efflorescence Loss of grouting and mortar
Metals	Iron, Copper, Tin, Zinc, Lead, Bronze, etc.	Reactive non-precious and semiprecious metals (e.g. iron and copper) corrode Existing corrosion is intensified
Textiles	Wool Silk Cotton Linen	Swells and shrinks, then deforms upon drying Weight increases because of water absorption Colourants bleed, staining Mould growth

Table 18. Overview of the different object types and materials, and the changes they undergo on exposure to water.

flooding is expected, objects can be raised from the ground on blocks, the legs of furniture can be placed in plastic boxes or tubes, and objects that cannot be moved elsewhere can be sealed in plastic.

Monitor and detect

Monitoring, to determine if the measures taken in the 'avoid' and 'block' steps are sufficient, starts with visual inspections. Inspect the quality of the building envelope (especially after a heavy rainfall and a thaw), the pipes, and technical equipment. Walk around the outside and inside looking for salt crystals on walls, discouloration of surfaces, algae and moss growth on wet spots, flaking paint, mould growth, and check for mouldy smells.

The visual inspection can be supplemented by warning equipment such as water detectors, which have sensors that provide an alarm when they get wet (Figure 55). These should be placed on the floor at a low spot or in the expected path of the water flow. Monitoring the relative humidity and temperature and analysing the absolute humidity give an insight into presence of humidity sources.

External sources of water are monitored by the meteorological office, water authorities and emergency services. When there is a threat of high water or heavy rainfall, it is important to keep an eye on the weather forecast and the relevant websites. This allows for early preparation, for instance placing sandbags or other water barriers near doors and windows.

Finally, registering incidents or near-misses in a logbook or database (such as DICE in the Netherlands) is part of monitoring. The data may reveal patterns and allow the most effective measures to be taken for the future.

Figure 55. Water detector

Basic resources	Advanced resources	Complete salvage
polyethylene film (roll) mop buckets chamois leathers rubber gloves rubber boots helmets torches and batteries absorbing paper newsprint paper (roll) towels freezer paper sponges	Basic resources + wet/dry vacuum cleaners industrial fans extension cords ladder trolley dehumidifiers toolkit	Advanced resources + more trolleys freezers access to a freeze-dryer quarantine space

Table 19. Resources to limit water damage

Respond and treat

The extent of water damage to the collection depends strongly on the responsiveness of the organisation. When the correct precautions are taken and when sufficient knowledge and resources are available to allow an adequate response, water damage can be limited significantly.

Even during an emergency, the collection – or at least the most valuable and vulnerable pieces – can be taken to safety. Evacuation to another location is not always possible because the emergency services have other priorities and there are usually few transport options. But 'vertical evacuation' to a higher place in the building is often still possible.

When an incident or emergency has taken place, act as quickly as possible, preferably within 48 hours. Water damage and the repair costs grow exponentially with time. Due to the absorption of water, parts of a building, such as stucco ceilings, can collapse under their own weight and crush the collection. Evacuate objects in the areas at most risk as quickly as possible. First move the most sensitive, valuable objects that have a short response time. Remove the water from the room as soon as possible. For information see, for example, the Emergency Planning e-learning tool (Museum of London, 2012) or the resources from the US National Parks Service (NPS, 2012).

Response and salvage require good preparation. All those involved should know in advance how to act, what are the priorities, who to call and where to take wet objects. There should also be resources available to remove the water, protect the objects and treat wet collections (see Table 19 and, for example, NPS, 2002). This should all be set out in the organisation's *emergency plan* or *disaster plan*. However, this is only useful if it is kept up-to-date and backed up by regular training (Dorge and Jones, 1999; Northeast Documentation Center, 2006; NPS, 2000; FEMA, 2005; Harwell Document Restoration Services, 2010).

When water damage occurs after a fire, insurance companies will often contact professional salvage companies. When this is not the case, it is advisable to contact an external salvage company.

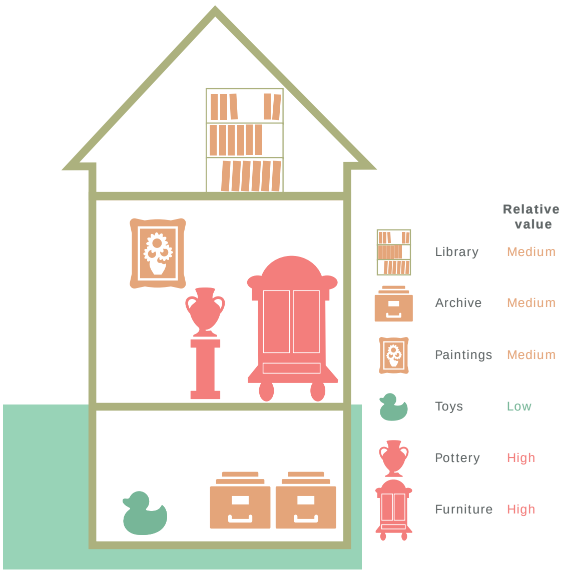
Example of QuiskScan water risks

It is difficult to assess the magnitude of water-related risks accurately, because there are insufficient quantitative data on the probability of ruptured pipes, leaking roofs or groundwater entering particular spaces in specific situations. The extent of damage is also difficult to estimate, since the time between water reaching the collection and stabilising wet objects has a great effect on the final loss of value. Nevertheless, a QuiskScan approach can provide a reasonable insight into one's water risks, as illustrated in the following example.

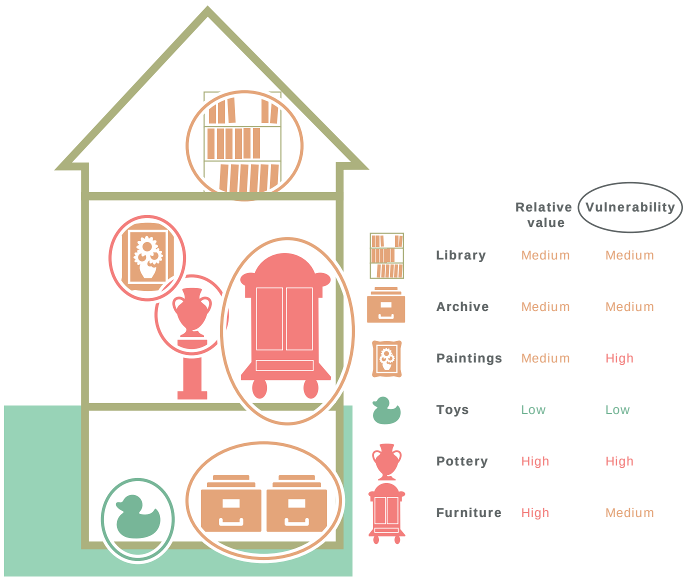
I. How are the collection and collection value spread through the building?

Indicate the collection anatomy on a floor plan or diagram of the building. Indicate the relative value of the objects with traffic light colours (red for high value, yellow for medium and green for low value). In this way, the distribution of the collection value throughout the building is made evident. This is an alternative representation of the 'value pie' (the pie chart that shows the distribution of the total collection value over the sub-collections or objects) as it shows the distribution of total collection value across the objects in the building. In this example, the collections are valued as follows:

- Library on the upper floor – medium value
- Paintings along the walls of the ground floor – medium value



I. Collection anatomy and value distribution



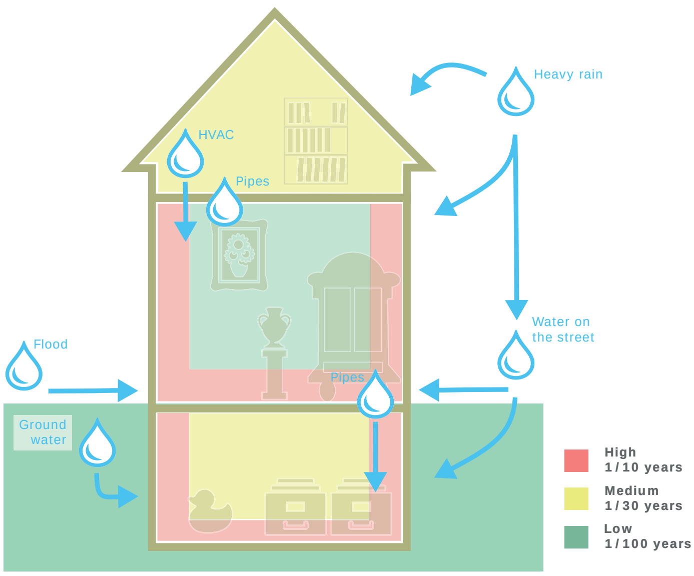
II. Vulnerability of collection to water

- Furniture and pottery on the ground floor – high value
- Archives in the basement – medium value
- Toys in the basement – low value

II. How vulnerable are the objects?

Determine the vulnerability to water and the expected changes in shape and function to get an idea of how much value will be lost when the objects become wet. Indicate the vulnerability of the objects on the floor plan or in the diagram, using traffic light colours for high, medium and low. In this example:

- Tightly packed books on shelves in the library may become mouldy – medium vulnerability
- Paintings on canvas will sag and lose paint – high vulnerability
- Furniture can suffer loss of veneer and some cracking – medium vulnerability
- Pottery contains unfired and breakable objects – high vulnerability
- Archival documents in boxes may suffer water staining, bleeding ink or mould – medium vulnerability
- Toys in basement, made for use in water – low vulnerability



III. Water sources and probability of exposure

III. What water sources are present and what are the chances of exposure?

Map the different internal and external water sources. Ask employees what they remember of previous water-related incidents and consult incident reports. What were the causes; which measures were effective and which were not; how did the objects get wet and how bad was the effect? Which measures have been implemented or improvements undertaken subsequently? Look at the condition of the building envelope, equipment, pipes, taps and drains.

For every source of water, the pathway and potential area that may get wet can be drawn on the floor plan or diagram. In our example, traffic light colours are used to indicate the probability of water exposure in various parts of the building:

- Once every 10 years (red) exposure to water is expected for the ground floor walls and floor. The sources are leaks from internal pipes and equipment and external heavy rain that leads to flooding in the street
- Once every 30 years (yellow) the upper floor and the greater part of the basement are expected to get wet due to leaking equipment and pipes, or from a leaking roof
- Once every 100 years (green) the internal space on the ground floor becomes wet due to an exceptional flood

IV. Exposed vulnerable value = risk

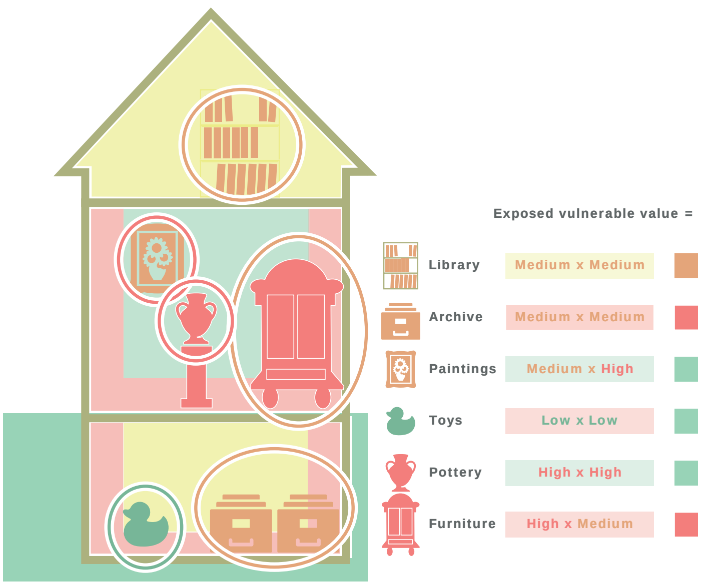
Superimposing or combining floor plans or diagrams I, II and III reveals how probable it is that vulnerable value will become wet. When all three factors are 'high' for a particular object or collection, there may be a high risk if exposure leads to a loss of value. A more detailed assessment of that particular scenario is then justified. In the example, the outcome is that:

- The furniture on the ground floor faces the largest risk, since there is a high probability that these high value objects of medium vulnerability will be exposed to water
- The boxes containing archives in the basement also face a high risk, although their value is lower than the furniture
- Although the pottery has a high vulnerable value and the paintings are rated slightly lower, the probability that either of these collections are exposed is low. The pottery objects are kept well above the floor and the paintings are hung with spacers that hold them away from the walls down which water may run. As a result, the risk for either sub-collection is small.
- The toys have a high likelihood of exposure, but low vulnerable value, so they face a small overall risk

Relationship with other agents of deterioration

Measures that reduce one risk can have side effects on other risks. They can have a synergistic effect with a positive effect on reducing other risks, but they can also have a negative effect, leading to a (temporary) increase of other risks. Maintenance work on the roof to reduce the water risk can increase the fire risk, particularly when blow torches are used to join or seal parts. A painting in a microclimate frame also has added protection against water and fire.

Examples of the relationship between 'Water' and other agents of deterioration are listed in Table 20.



IV. Superimposing figures I, II and III shows the exposed vulnerable value, or the risk

Schadefactor	Interactie
Fysieke krachten	Sommige vochtige materialen verliezen sterkte en draagkracht en bezwijken bij hanteren, bijvoorbeeld natte dozen en kranten. Bij evacuatie van de collectie kunnen objecten ruw worden gehanteerd. Bij wateroverlast kunnen delen van het gebouw bezwijken, bijvoorbeeld een plafond dat naar beneden komt.
Brand	Bluswater kan waterschade veroorzaken zoals vervormen van materialen en uitlopen van kleurstoffen. Uit blusapparatuur kan, al dan niet opzettelijk, water vrijkomen.
Dieven en Vandalen	Bij ontruiming van het gebouw en evacuatie en opvang van de collectie buiten het gebouw neemt het risico op diefstal toe. Vandalen kunnen water uit bijvoorbeeld brandhaspels gebruiken.
Ongedierte en Onkruid	Knaagdieren, sommige insecten en planten hebben water nodig om te groeien. Hun aanwezigheid is een indicatie voor waterbronnen.
Verontreiniging	Water uit leidingen, installaties of overstromingen is vrijwel altijd vuil en zal tot verontreiniging leiden. Wassen met water als behandeling om verontreiniging te verwijderen kan schade veroorzaken.
Licht, UV- en IR- straling	Lichtniveaus binnen kunnen hoger zijn dan verwacht door reflectie op vijvers en water buiten het gebouw.
Onjuiste temperatuur	Aan koude oppervlakken zoals ramen, buitenmuren, vloeren en koude waterleidingen kan condensvorming optreden en watervorming plaatsvinden. Koel- en verwarmingsinstallaties kunnen lekkage met waterschade veroorzaken.
Onjuiste RV	Aanwezigheid van water leidt tot een verhoging van de RV in de lucht. Luchtbehandelingsinstallaties vormen een bron van wateroverlast.
Dissociatie	Bij overstroming is de kans groot dat etiketten nat worden, scheuren of de tekst uitloopt en onleesbaar wordt. Bij evacuatie in geval van wateroverlast neemt de kans op dissociatie toe.

Table 20. Examples of the relationship between 'Water' and the other agents of deterioration

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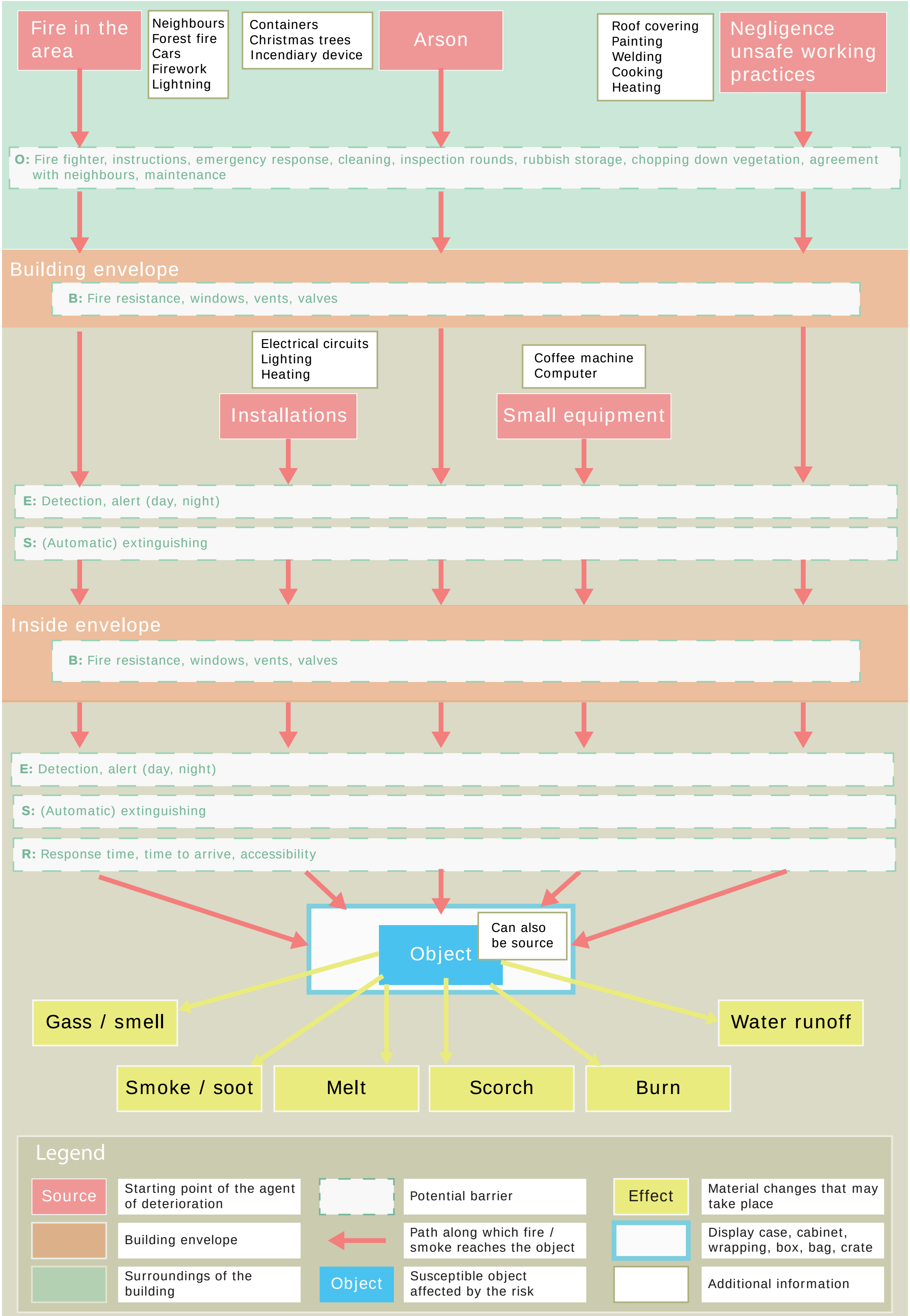
The first time we made a risk assessment was in 2004, because we were moving the archive to a new building – De Bazel in the Vijzelstraat. The plan was to create a 'Treasure Room' in the former gold safe, with 250 masterpieces from our collection, where our visitors would always be welcome. It would contain books, prints, drawings and documents on parchment and paper, sometimes very fragile, which were normally kept in storage. What were the dangers if these were put on display in a permanent exhibition? Nobody knew exactly. All the possible risks were identified and analysed by staff from various departments of the Amsterdam City Archives in collaboration with RCE. Would we get more incidents of theft or vandalism? De Bazel is an eye-catching building, much more so than our old building along the Amstel river. How about agents of deterioration such as light, temperature and relative humidity in the Treasure Room? Would they differ very much from the storage areas?

After some brainstorming sessions, it turned out that the lighting strategy for the Treasure Room had to be adjusted, because the fading of ink-wash drawings proved to be more rapid than we first expected. A solution would be to rotate such vulnerable prints every three months, but we simply did not have enough staff to do so. Therefore, we decided to shorten the exposure time for each object and to exhibit mostly items that are less fragile. Later, the risk assessment also helped us to draw up a conservation plan. At this point we discovered that acidic paper objects from the 19th century, which are packed in old folders, suffered more damage than the much older, individual letters on parchment or rag paper that are written in iron gall ink. Although these old folders are less frequently requested in the study room, they were given – justifiably so – the highest priority for care after the risk assessment.



Scenario scheme for the agent of deterioration 'Fire'

Fire

Scenarios for fire

This scenario scheme outlines the most common scenarios related to fire. At the top is the outside world, while at the bottom is the object or collection, probably indoors, in a room, and perhaps in a showcase, cabinet or box. The scheme shows a cross-section through the layers around the object. The alternative scheme on the opposite page presents the same scenarios on a generalised floor plan of a building.

The red boxes represent the sources of fire, grouped by the most common causes; they can be found outdoors, indoors, in a particular room or within a display case.

The orange bars outlined in grey represent the barriers that fire meets on its path from source to object. These can be at a building level (B), through electrical systems for detection and alarm (E), and organisational (O) measures to prevent and detect fire. A quick response (R) and adequate suppression (S) to minimise the damage in case of a fire, can also be considered as part of this set of barriers. The green texts in the bars below the scheme provide guidance on how to determine the performance of the barrier. When an object is placed outdoors, there are probably no barriers, except perhaps a protective cover over the object.

The red lines represent the pathways that fire can take. Fire-resistant barriers reduce the probability of fire reaching an object, or reduce the spread of the fire through the building, and thus the impact on the whole collection.

The blue box represents the object, which has a specific sensitivity to fire. Some materials are more flammable or affected by fire than others; the object itself can also be a source of fire.

The yellow boxes outlined in green describe the most common effects of fire.

Each line drawn from a source, via one or more barrier, to the object and an effect, represents the scenario for one specific risk.

Introduction

Fire is an agent of deterioration for which the risks are often underestimated. Fires usually affect other people – not us. But on closer examination, fire always has a high score in a risk assessment because, while the probability of fire in an institution is relatively low, the impact is great. Objects are usually seriously damaged in a fire and a large part of a collection could be damaged.

To identify the risks from fire, it helps to think of three types of scenario. First, a small local fire, which might perhaps result from a fallen candle or a smouldering cigarette butt; this can be dealt with quickly to limit the damage to a few objects. Second, a medium-sized fire confined to a room or fire compartment and affecting only part of the collection. Third, a large fire that engulfs the entire building as well as the collection.

A large blaze will, of course, always start as a small, local fire. The amount of combustible material (the fire load) in the vicinity of the seat of the fire, as well as the speed of detection and response, determine if a local fire will develop into a larger blaze. Small fires occur more frequently than larger incidents, but may nevertheless create much soot and water damage.

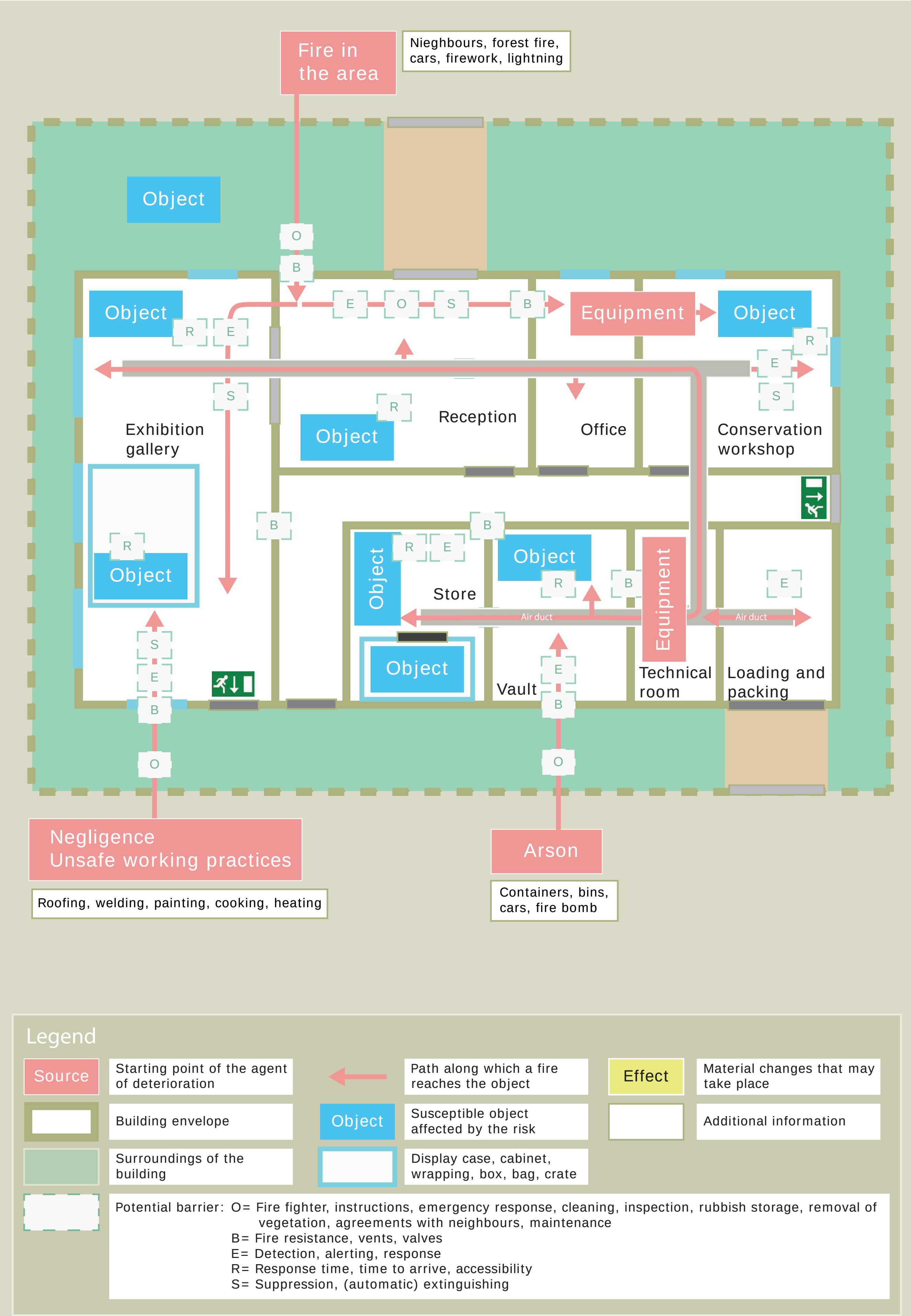
Museums do not experience fires frequently enough to generate useful statistics in their own right, and so need to make use of shared experiences and (inter)national statistics. In the Netherlands, the Central Bureau for Statistics (CBS) collects fire statistics from each fire department, but data on fires at cultural institutions are not collected specifically (CBS, 2014). The Dutch Database of Cultural Heritage Incidents (DICE) contains information on every type of incident in heritage institutions; each year the quantity of data on fires increases (RCE, 2015). In the built heritage, fire incidents number nearly 40 per year and in museums, a fire incident is reported each year ('Erfgoedmonitor' – Heritage Monitor, 2015). Experience shows that museums hosting events that include catering have an especially high risk of fire incidents; one incident per 100 events is not uncommon. These may not result in damage to the collection, since preparedness and a rapid response can prevent damage.

In determining the risks of fire, institutions should make use of their own experience and generic statistics from their own country, as well as studies by museums abroad. The most comprehensive study of this type was undertaken by Jean Tétreault for museums in Canada (Tétreault, 2008). Other helpful publications emerged from the European Fire-Tech Project (FiRE-TECH, 2003).

Fire pentagon

The fire pentagon (Figure 56) is a schematic overview that includes the three essential factors required *simultaneously* for a fire to occur:

Combustible material – This can be a solid, liquid or gas. Heritage collections with organic objects are highly flammable, as are materials that are not part of the collection, such as packing materials, furniture, solvents, oil and gases.
Oxygen – At least 16% oxygen is needed in the air for materials to burn. The degree of ventilation has a great effect on the intensity of the fire: more air produces more flames. To prevent a fire,



Scenario scheme for the agent of deterioration 'Fire' (alternative)

reducing the oxygen content in the air from 21% to less than 16% is sufficient (termed hypoxia). To extinguish a fire, the oxygen content must be much lower.
Ignition energy or heat – A flammable substance does not ignite spontaneously; a certain amount of energy is required and this can be supplied by a flame (e.g. a lighter), a spark (short-circuit) or a high temperature (heat, pressure or friction).

In addition, there are two factors that influence the combustion process positively or negatively:
- the **mixing ratio** between the three essential factors determines if the fire produces more energy (when the ratio is optimum) or more pollution in the form of soot (at a sub-optimal ratio);
- a **catalyst** is a substance that is not involved in the combustion reaction, but can speed up or slow down the process.

Fire development

A fire develops in several phases. In the *incipient phase*, the fire is small, material begins to smoulder and a flame gutters from lack of air. In this phase a fire is still easy to control but is not usually detected, because there is hardly any smoke. Smouldering can take hours, but the initiation phase can also be very brief – in the case of a gas leak, for example.

Next comes the *growth phase* in which the smouldering material burns and smoke is released; the fire is usually noticed in this phase. The temperature can reach up to 300–600°C, but this rise in temperature is local so that, with rapid detection, alarm and response, the fire can still be controlled. Depending on the circumstances, this stage can take about 10–15 minutes, and this is a crucial moment if an adequate response is to be made.

Above a temperature of 300°C, heat radiated from the growing smoke layer can raise the local temperature high enough to cause the decomposition of materials and subsequent emission of flammable gases. When they reach their auto-ignition temperature an explosive chain reaction evolves. This moment of *flashover* is very dangerous. In the *fully developed phase* that follows, all the combustible materials in the space have caught fire and the temperature rises to around 1,000°C. The fire has reached its maximum extent and firefighting in the space no longer reduces damage; the firefighters can only make sure the fire does not spread to surrounding areas.

When fewer decomposition products are formed and fuel thus runs out, the fire enters the *decay phase* and finally *extinguishes*. In the absence of oxygen, the fire can continue to smoulder for some time, releasing decomposition products that may accumulate in unexpected places (for example, behind a suspended ceiling).

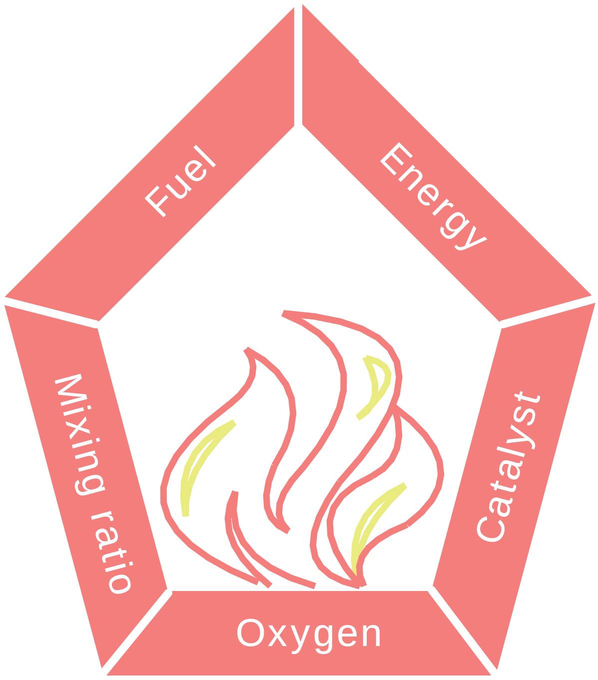


Figure 56. Fire pentagon

When oxygen is added – for instance, when a door is opened – these gases may suddenly combust explosively; a so-called *backdraft*. The whole process is illustrated in videos on various websites (see for example National Institute of Standards and Testing, 2010).

Smoke

The smoke released during a fire consists of hot gaseous combustion products (carbon dioxide, water vapour), toxic and corrosive gases (carbon monoxide, hydrogen chloride), solid and liquid soot and tar, solid and glowing semi-burned particles, and air that has not been consumed in the combustion reaction. A great deal of smoke is formed rapidly, which is harmful for people and materials. Inhalation of toxic smoke is deadly and the hot air burns the respiratory system, while smoke reduces visibility and hinders escape. Hot air and smoke rise to the ceiling and can spread through openings and ducts to other parts of the building. Even small fires can cause major smoke damage and removing soot from interiors, furniture and the collection is time-consuming and costly.

Cause	The Netherlands (Hagen, 2009)	Europe (Tétreault, 2008)	Canada (Tétreault, 2008)
Negligence and carelessness (smoking, cooking, candles, painting, renovations, welding, smouldering)	29%	18%	32%
Arson (intentional, targeted protest, statement)	24%	26%	30%
Fire in the vicinity (neighbours, forest fire, lightning, fireworks)	14%	5%	10%
Building systems and installations (wiring, gas pipes, heating, lighting)	14%	33%	20%
Small equipment (coffee machines, monitors, office appliances, tools)	19%	18%	8%

Table 21. Causes of fire in collecting organisations with their relative frequency as a percentage of total incidences (data from Tétreault, 2008, Table IV; Hagen, 2009).

Figure 57. Fuse boxes: an electrical source of fires

Fire classes

Fires are classified based on the type of fuel. This distinction is important when choosing the correct extinguishing agent. Different regions of the world have slight differences in their classification system. Here the European classification is used, with the systems used in the United States and Asia/Australia in brackets. More information about different extinguishing agents follows later in the text.

Class A (US Class A; Asia/Australia Class A): ordinary combustible materials, solids of predominantly organic origin (wood, paper, textile, paint) that burn without necessarily producing a flame and leave ash (collection and building). Best extinguished by water or foam, which cool the fuel to below its ignition temperature.
Class B (US Class B; Asia/Australia Class B): flammable liquids (burn at room temperature) and combustible liquids (require heat to ignite) such as petrol, alcohol and solvents. Best extinguished with foam, CO_2 and powder, creating a barrier between the fuel and oxygen. Water may not extinguish these fires.
Class C (US Class B; Asia/Australia Class C): flammable gases such as natural gas, propane and LPG (liquid petroleum gas) (during work, in installations). Extinguish by closing off the gas supply and inhibiting the chain reaction with powder.
Class D (US Class D; Asia/Australia Class D): flammable metals such as aluminium and magnesium. Extinguished with special powders or clean dry sand. Extremely high flame temperatures can break down water into hydrogen and oxygen, heightening the fire.
Class E (no longer used) (US Class C; Asia/Australia Class E): electrical fires (installations, relay stations, fuse boxes, monitors). Electricity may be the cause of the fire, but Class A or B material

usually provides the fuel. Extinguished by switching off the power and using the methods appropriate for a Class A or B fire, usually CO_2 or powder. The use of water or foam is very dangerous because they conduct electricity.
Class F (US Class K; Asia/Australia Class F): cooking oils and fats (kitchen, restaurant and catering). Extinguished by removing oxygen using a hood or blanket, water mist or foam sprays or special fat- extinguishing agents.

Sources

In his research Tétreault studied the locations at which fires started. Of the 100 fires in Canadian museums between 1994 and 2004, only 3% started in collection areas (Tétreault, 2008). Table 21 lists the most common causes of fire in heritage organisations in the Netherlands, Europe and Canada. By far the most fires occur where people are present or where electrical equipment is operating. The causes of fires can be divided into five categories. Tétreault provides data on the distribution between categories in Canada (100 fires in the period 1994–2004) and Europe (during 1980–1988).

These are compared with data from a small register of 27 fires in collections in the Netherlands (1987–2009) that were reported in news archives and on the websites of insurance companies (Hagen, 2009), which show a similar distribution.

Although the Dutch Central Bureau for Statistics (CBS, 2014) does not have specific numbers for fires in museums, they give an overview of the causes for generic indoor fires. In 2013, there were approximately 15,000 indoor fires in the Netherlands. The causes were: defects in, or incorrect use of, equipment or products (42%); arson (19%); smouldering or self-ignition (17%); negligence and carelessness (12%); smoking (7%); fireworks (2%); and playing with fire (1%).

Frequency of fire in museums

To determine the likelihood of fire, one needs to look at the frequency with which fires occur, expressed as 'the mean time between events'. This can be calculated by dividing the number of fire incidents in museums by the number of museums and the period over which data on incidents was collected. Tétreault's analysis shows that the mean time between fire incidents in Canada for an individual institution is 160±70 years.

In the Netherlands a number of surveys on safety, security and incidents in museums have been carried out. A study by Etman and Eelman (1992) over the period 1987–1991 found that of the 352 participating museums, five museums had one or two incidents in five years and one museum had three to five incidents. That gives a mean time between events of between 117 and 220 years per institution (on average, 170±50 years).

As is clear from the data, an institution may have to deal with a fire-related incident several times in a particular period, while other institutions will go longer between events. In comparison, the data from the CBS for 2008 show that there were 200 fires in office buildings, while in 2010 there were 100 fires. With approximately 20,000 office buildings in the Netherlands, the 'mean time between events' is 100 to 200 years.

To determine the frequency of fire incidents in one's own institution, one should consult the institution's incident register and the 'memory of the organisation'. If the situation has not changed since the last incident, then the period between incidents in the past is the starting point for determining future frequency. If there are no known incidents, then it is possible to work with the national averages, given above for the Netherlands and Canada (170±50 and 160±70 years). These periods are based on an average level of control. If that level is lower or higher, then the 'mean time between events' increases or decreases accordingly (see Table 23).

Pathways and barriers

The effectiveness of the barriers that a fire encounters on its path from the source to the object is determined by a combination of building physics, installations and organisational measures. In the scenario scheme they are described by the text in the barriers. Taking a particular measure does not automatically mean that it is effective. Creating fire compartments limits the spread of fire through a building and reduces the loss of collection, but a fire door is ineffective if it is left open or does not close automatically when the fire alarm goes off. A fire-resistant wall loses its effectiveness when pipes are routed through the wall and the openings are not sealed correctly. Procedures for working safely are only effective when they are followed. Drawing up an emergency preparedness plan, updating it frequently, regular training in its execution, and consulting with the local fire brigade, can increase the effectiveness of the barriers significantly.

Vulnerability	Description	Examples	Relative flammability
Very low	Not flammable, does not deform, but can become brittle	Plaster, stucco, gypsum, chalk, ceramics, stone	0.1
Low	Not flammable, can deform at high temperatures	Glass, thin metal under pressure	0.5
Medium	Solid organic material, can melt and deform, ignites slowly when in contact with small flame or heat	Solid wood, bound paper, books, archives in boxes, animal fibres	1
High	Thin organic material, melts or deforms, ignites quickly when in contact with small fire or heat	Loose sheets of paper, textiles, vegetable fibres, paintings, plastics	10
Very high	Fast burning and explosive material, ignites at low temperature, vigorous reaction when in contact with small flame	Cellulose nitrate (film), solvents, ammunition, fireworks	1,000

Table 22. The vulnerability to fire of materials found in heritage collections (after Tétreault, 2008, Table VIII).

Objects and their vulnerability

Damage to objects can be categorised in four groups (related to the loss of value per affected object):

- Undamaged and no treatment required (no effects of fire, smoke or water);
- Damaged but can be restored (significant effect of fire, smoke or water);
- Damaged and cannot be restored (disastrous effect of fire, smoke or water);
- Total loss (completely burnt surface or object).

The extent of the damage depends on the response time, in combination with the flammability of the material of which the object or collection is made, the ease with which soot adheres to the materials, and its sensitivity to the agents used to extinguish the fire. The flammability depends, among other factors, on the ignition temperature and the ease with which the material reacts with oxygen. The flammability also influences the spread of the fire. The experts who were questioned by Tétreault classified the materials found frequently in collections; Table 22 shows this classification with some additions.

Options for risk reduction

When devising options to reduce the risk of fire, the whole 'safety chain' needs to be taken into consideration. This chain generally includes five steps: pro-action, prevention, preparation, repression and aftercare. They closely resemble the common steps followed in preventive conservation: avoid, block, detect, respond, recover or treat. In the experience of fire brigades, the most cost-effective measures are those covered by the first three steps. In addition, the fire brigade increasingly relies on institutions to act responsibly and be self-reliant in terms of fire prevention and rapid initial response to fire.

The most important precaution to prevent fire is to remove as many sources as possible or to reduce the chance of fire at the source: prohibit open flames, remove flammable materials from the vicinity of the building, avoid faulty electrical systems, and regularly maintain buildings systems.

When blocking fire, it is important to incorporate resistance to propagation and flashover. The resistance rating indicates the time before a fire will penetrate the perimeter of a fire compartment. This is determined for the walls, doors and glass, and can range from 30 to 240 minutes.

Figure 58. Commonly used detectors: manual alarm switch (break glass and press button), smoke detector, heat detector and CO detector.

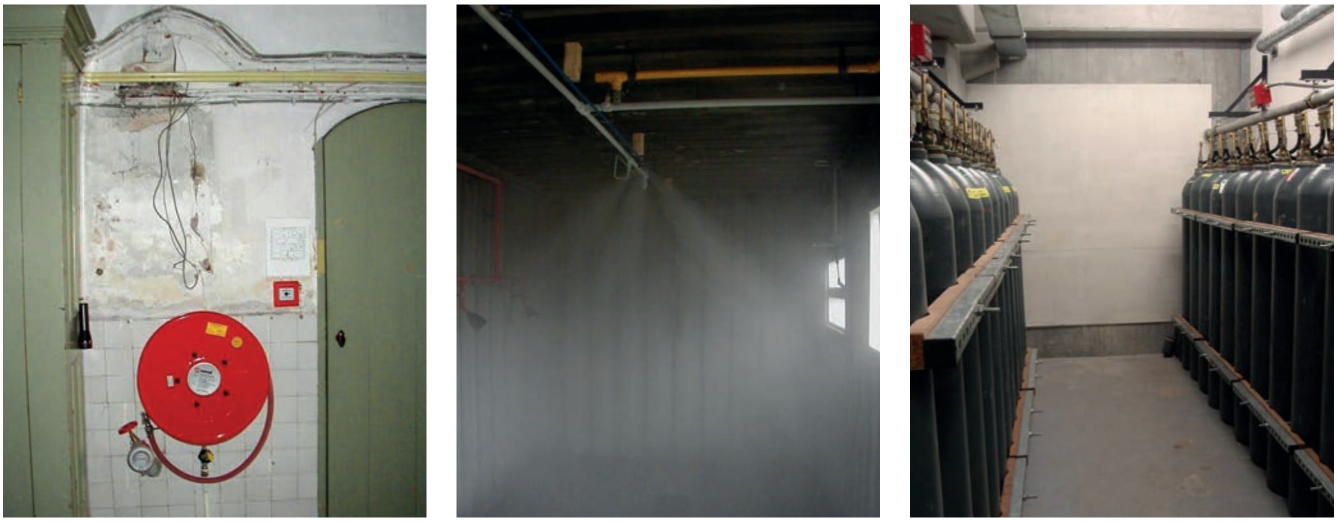


Figure 59. Extinguishing at the source (left) and automatic suppression systems: a water mist sprinkler (centre) and an argon system (right).

Figure 60. A chimney fire in a historic house and the fire brigade limiting water damage by using a tarpaulin.

Once a fire has started, rapid detection, alarm and response should ensure swift control of the fire to limit damage. There are many options for detection and alarm (see Figure 58). Detection can be through people present in the spaces activating a manual alarm, or sensors that sound an alarm signal when they detect heat, smoke, flames or gases. The alarm may or may not be automatically relayed to a central alarm facility or the fire brigade. Alternatively, the detector can be connected to an automatic suppression system such as a sprinkler system.

There are different methods and extinguishing agents available to confine and control fire (see Figure 59). For a quick first response at the source, an employee can intervene manually using a fire blanket, a portable extinguisher or water from a fire hose. If there are no people present, an automatic fire extinguishing system at the source (a small aerosol powder extinguisher in a switch box or near electrical equipment), or in the room, are most effective. Automatic suppression systems can use water (sprinkler, water mist sprinkler) or gas (argon, nitrogen, Halon, Inergen).

After a fire, the collection must be recovered and treated. How this is accomplished will vary between types of material and object. Information can be found in, for example, Stewart (2016). As fire damage is usually an insurance issue, insurers often contract salvage companies to provide object first aid and salvage after a call from the fire brigade or client.

More information on measures to prevent and control fire can be found in Kidd (2010), Stewart (2016), the Fire Damage Wheel (RCE, 2011) and national fire department websites. For good advice, see an expert in the field of fire protection. Regular contact and consultation with the local fire brigade is always very important. Their primary concern is the safety of people and animals, but if their attention is also drawn to the collection and the building, the fire brigade can take these into account in case of an emergency (Figure 60). Joint exercises are a very useful way to reinforce this relationship (Figure 61).

Fire extinguishers

Extinguishing a fire focuses on removing or isolating at least one of the three essential factors from the fire pentagon. The *fuel* can be isolated (cover it with extinguishing foam or a fire blanket) or can be removed (turn off the gas in a gas fire, fell trees in a forest fire, limit fuel by partitioning). *Oxygen* can be extracted or displaced (argon extinguishers, hypoxia) and the *temperature* can be lowered (water). Various commonly-used extinguishing agents are described briefly below; extinguishing agents often have a combined effect.

Water

Water is the most common extinguishing agent. Its action is based on the cooling effect. Water can be used from a fixed fire hose or a suppression system. In some countries, portable water extinguishers are used. Depending on the nozzle, water is sprayed in jets or as a mist from either hoses or sprinklers. Some sprinkler heads react to the heat generated by the fire and release water locally, near that heat source. A sprinkler system uses only a fraction of the amount of water that the fire brigade will require to put out a fire.

Foam

Most flammable liquids are lighter than water and float on its surface, which is why such fires cannot be extinguished with water. So that water can be used as a coolant in these circumstances, foaming agents are added. The extinguishing action is thus based on cooling, partial coverage of the fuel and partial absorption of radiant heat. A large volume of foam extinguishing agent can be produced from a small amount of water,

The synthetic aqueous film-forming foams (AFFF) are very effective but can cause corrosion. Upon drying, the extinguishing agent remains as a sticky liquid on the surface of objects and these residues must be removed cautiously to prevent damage. Biodegradable foams based on proteins are less harmful to the environment and the object and the residues can be removed more easily (from smooth surfaces). Foam extinguishers offer a combination of good effectiveness and limited collateral damage.

Figure 61. Evacuation exercise by museum staff with the local fire brigade.

Another important benefit is that the foam can be aimed directly to where it is most needed so that any damage remains local.

Carbon dioxide

Carbon dioxide is used in portable fire extinguishers and can be mixed with other gases in automatic systems. It controls fire by displacing oxygen and thus suffocating the fire. An advantage of carbon dioxide is that because it is not an electrical conductor it can be used to put out electrical fires. Furthermore, it does not cause collateral damage. However, high concentrations of carbon dioxide in confined spaces are dangerous because they can suffocate both people and animals. Carbon dioxide does not penetrate beyond the surface and, despite its low temperature, does not cool the fire, so that it is ineffective against smouldering material and is used only for incipient fires. Carbon dioxide extinguishers are easy to use, but empty quickly.

Powder

Powders are used in portable fire extinguishers and suppression systems. Their extinguishing action is based on interrupting the fire's chain reaction. The powder from these extinguishers does not conduct electricity and is highly effective for virtually every type of fire. The police, for example, often carry a powder extinguisher in their car and use it when they arrive at an incipient fire. However, powder extinguishers are unsuitable for collections as the powder spreads over a large area, penetrates everywhere and into everything, causes corrosion and at high temperatures bakes into an enamel-like layer on the surface of objects. They cause considerable collateral damage and removing the powder residues requires specialised cleaning by experts.

Level of control and measures	Mean time between events MTBE (years)	Damage to single object (years)	Damage to collection limited to one space (years)	Damage to the building and large proportion of the collection (years)
Basic (CL1 or CL2) One or more staff for emergency response Basic emergency response plan Local smoke detectors Manual extinguishers and hoses inspected annually Procedures for smoking and open flames	Tétreault 140	100±30	100±30	100±30
Average (CL3) Awareness among all staff One or more staff for collection emergency response Extensive emergency response plan Training in extinguishing and evacuation Fire doors Fire detector and alarm system Comprehensive water supply network Regular inspection of electrical systems Monthly inspection of alarm systems	Tétreault 160 Etman and Eelman 170±50	200±60	200±60	1,000±300
Extra attention (CL4) Electricity supply to non-essential functions switched off at night Training in emergency response Compartmentalisation Alarm system connected to central emergency room Automatic suppression in important areas or near sources Preventive maintenance of systems Procedures for safe working	Tétreault 720	300±100	300±100	3,000±1,000
Maximum attention (CL5 or CL6) Regular training in emergency response Fire resistant outside envelope Automatic suppression throughout entire building Annual inspection by fire brigade	Tétreault 1,500-2,800	1,000±300	3,000±1,000	10,000±3,000

Table 23. An assessment of the mean time between events per museum (in years) for fires with different consequences at various levels of control. Based approximately on the data from Etman and Eelman (1992) and on Tables III and V and control level CL in Tétreault (2008).

Hypoxia

Hypoxia is a form of fire prevention in which the concentration of oxygen in an area is permanently reduced from the usual 21% in the air to about 15%, a level at which materials cannot ignite.

Level of control

The chance of a fire starting, how it subsequently spreads and develops, and the scale of the eventual damage, depend greatly on the level of control. The average of 170±50 years between fires per institution is based on a medium level of control. The frequency and effect decrease at higher levels of control. In his research Tétreault asked Canadian experts to correlate the distribution of fires with the level of control. His results are contained in Table 23, which presents the probability of a scenario and how much of the total collection it may affect.

Table 23 lists four levels of control with their 'mean time between events' and the time between events that cause a particular level of damage to the collection. Successively higher levels of control add measures to those already implemented at the lower levels. For every level of control, the fire can spread from the material or object where it starts to the space or room where the object is located and subsequently to the entire fire compartment or zone (for example, a floor). Finally, the fire engulfs several fire compartments or the entire building.

The higher the level of control, the faster and more effective the response and the more the fire should be confined. In that case, the mean time between events with a large impact increases. It is notable that the mean time between events increases enormously when an automatic suppression system is installed. Due to the quick response at the seat of the fire, the pathway for the fire is cut off immediately. One can no longer argue that sprinklers cause unacceptable water damage. The chances of a sprinkler head discharging water unintentionally are minimal, and the volume of water used by a sprinkler system is small, especially compared to the amount of water used by a fire hose. There are also automatic systems that release water mist or gas.

Possible water damage never outweighs the damage caused by fire. In historic buildings, the installation of sprinklers often encounters objections, but there are now several solutions, for example mobile sprinkler units; for Scottish examples, see Kidd (2010). Local automatic aerosol extinguishers near the source are an option where there is electrical equipment (for instance switch boxes and monitors) nearby. Although aerosol extinguishers are less suitable for use in collections, they can be very effective in those areas where there are no objects.

To achieve a given level of control in Table 23, all the measures needed for the lower levels must already have been implemented. So, level 'Extra attention (CL4)' will only be achieved if the requirements for CL1 to CL3 have also been met.

Rules of thumb for determining the magnitude of risk for specific risk scenarios

As fires in institutions do not occur often enough to generate useful data on frequency and impact for one's own situation, national or pooled data are needed. But, due to the lack of statistics on fire in heritage organisations in the Netherlands or elsewhere, it is difficult to determine the magnitude of risk for specific risk scenarios. If there is no expertise available to determine the frequency and impact of a specific risk scenario for one's own situation, then the following steps enable a rough estimate to be made.

1. What does the institution remember about fires in the past? Refer to incident reports and ask staff with a long service record. Have there been any incidents? What was the cause? Was anything damaged? What went wrong and what went well?
2. What is the level of control for the institution? Ask the staff responsible and local fire brigade. Which measures are in place?
3. Use the level of control to determine the expected mean time between events (MTBE) for fire incidents that will result in a certain level of damage (Table 23). If the last fire happened more recently and the protection has not been improved, then use the shorter time span as the MTBE. Note that a long MTBE is no guarantee that there will not be a fire tomorrow.
4. To determine frequency and effect of a specific risk scenario with a particular cause, the MTBE in step 3 is divided by the percentage of events with that cause (Table 21 for the Netherlands).
5. Determine which part of the collection and of the total collection value is located in the area of the fire.
6. Use the vulnerability of the 'exposed' part of the collection (Table 22) to determine how much value each affected object will lose within the response time.

Example:
In a natural history museum in the Netherlands a short-circuit in the lighting system causes a fire in a storage space with a basic level of control. The space houses a significant part (10%) of the collection with a high value. The museum has no recollection of fire incidents in the past.
According to Table 23 the MTBE for fire at a basic level of control in the Netherlands is 100±30 years. Table 21 shows that in the Netherlands 14% of the fires are caused by faulty building systems. The MTBE for this specific scenario is therefore 100±30 years / 0.14 = 700±200 years.
Natural history collections are not mentioned in Table 22, but based on their material characteristics they have a medium to high vulnerability. Table 23 shows that one can expect heavy damage to the objects in that space at some stage during the period covered by the MTBE.
In the context of QuiskScan, the example portrays a collection with a high value and high vulnerability; this is potentially a high risk.
When analysed in more detail with the ABC-method, the probability of exposure in this scenario would score A = 2–2.5. Heavy damage would score B = 4–5, and a significant part of a highly-valued collection would score C = 4–4.5. The resulting magnitude of risk ranges from a minimum of A + B + C = 2 + 4 + 4 = 10 to a maximum of A + B + C = 2.5 + 5 + 4.5 = 12. Given that the maximum score is 15, this is a high priority risk despite the small probability.

Agent of Deterioration	Interaction
Physical forces	Fire affects the strength and load-bearing capacity of materials and constructions, causing parts of the building or object to collapse. When evacuating the collection, objects are handled roughly.
Water	Water from firefighting can cause water damage, such as deformation of materials and bleeding of dyes and inks. Water can be released from fire extinguishers, intentionally or accidently.
Thieves and Vandals	When evacuating the building, as well as during removal and salvage of the collection outside the building, the risk of theft increases. Installation of fire safety measures requires access by strangers and an increased chance of theft.
Pests and Plants	Good fire compartmentalisation impedes the spread of vermin. Hypoxia also reduces the chance of damage due to infestations.
Contaminants	Water from firefighting equipment can be contaminated. Extinguishing agents leave residues. Fire produces smoke, soot and corrosive gases. Fire can produce harmful reaction products from the objects.
Light, UV and IR radiation	Emergency exit lights are lit day and night at low light levels (they only need to be lit when there are people in the room).
Incorrect Temperature	In areas not exposed to fire, an increase in temperature can nonetheless occur. Storing cellulose nitrate objects and film at low temperatures prevents self-ignition and extends their lifetime.
Incorrect Relative Humidity (RH)	After a fire is extinguished with water the RH is high causing deformation and a high risk of mould growth.
Dissociation	During evacuation of the collection, there is a high risk of disorder and displacement; labels can get lost and parts of objects can be separated.

Table 24. Examples of the relationship between 'Fire' and the other agents of deterioration

Relationship with other agents of deterioration

Measures that reduce one risk can have side effects on other risks. They can have a synergistic effect with a positive reducing effect on other risks, but they can also have a negative effect leading to a (temporary) increase of other risks. Constructing a fire alarm system to reduce the risk of fire requires outsiders to work in the building, which increases the risk for theft. Maintenance work on the roof to reduce the water risk could increase the fire risk, especially when roofers need to use open flames to melt or weld materials. The framing system fitted to a painting to protect it from an incorrect indoor climate also provides protection against fire damage.

Agents of deterioration may also act sequentially. During a fire evacuation, loose labels may become detached, which increases the risk of dissociation. Examples of relationships between 'Fire' and the other agents of deterioration are listed in Table 24.

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Manon Borst

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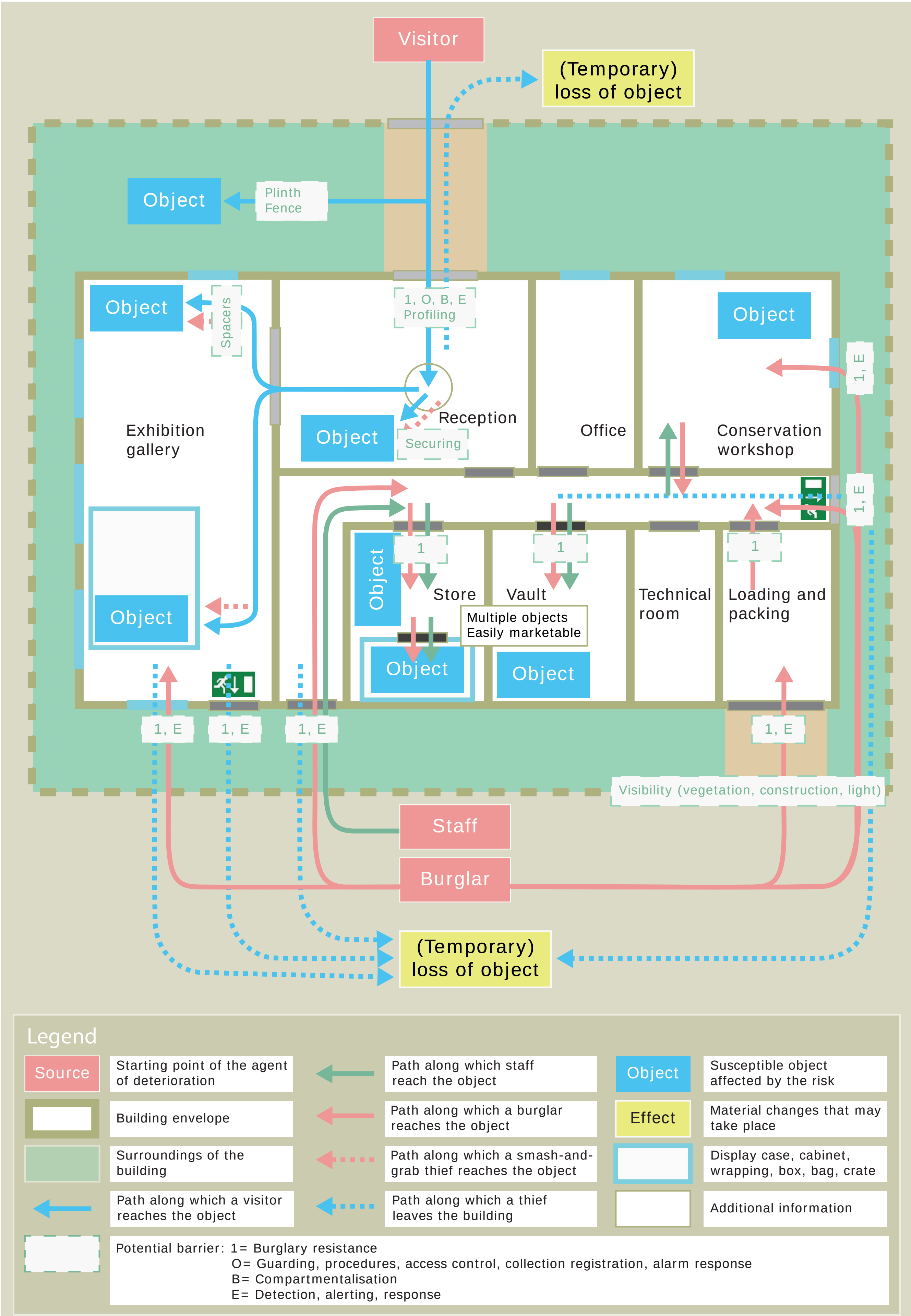
In 2006, our museum moved to its current premises in the centre of Franeker – a castle built in 1506. It is a beautiful monument, but centuries-old and full of cracks. Before we moved in, it had to be adapted to meet modern requirements. An expensive climate control system was, therefore, installed in the attic. Subsequently, the museum was fitted out and the first visitors came. Everything was under control – or so it seemed. But after a month, we got our first energy bill. I was shocked; it was huge. And to say the climate was fine; well, no, the thermohygrograph readings were all over the place. At the time we tried to follow the strict guidelines of 18°C and 50% RH provided by the former Netherlands Institute for Cultural Heritage (ICN). I called them immediately and, fortunately, it was just when they were thinking about the management of collections in old and difficult buildings. Together with the University of Technology in Eindhoven, we initiated a study. First, we looked carefully at our building and the collection. We concluded that we did not have any Mona Lisa-like objects and that we could decide for each object if a relative humidity of 50% was really necessary; could it possibly cope with a RH that was bit higher or lower? In short, we switched to using our common sense rather than a given number.

Eventually the climate control system was turned off and we took other measures. In the winter, the temperature is set at 17 to 18°C, the appropriate temperature for our collection and still pleasant for our visitors. Vulnerable paintings are placed in microclimate frames, the showcases have been fitted with good seals and some mobile humidifiers have been installed. As for the climate control system, it's still in the attic under a thick layer of dust.



Scenario scheme for the agent of deterioration 'Thieves and vandals'

Thieves and vandals

Scenarios for thieves and vandals

This scenario scheme sketches the most common scenarios for thieves and vandals. It is based on a generalised floor plan of a building and presents a cross-section through the layers around the object. Around the perimeter is the outside world. In the building are several objects or collections, on display or in storage, perhaps in a showcase, cabinet or box. They are represented by pale blue boxes and have a specific vulnerability to theft or vandalism.
The red boxes represent the different types of thieves and vandals. They come from outside and can enter the building with or without permission. Their acts can be spontaneous or premeditated, but in either case, the damage is deliberate.
The arrows from the sources to the objects show the path the thief or vandal takes, or the pathway along which the risk develops.
The possible barriers that the thief or vandal may encounter on their way to an object are given in the boxes with green text. The scenario scheme for theft is slightly different to others, because a theft is only successful when the thief leaves the building with the stolen object(s). Accordingly, there are arrows drawn from the object to the outside, and these also encounter barriers.

Each line drawn from a source, via one or more barrier, towards the object (and in the case of theft, back outside from the object) and an effect, represents the scenario for one specific risk.

Introduction

Theft is the intentional, illegal removal of an object, either premeditated or because there was an opportunity to do so. The principal aim of every museum is to offer access to the collection, so it is impossible to keep the collection completely locked behind bars. There is always a conflict between security and accessibility.

Many instances of theft from museums are isolated cases and are not carried out by professional criminals, but rather by someone who was given the opportunity. The thief – a visitor, guest or employee – seizes the opportunity to take or 'borrow' something that was within reach or unprotected. This usually involves only a few objects or small objects of low value. This type of theft is normally not made public, which is why there is so little data available on probability and type of objects stolen for this scenario.

More spectacular, often (inter)national cases, such as the theft from the Van Gogh Museum in Amsterdam (2002) or of Munch's *Madonna* and *The Scream* from the Munch Museum in Oslo (2004), the vandalisation of Rodin's *The Thinker* and other sculptures in the garden of the Singer Museum in Laren (2007), and the burglary at the Kunsthal Museum in Rotterdam (2012), are widely reported by the press. But the number of such incidents is too small and the information too incomplete for statistical analysis of probability and effect. For this reason, it is very difficult to estimate the likelihood of a robbery taking place.

To take appropriate measures against theft, an analysis of the risks is essential, but there are insufficient data. In the Dutch Database of Cultural Heritage Incidents (DICE) during the period 2008–2014, 15 museums reported a break-in, theft or attempted theft (RCE, 2015a). Some of these museums reported more than one instance so that, in total, there were 23 registered incidents. In eight of these incidents, objects were stolen from the collection: metal (silver and bronze), textiles, paper (books and maps) and a painting. In other cases, office supplies or personal items (e.g. mobile phone, wallet) were taken.

Vandalism was reported 31 times in nine museums: damage to the building, the interior and the collection. Misbehaviour by young visitors or teens loitering around the museum was the cause in 28 cases, in eight of which damage was done to the collection, such as a broken part, a scratch or a tear (RCE, 2015b).

In 2010–2012, the Cultural Heritage Agency of the Netherlands conducted a study into the probability and consequences of museum theft in relation to the level of security in a heritage institution. The research focused on experiences and opinions of (security) experts. It allowed a projection to be made of both the types of theft and the objects likely to be stolen over the coming five years (Peek, 2011).

Figure 62. Armed thieves leave the Munch Museum in Oslo carrying paintings, including The Scream by Munch (2004) (Source: Wikipedia).

Vandalism

Vandalism is the intentional destruction of, or damage to, other people's property, whether premeditated or not. This damage can be inflicted using intentional 'Physical forces', such as: breaking, bending or smashing an object, cutting or carving into it, or toppling it over. But it can also include intentional 'Contaminants' (acid or solvent attack, graffiti), or intentional 'Dissociation' (moving objects, adding parts).

In some cases, specific objects or objects by particular artists have been attacked. For instance, Rembrandt's *The Night Watch* was attacked twice: in 1975 with a serrated knife (see Figure 63) and in 1990 with sulphuric acid. Two paintings by Barnett Newman were attacked with a 'Stanley knife' in a museum in Amsterdam by the same person; the first (*Who's Afraid of Red, Yellow and Blue III*) in 1986 and the other (*Cathedra)* in 1997.

Because protecting sculptures in public spaces is generally much more difficult than in a museum, theft and vandalism of art in such areas is a serious problem. A combination of value, vulnerability and opportunity will determine likelihood. Outdoor sculptures that are easy to reach are more frequently climbed, defaced and damaged than sculptures on a high plinth or behind a fence. A result of current high copper prices is an increase in the number of bronze sculptures, copper gutters, drainpipes, lightning conductors and cables stolen (Morelissen, 2016) (see Figures 64 and 65).

Figure 63. On 14 September 1975, a disturbed man damaged Rembrandt's The Night Watch with a kitchen knife. Despite the 12 slashes – of which a few went through the canvas – the resulting damage was less problematic than expected at first sight. Only 'a fraction of the original material' was lost (Source: Wikipedia).

Figure 64. Scratching a name and date into the surface of an object or building as a token of presence has been a common practice for centuries. When it records famous people or historic moments, such graffiti may be considered to enhance value, while on a modern outdoor statue it is seen as very disfiguring and represents a great loss of value.

Figure 65. In 2002, 15 sculptures were stolen from the sculpture garden of the Beerschoten Foundation in De Bilt, the Netherlands.

Types of theft

Based on motive and modus operandi, eight different types of theft can be distinguished (Peek, 2011).

- Break-in: forced entry into a building by outsiders with the intention of committing theft (breaking and entering);
- Intrusion: unauthorised access, but not forced entry, aimed at stealing something;
- Shut-in or lock-in: purposely staying behind after opening hours;
- Internal theft: theft by insiders; the institution's own staff, volunteers or frequent users with direct access to the collection;
- Opportunistic theft: unpremeditated act by somebody who seizes the opportunity to steal an object, for instance souvenir hunters;
- Armed robbery: a premeditated act that involves violence and fear (raid or hold-up);
- Smash-and-grab: bold entry and action with a quick getaway to avoid being caught; and
- Pre-rehearsed theft: carefully planned theft with several visits to the museum to prepare; executed during opening hours.

Motive

There are several motives for theft (Korsell *et al*., 2006). The three most important are: financial gain (sale, ransom, investment, trading goods among criminal organisations), acquisition of status (souvenir hunters, collectors), and psychological and political (blackmail). According to Peek's research, paintings have a high likelihood of being stolen to sell or for a ransom. Despite their great cultural and financial value, famous paintings will be difficult to sell, but are suitable for ransom as they have a high insurance value.

In addition to cultural value, the financial value of the material itself, such as bronze, is reason enough for the theft. Because of the relatively high price of copper, the theft of bronze sculptures has greatly increased (Figure 65). Precious metals and jewellery can be melted down and re-used, while gemstones can be removed and traded individually. The increased demand for aphrodisiacs has made rhinoceros horn a much sought after commodity and objects made from it are regularly stolen from museums.

Research by Latski (2012) shows that thieves do not generally specialise in art or museum objects. They select their targets based mostly on interesting booty, relatively low levels of security, the slight chance of being caught and the probability of a lenient punishment if caught. The thieves will not benefit hugely from the theft, as those who receive or trade the stolen goods make the greatest profit. For the time being, there is no evidence for theft to order.

Frequency

The experts in Peek's research believe that Dutch museums deal with an average of one or two thefts per year. The chance of internal theft is ten times higher than theft by outsiders and the probability of theft of small objects is greater, as these can be carried out of the building more easily than larger objects, whose theft requires a whole team.

In a study by Etman and Eelman (1992) in which 224 Dutch museums participated, 20% indicated that they had been the victim of one or two thefts from an exhibition in the past five years, 5% registered three to five thefts and 2% registered six to ten thefts. These data imply that, on average, there is one theft every five to ten years per museum.

In a study by Intomart (2000), 15% of 227 Dutch museums indicated that they had been the victim of theft from an exhibition during the year, which corresponds to the average of one incident every seven years per museum. The data suggest an expected frequency of one theft every ten years for any given museum in the Netherlands. Depending on the level of security, the frequency may be somewhat higher or lower. The reason why security experts expect one theft per year is that they probably consider a worst-case scenario, in which they also assume that some incidents are left unreported. A study in Scandinavia found a lower frequency, where 10% of the museums and libraries reported the theft of an object once every ten years (Korsell *et al.*, 2006).

Place and time

According to Dutch experts, most burglaries take place during the night and at weekends, and are less frequent on weekdays; the theft often involves objects on display. Burglars take into account circumstances such as traffic, the presence of people, surveillance by external security companies or police, and escape routes. The question has been raised whether thieves can now better prepare their crimes as a result of easy access to information about the collections and floor plans on the internet.

Opportunistic thieves act during opening hours and remove objects that are on display. Internal theft also occurs during working hours, but the objects are usually taken from storage or the archive. Armed robberies also tend to be carried out during opening hours, when there are few visitors, for example at the start or end of the day. The theft of a gilded silver monstrance set with diamonds from a museum in Utrecht (January 2013) happened in broad daylight as a smash-and-grab raid. Table 25 summarises the results of the research by Peek.

Sources of vandalism

Based on motive, several types of vandalism can be distinguished: revenge, prestige, malice, political, religious, anger or madness. In common with thieves, vandals can be divided into opportunistic vandals and persons who prepare to damage an object deliberately. Although they carry out these acts on purpose, mischievous youths are often unaware of how much (emotional) damage they inflict when they push over gravestones, daub war memorials or damage sculptures. Playing children who break a sculpture while climbing on it do not act intentionally and could, therefore, be considered as the agent 'Physical forces'. In the case of opportunistic vandalism, the vulnerability of the objects is determined primarily by their accessibility and location.

Somebody who enters a museum intending to slash or throw acid over a painting, performs an act of protest or wants to make a statement. Objects with strong emotional, religious and/or political content, can arouse such an extreme response and are, for that reason, more susceptible to attack. Extreme forms of vandalism occur in conflict areas where the intentional destruction of heritage and identity is a means to hurt the enemy.

Generally, areas with much graffiti or an object that has already been vandalised (for example with paint or by the removal of parts) are more likely to provoke further acts of vandalism than undamaged objects in clean and tidy surroundings.

Pathways and barriers

Thieves and vandals must enter the area and the building from the outside to reach the object. Normally they do so by the route that is easiest and poses least risk. They can encounter different

Type	Likelihood	Stolen objects	Location	Motive	Time
Burglary	Medium	Old Master paintings (4) Precious materials (2) Weapons (2)	Exhibition (6) Storage (3) Public area (3)	Ransom (6) Sale (3) Collector (3)	Weekend night (5) Weekday night (4) Day, while closed to visitors (3)
Unauthorised access or Intrusion	Low	Old Master paintings (1) Precious materials (1) Weapons, coins (1)	Exhibition (5) Public area (5) Office (3)	Ransom (2) Collector (2)	Weekend, at closing time (3) Weekday, at closing time (3)
Shut-in Lock-in	Low	Old Master paintings (1) Precious materials (1) Weapons, coins (1)	Exhibition (3) Storage (2)	Ransom (1) Collector (1)	Weekend, at closing time (3) Weekday, at closing time (3)
Internal theft	High	Books/archives (4) Works on paper (3) Coins (2)	Storage (8) Offices (3)	Own interest (4) Sale (2)	Weekday, closing time (2) Weekday, when open (1)
Opportunistic	Medium	Books/archives (3) Historic objects (3) Coins, archaeological finds (2)	Public area (5) Exhibition (3)	Own interest (2) Souvenir (2)	When open (5) Day, at closing time (2)
Armed robbery	Low	Old Master paintings (3) Precious materials (3) Modern paintings (2)	Transport (8) Cargo space (4) Public area (2)	Ransom (4) Sale (3) Collector (2)	Weekend, at opening time (4) Weekday, at closing time (4) Weekday, at opening time (3)
Smash-and-grab	Low	Precious materials (4) Old Master paintings (1) Weapons, coins (1)	Exhibition (4) Transport (2) Loading (2)	Ransom (1) Sale (1) Own interest (1)	When open (3) Weekend, at opening time (2) Weekday, at opening time (2)
Pre-rehearsed theft	Medium	Modern paintings (3) Precious materials (2) Books/archives (2)	Exhibition (5) Public area (3)	Ransom (2) Sale (2) Own interest (2)	Weekend, when open (2)

Table 25. Likelihood of theft in a museum, based on the type of theft, type of stolen object, place of theft, motive and time of the day. The numbers in brackets indicate how many experts believed a particular option was feasible. The likelihood is defined as: high, equal to or greater than the average of 1–2 incidents per museum per year; average, once every 2–5 years; low, less than once every five years.

kinds of barriers. In the security industry, these are divided into the following categories:
- Organisation (O)
- Building and physical (B)
- Electrical systems (E)

The combination of the security measures that have been implemented and adequate response to incidents gives a certain level of security or control (CCV, 2016). The primary aim is to prevent crime (reduce likelihood) and secondarily to create delay, so that there is enough time for an effective response once the alarm is raised (reduce impact).

When thieves or vandals enter during opening hours, they must pass a desk or reception area to enter the museum (see the scenario scheme). There is a brief moment of contact with the person at the desk. Lists with names and images of known thieves and vandals can help to deny entry to someone at this point. Access control and training in recognition of unusual behaviour can aid in identifying perpetrators at an early stage.

When thieves wish to enter the building outside of opening hours, they will look for the weakest spot in the building envelope. In these cases, thieves are focused on postponing the moment of detection for as long as possible. They search for a door or window without a contact or glass breakage detector and try to be as invisible as possible. Unlit doors or windows offer the perfect opportunity to break in without being seen. Clear sightlines with appropriate lighting along the façade, trimmed vegetation and an absence of hiding places around the building perimeter are all methods to discourage potential thieves or burglars.

Early detection with a rapid response to alarms form the next barrier. Certified locks in combination with an effective key policy further delay a burglary. Any weak spot in façade and the building's surroundings can be equipped with glass breakage detectors and contact or movement sensors as appropriate. Every effective barrier blocking the pathway delays the thief, thus further increasing the chances that security staff or police arrive in time to arrest the perpetrator.

Measures to limit the removal of objects, such as securing them firmly, contact sensors with alarms and showcases, are the last barriers at object level.

Date and time	Museum	Type of theft	Objects	Retrieved
May 1988	Stedelijk Museum Amsterdam	Burglary	Three paintings, including a Van Gogh	No
December 1988	Kröller Muller Museum, Otterloo	Burglary	Three paintings by Van Gogh	Retrieved but damaged
April 1991	Van Gogh Museum, Amsterdam	Burglary	20 paintings by Van Gogh	Retrieved, three heavily damaged
March 2002 (weekend, night)	Frans Hals Museum, Haarlem	Burglary	Five 17th century paintings	Recovered by the police in 2008
December 2002 (weekend, night)	Museon, The Hague	Burglary	Diamonds and jewellery	No
December 2002 (Saturday, early morning)	Van Gogh Museum, Amsterdam	Burglary	Two paintings by Van Gogh	Recovered by Italian police in 2016
December 2002	Karel Appel Foundation	Transport robbery	400 paintings, sketches and notes	Retrieved February 2012 in a warehouse in Great Britain
1997–2003	Army Museum, Delft	Internal theft	Prints, books and paintings	Partially retrieved
January 2005 (weekend)	Westfries Museum, Hoorn	Shut in	Paintings and silverware	No
January 2007 (weekday night)	Singer Museum, Laren	Burglary	Seven bronze statues from the garden	One retrieved, heavily damaged
August 2008 (weekend, night)	Clock Museum of the Netherlands, Zaandam	Burglary	Two clocks	No
May 2009 (Sunday during the day)	Scheringa Museum, Spanbroek	Armed robbery	Two paintings	No
May 2009 (weekday night)	City Museum IJsselstein	Burglary	Six paintings, two damaged	One retrieved
January 2010 (weekend)	De Oude Wolde Museum, Bellingwolde	Burglary	Seven icons	No
June 2010 (weekday night)	Freriks Museum, Winterswijk	Burglary	Painting by Mondriaan	No
May 2011 (weekday night)	Hofje van Mevrouw van Aerden Museum, Leerdam	Burglary	Two paintings by Frans Hals and Jacob van Ruysdael	Yes, by police several months later
August 2011 (Friday night)	Natural History Museum, Rotterdam	Burglary	Two rhino horns	No
September 2011 (weekend, night)	Castle Museum, Boxmeer	Burglary	Monstrances, chandeliers and goblets	No
February 2012 (weekend, night)	De Oude Aarde Museum, Giethoorn	Burglary	Jewellery, ivory, gold and gemstones	No
March 2012 (weekday night)	Gouda Museum	Smash-and-grab	Monstrances	No
October 2012	Kunsthal, Rotterdam	Burglary	Seven paintings	Probably burned in Romania
January 2013	Museum Catharijne Convent, Utrecht	Burglary	Monstrances	Retrieved but damaged

Table 26. Overview of thefts that made headlines in the Netherlands in the period 1988–2013.

Public zone	Reception zone	Operations zone	Security zone	High-security zone
Free access, some areas open 24 hours, no collection unless exhibited in the garden, no supervision	*Free access as far as reception desk, closed at night, surveillance*	*Restricted access, closed at night, collection accessible for public or study, surveillance*	*Restricted access, closed at night, no public, collection*	*Strictly limited access, closed day and night, collection and important business information*
Outdoor area, car park, entrance hall, lobby, café, restaurant, auditorium, museum shop	Visitors' entrance, service entrance	Exhibition room, reading room, preparation room, packing room, loading bay, maintenance room, plant room, mailroom, offices	Storage areas, conservation studios, offices with collections, photo' studios	Permanent and temporary storage, vault, server room, security control room

Table 27. Typical security zones in heritage institutions

Barriers can also be erected to block the escape route: guards in the room who can react immediately (but note that the personal safety of staff is more important than arresting the perpetrator), doors that close automatically and bag checks obstruct those taking objects out of the building.

Objects and their vulnerability

Why are cultural objects attractive and consequently prone to theft and vandalism? For theft there are two aspects that play a role: the financial value of the object or the materials of which it is made, and the ease with which it can be taken.

As a rule of thumb, there is a relationship between the financial value of an object (or the material of which it is made) and the chances of theft. The higher the value, the higher the risk a thief will be willing to take to steal the object, and the more time he or she will invest in preparing the crime. The vulnerability to theft depends on the type of theft. For the opportunistic thief, accessibility and the ease with which an object can be taken are decisive: regardless their value, small objects within reach are the most susceptible.

For an internal thief, accessibility in combination with a personal collecting interest may be important, although when the purpose is to sell the object, its financial value will feature. High-risk and complicated burglaries or other types of theft normally focus on objects with a high value that can be sold or serve as security in the criminal world.

Table 25 gives an indication of the vulnerability of different types of objects to different types of theft. Table 26 offers an overview of thefts from Dutch collections that have been reported by the media over the last 25 years. It is worth noting that high profile thefts of works by famous artists from well-known museums are the most newsworthy, but they probably represent just the tip of the iceberg.

Objects are most vulnerable to vandalism when they are accessible and in places where vandals can act unnoticed. Objects with special political or religious significance can also be attractive; the Auschwitz Monument with 'broken mirrors' in Amsterdam, was damaged in 1993, 1997 and 1999.

Options for risk reduction

The risks of theft in museums are only effectively reduced by an integrated security strategy, in which organisational, building/physical and electrical barriers (OBE) are inter-related and combined with adequate response. Because these measures are strongly dependent on other museum functions, the strategy to reduce risks of theft is intimately connected with facility management and operation.

In the context of risk management for collections, the OBE strategy is combined with the five steps: avoid, block, detect, respond and recover/treat (see Table 28; CCV, 2016; Tremain, 2016).

Zoning

A common safety strategy in heritage institutions is the creation of a series of safety layers or security zones from the outside to the object. This starts with the choice of museum location, next considers appropriate mitigation measures around the building, then the security of the building, galleries and storage areas, and finally the selection of fixtures and furniture. The strategy will usually incorporate levels of increasingly restricted access for staff and visitors. The six levels or layers from the *Framework for Preservation of Museum Collections* (CCI, 1994) can be combined with the application of security zones.

Table 27 lists the five typical security zones that can be distinguished in museums and describes examples of the functions within them. The zones differ from each other in the extent to which the five measures (avoid, block, detect, respond

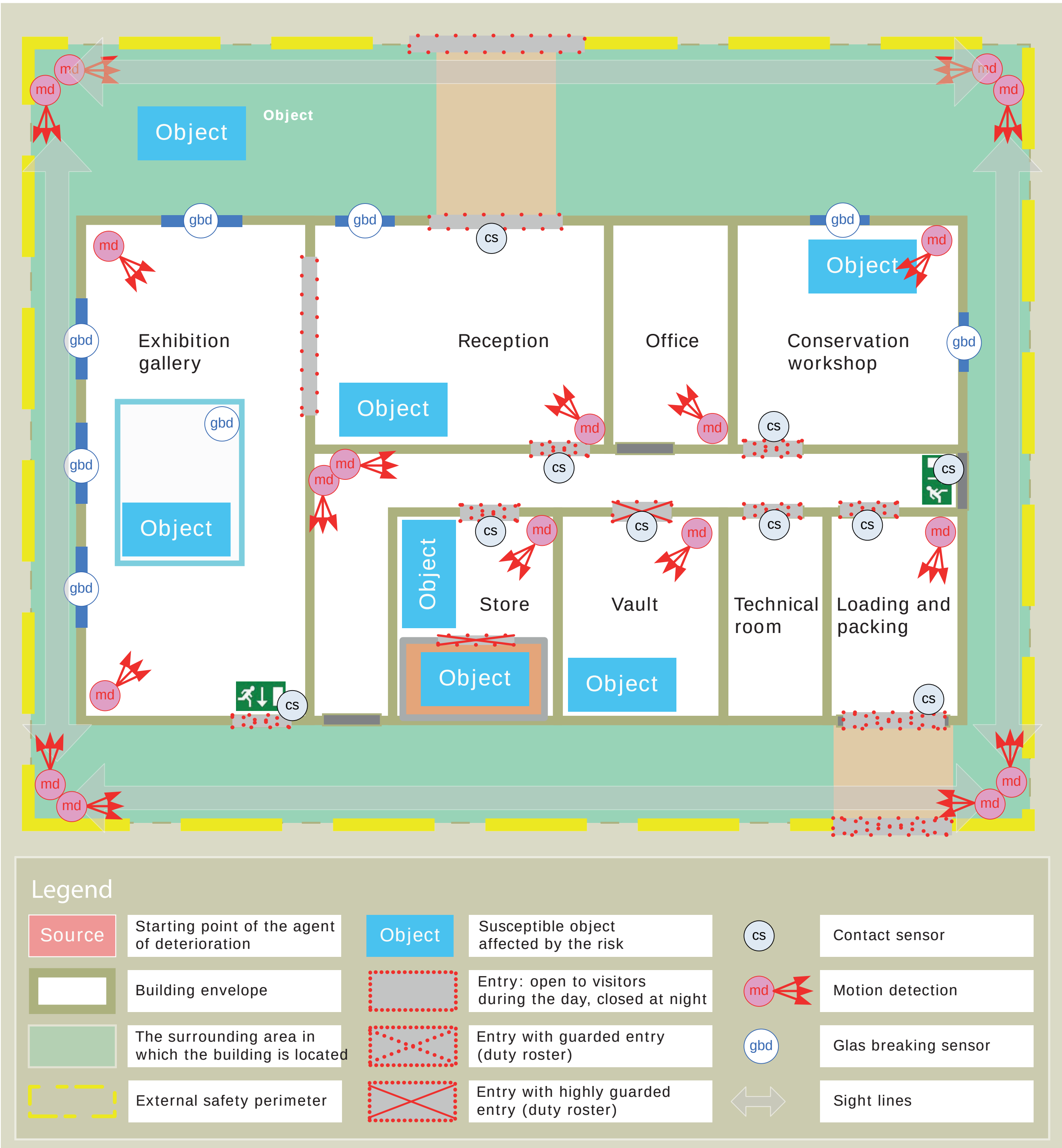


Figure 66. Schematic representation of different museum zones with options for detection

and recover) are implemented.

In general, security measures should match the institution (building and people) and the collection (cultural and financial value). As far as possible, the security strategy should be integrated with other measures and strategies (e.g. fire safety and emergency preparedness), other museum services and local or municipal security procedures.

Avoid

Creating an outdoor zone around the building with good sightlines (during all seasons) and without hiding places for intruders, begins to reduce the risk of theft significantly. The outdoor zone, managed by the museum, should be clearly indicated by fences, gates and signs. All entrances and exits to the building and the parking area should be lit so that the surroundings are clearly visible. Vehicles should not be able to park too close to the walls of the building to avoid their use to reach entry points on the upper floors.

The building is more vulnerable during exterior construction work, particularly when scaffolding is erected. In that case, extra measures, such as cameras, motion detectors and surveillance, need to be implemented, see Figure 67. During construction work in the (exhibition) rooms, external personnel should be accompanied by museum security staff.

Figure 67. Security at the Van Gogh Museum during the renovation in January 2013.

In most small heritage institutions, the reception area or desk is the base for various security procedures, for monitoring and for co-ordination of action. It is wise to have a person there who is not distracted by the issues of tickets, etc., but who can co-ordinate access to the different security zones (providing passes and keys or registering office visitors), answer the phone and deal with CCTV monitors, alarms, response, surveillance and communication (perhaps through portable radios). Large institutions often have their own control room and professional security staff.

Block

Make sure the different parts of the building exterior, such as the walls, doors, windows and roof, have good burglar-resistant properties. These properties should be matched to the time needed for alarm response, for example the time required for police or security to arrive. In many countries, building products are certified and there are systems to rate entry resistance. In the Dutch SKG system one star means the product resists entry for three minutes if the rest of the construction is good; two stars denotes resistance for three minutes irrespective of other building elements; and three stars that the product resists attempts to enter for five minutes (SKG, 2009).

Windows and showcases can be fitted with security glass that comprises sheets of glass laminated with a polymeric film whose mechanical properties ensure a high impact-resistance. Such glass is categorised from P1A to P5A depending on how well it resists an impact of a 4.1 kg steel ball, and from P6B to P8B according to its resistance against blows with an axe.

Intruders can be prevented from entering by fitting security grids in air shafts that have a cross-section larger than 930 cm^2. Proper locks should be fitted to rooms and cabinets with valuable objects and key issue protocols used to monitor access. Procedures for mutual monitoring should be applied, the so-called ‘four eyes’ principle, and (random) checks of bags and coats used to prevent opportunistic and internal theft. Robust and appropriately secure packing cases should be employed for transportation and they should only be moved by skilled and trusted transport companies. Objects on open display should be secured with lockable brackets or other security systems to prevent their easy removal. Objects that do not belong to the collection but are displayed for decorative purposes can often be secured more easily (see Figure 68), discouraging opportunistic thieves.

Damage to museum objects by knife or acid attack can be reduced by displaying susceptible objects behind glass (in showcases or framed) and by keeping visitors at a distance with cords, rails and glass walls. Constant surveillance can be provided for very valuable and/or highly susceptible objects. *The Night Watch* in the Rijksmuseum is guarded continuously during opening hours (Figure 69).

Art in public spaces cannot be protected in the same way as in museums. The objects are usually made from more robust materials that also tend not to be of high value. Furthermore, outdoor sculptures are usually placed on a high plinth, on which it is difficult to climb, or are surrounded by a fence. The choice of location is important if the risk of a sculpture being pulled off its plinth by a car is to be reduced (Morelissen, 2016).

Detect

Outside the building, intruders can be detected by local residents and passers-by, but good sightlines, adequate lighting and cameras are also useful. When light levels are low, infrared cameras that detect the body heat of intruders can be a solution.

Glass breakage sensors and/or contact sensors can be placed on vulnerable parts of the building exterior, such as doors and windows. Residents in the area will notice the sound and lights of the alarm when someone tries to break in.

Motion detectors (and possibly cameras) can be positioned inside the building in areas that staff and guards do not oversee. During the day staff will detect problems in the display areas, while at night it is possible to patrol the building. A separate contact sensor could be located on attractive objects of high value. Showcases that contain highly susceptible objects (those that are small, easy to take and sell) should be provided with a glass breakage sensor and/or a contact sensor. Alternatively, objects can be tagged with chips or radio frequency identification (RFID) tags, which will set off an alarm when they pass detection gates, or give off a signal that enables the object to be traced once it is outside the building.

The recognition of unusual behaviour is becoming an increasingly important means of averting theft or vandalism. Burglaries and internal thefts are usually preceded by a number of visits to the museum to assess the situation. During these visits the thief's behaviour is different from the regular visitor or member of staff. By recognising the unusual behaviour, it is possible to be forewarned and react swiftly.

Respond and confine

In the case of an incident, it is not only important that the alarm sounds, but that it results in a quick and effective response. This requires good internal and external communication with appropriate communication devices. The procedures should be made explicit in a security policy and an emergency plan, paying special attention to the way in which security is organised, the tasks of the security staff, and the responsibilities and authority of those involved. To make sure the response time is as short as possible, it is important to train regularly.

Inspecting the collection regularly for missing objects prevents or limits ongoing internal thefts by employees. A catalogue of missing objects can be a useful tool as it helps to identify objects after their theft and hinders the sale of stolen goods.

Figure 68. Pottery on display in a historical house is screwed to the shelf.

To reduce the effect of attacks on artworks in museums as much as possible, it is important to be able to react on the spot with the right resources. These emergency supplies can best be stowed in the direct vicinity of very susceptible and/or valuable objects. Different organisations offer training in emergency response.

When an object has been attacked, it is strongly recommended that the area around the object is secured immediately, to ensure that forensic evidence is not destroyed.

Recover and treat

Measures can be taken that will assist in the recovery of stolen objects and enable them to be identified unambiguously after they have been returned to the museum. These techniques rely on the use of invisible marks that can be detected once after recovery, such as invisible inks that can be read under UV radiation or marks made with a DNA spray that can subsequently be analysed. It is also possible to set up a DNA spray that is triggered when the object is removed, marking both the thief and the object. Another technique is 'fing-art-printing', which involves taking a detailed scan of the topography of a specific area of the surface that can later be used in the manner of a fingerprint to identify an object unambiguously. Damaged items must be treated appropriately. This both avoids further damage, such as the loss of flaking paint, and reduces the likelihood of a further attack on a visibly damaged object (It is, for example, considered that graffiti on buildings makes an art work


Figure 69. In front of The Night Watch a rail keeps visitors at a distance. A guard supervises and is able to react quickly in case of an incident (left). Children are kept at a distance by placing susceptible objects on a plinth (right).

in the surrounding area more vulnerable to vandalism).

Registering incidents and 'near misses' in a database, such as the Dutch DICE database, can be considered as a form of treatment. By registering and analysing these incidents, security weaknesses are revealed and improvements can be made. With such a database it is possible to exchange knowledge, information and experiences between heritage managers or between heritage managers and the government (RCE, 2015a). Trends will be more visible and it will be easier to respond. In the Netherlands, an 'alert' is occasionally sent to museums when there is a reason to do so. RCE provides an annual overview of incidents reported to DICE, including incidents reported both by heritage managers and by the media (RCE, 2015b).

An incidence of theft or vandalism leads to loss of, or damage to, cultural heritage but it also has an impact on the reputation and image of an institution. Accordingly, it is recommended that press releases and other contacts with the media are carefully prepared.

Rules of thumb for determining the magnitude of risk for specific risk scenarios

The level of control for theft or vandalism in a cultural institution depends on the quantity, quality and coherence of different

Figure 70. On 18 March 1990, the Isabella Steward Gardner Museum in Boston was the target of an audacious art robbery by men disguised as police officers. Thirteen paintings where stolen, including The Storm on the Sea of Galilee by Rembrandt. The museum still displays the empty frames in their original locations.

Stage or step	Organisation	Building physical	Electrical systems	Measures to limit carry-off
Avoid	Design security policy (organisation, tasks, responsibilities, authority) Staff availability (co-ordination, reception, guards) Implement procedures (alarm response, key management, rounds) Implement institutional emergency plan and emergency response plan Ensure training of staff Practise with staff Make arrangements with emergency services	Choice of location Choice of building materials Creating security zones Control room Lockers	Lighting outside Cameras outside	Secure objects Invisible marks 'Fing-art-printing' Chips (e.g. RFID tags) DNA marks
Block	Bag checks Access control	Fence Doors Hinges and locks Safety glass Spacers, rails, glass walls Showcases Cabinets Interlocked double doors	Entry gates Turnstile	Turnstile
Detect	Guards Surveillance Lock-up round Weighing books before and after use Reporting Alarm response Location checks		Glass breakage detection Infrared detection Motion detection Vibration detection Acoustic glass break detection Signalling open or locked position Security camera Fence detection Gate detection	'Fing-art-printing' Chips (RFID) DNA marks
Respond and confine	Emergency response plan Training		DNA-spray Smokescreen Shutters	
Recover and treat	Emergency response plan Training Incident registration			

Table 28. An overview of OBE measures in combination with the five steps of the Framework for Preservation of Museum Collections (CCI, 1994)

organisational, building/physical and electrical (OBE) measures, and on the steps taken to limit the possibility of escaping with objects. There are no known studies that show a clear relationship between a specific measure and the extent to which it reduces the risk of theft and vandalism. In 2012, the Centre for Crime Prevention and Security in the Netherlands defined risk classes and security levels for businesses and residential homes. Museums and heritage institutions belong to the highest risk class and for insurance purposes must meet the highest level of security.

The likelihood of loss of value in a certain period (for instance ten years) is determined by the frequency with which incidents that result in a loss of value occur or alternatively on the mean time between events (MTBE). The loss of value per stolen object is usually 100%. In an unsuccessful or disrupted theft, an object can be damaged and the loss of value may be smaller. With vandalism, the loss of value can also differ. How this affects the total collection value depends on the importance of the stolen or damaged assets within the collection. Besides loss of collection value, there are also other interests at stake; theft and vandalism have a significant impact on the reputation of an organisation.

Table 29 gives estimates for the likelihood of loss of objects in ten years for three levels of control: low, medium and high (see also CCV, 2017). These estimates can be used as an indication and as a starting point for further analysis of specific risk scenarios.

Level of control	Likelihood of loss in ten years			Period in which loss of one object is expected
	1-2 objects	10-20 objects	100 objects	
Low	Very likely	Very likely	Probable	1 year
Medium	Very likely	Probable	Possible	1-10 years
High	Probable	Possible	Unlikely	>10 years

Table 29. Probability of loss through theft for different protection levels, based on the research by Peek (2011) that forecasts an average of one or two objects per museum per year.

Agent of deterioration	Interaction
Physical forces	Rough handling during and after a theft leads to physical damage. Vandalism, such as toppling, breaking off parts and incised graffiti, is intentional physical damage. Installing security systems and their electrical supplies can lead to physical damage to the building and objects. Scratches increase the risk of further vandalism. The removal of graffiti, for example by sandblasting, can lead to physical damage.
Fire	The risk of theft is high during fire evacuations. While staff members are salvaging the collection, many people watch and the supervision of evacuated objects may be less thorough. In the emergency response plan, measures against fire can be integrated with other security and safety measures.
Water	The risk of theft is greater when people from outside are involved in the salvage of objects after a water-related incident. In the emergency response plan, measures against water can be integrated with other security and safety measures.
Contaminants	Graffiti can have a chemical effect on the surface of an object, which can be seen as intentional contamination. Dirty objects ‘invite’ vandals to further contaminate the surface. Thieves can leave dirt and other traces behind on objects during handling.
Light, UV and IR radiation	Security lighting can cause light damage.
Pests and plants	People from outside who are brought in for pest control increase the risk of theft. When treated for pests off site, objects could disappear from that location. Security lights can attract insects.
Incorrect Temperature	External maintenance staff increases the risk of theft.
Incorrect Relative Humidity (RH)	External maintenance staff increases the risk of theft.
Dissociation	Badly registered objects can be removed without being noticed.

Table 30. Examples of relationships between ‘Thieves and vandals’ and other agents of deterioration

- Low: only a (very) limited number of the possible OBE measures has been implemented or the quality of implementation of these measures is mediocre.
- Medium: a significant proportion of the possible OBE measures has been implemented and the quality of implementation is fair to good.
- High: many to most of the possible OBE measures have been implemented and the quality and coherence of implementation is good.

Relationship with other agents of deterioration

Measures that reduce one risk can have side effects on other risks. They can have a synergistic effect with a positive reducing effect on other risks, but they can also have a negative effect leading to a (temporary) increase of other risks. Illuminating a building to deter burglars may lead to an increase in light damage to susceptible objects or attract insects that might subsequently enter the building.

Agents of deterioration may also follow upon one another. The risk of theft increases after a fire evacuation. Vandalism may result in a fire. Examples of relationships between ‘Thieves and vandals’ and the other agents of deterioration are listed in Table 30.

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Placing vulnerable objects against each other increases the risk of abrasion during handling significantly

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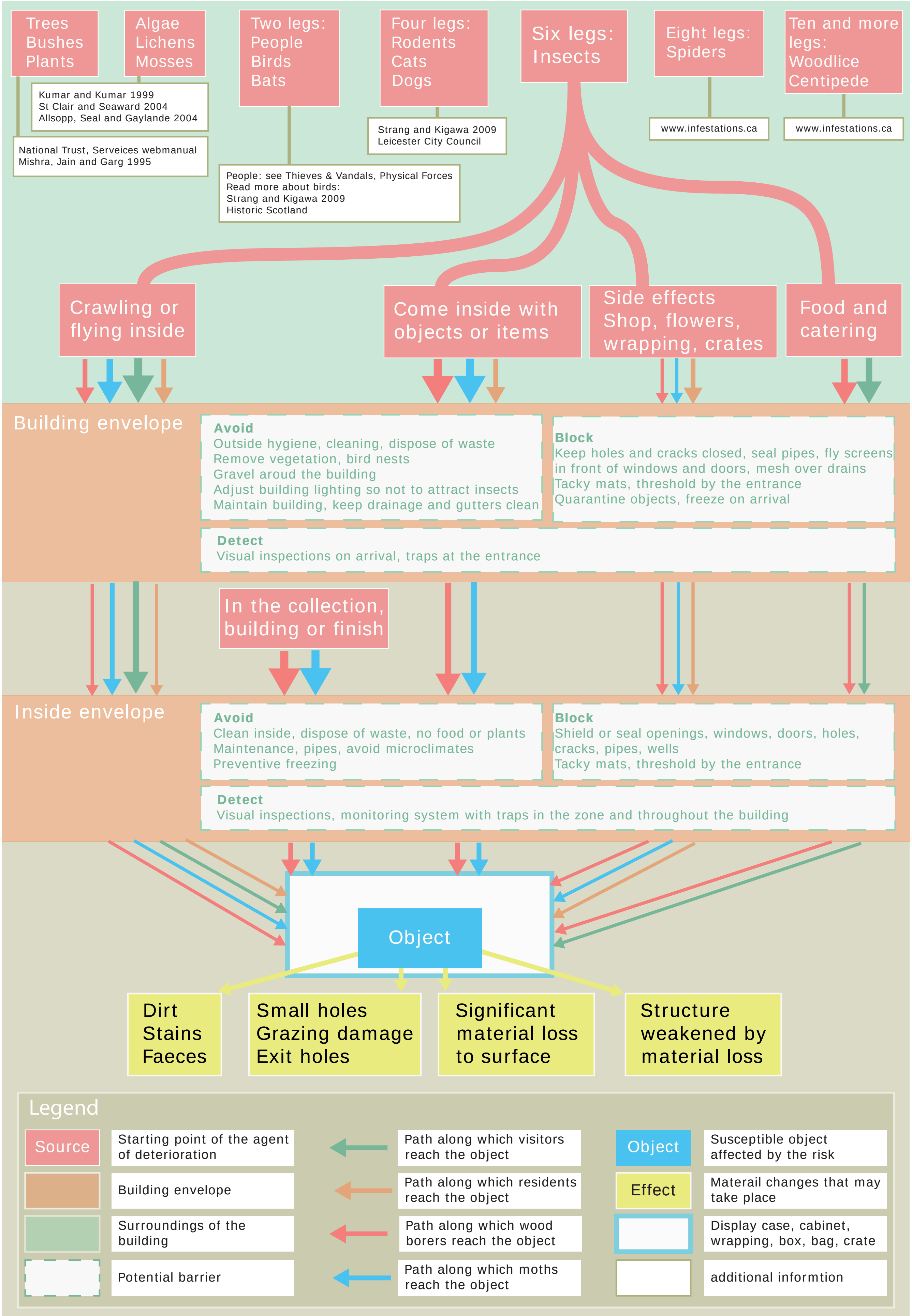
In 2016, the Zutphen Museums (Stedelijk Museum, Henriette Polak Museum and the archaeological department of the city of Zutphen) moved to the Hof van Heeckeren, a palace in the centre of town, the oldest part of which was built in the 13th century. It is listed as a national monument. A beautiful, old building in a good location, but perhaps not ideally suited as a museum, especially when compared with some other high-tech, modern museum buildings. We immediately wondered: what type of indoor climate can we expect in this centuries-old construction? Can we hang our watercolours there, or will it be too damp?

Together with RCE we made a first broad-brush scan of what we considered to be the minimum and maximum conditions for our collection. In consultation with the architect, these data were incorporated into the specifications for the refurbishment of the old complex into a museum building. Subsequently we identified and analysed more risks. Not only the indoor climate, but also light damage and object safety and security were examined. We knew of course, that some objects are more vulnerable than others, but what happens to an object if it is exposed to daylight for a certain period? RCE made simulations of light aging for our most valuable items so that we could determine what we would consider a significant loss of value. This process revealed to us that not all fading is the same, so that the fading of the dark red blouse in a portrait of the famous sculptor Charlotte van Pallandt by local painter Kees Verwey was perceived as a smaller loss of value than similar degree of fading to her face. Her blouse would remain a blouse, but her face would become unrecognisable. As a result, we now have a better understanding of the lighting we want in the Hof van Heeckeren and of how long we can exhibit certain objects without too much loss of value.



Scenario scheme for the agent of deterioration 'Pests and plants'

Pests and plants

Scenarios for pests and plants

This scenario scheme sketches the most common scenarios for pests and plants. The red boxes at the top of the scheme show the general classes of pests and plants with some useful references in the white text boxes beneath. The rest of the scheme focuses on insect pests. The red boxes in the green field represent the sources of insects and their most probable route of entry. Insects can enter the building from outdoors or are already inside the building, room or showcase.

The grey and orange bars represent the barriers that the insects meet on their way from source to object. The green text in the bars provides guidance for determining the performance of the barrier. When an object is placed outside, there are unlikely to be barriers, except perhaps a coating on the object itself.

The coloured lines represent the pathway that insects follow to reach the object. The different colours represent the four types of insect (woodborers, moths & beetles, residents, and visitors). The thickness of the line indicates the likelihood that a type follows that particular pathway. Generally, each barrier reduces the likelihood of an insect reaching the object.

The blue box represents the objects that have a particular sensitivity to the different types of insect.

The four yellow boxes with text at the bottom describe the most common damage that insects can cause; from left to right ascending from 'negligible damage' to 'heavy damage with loss of structural integrity'. Each line that can be drawn from a source, via one or more barriers, to the object to which it causes an effect, represents the scenario for one specific risk.

Introduction

The agent of deterioration 'Pests and plants' encompasses causes of decay and damage from living organisms, which can be further divided into animals, plants and the group comprising algae, mosses and lichens. Mould and bacteria (micro-organisms) are not discussed here because the primary cause of their presence is high relative humidity. They are dealt with in the chapter 'Incorrect indoor climate'.

Animal pests can be classified based on their number of legs: birds (two legs); rodents, bats and pets (four legs); insects (six legs); spiders (eight legs); and woodlice and centipedes (more than eight legs).

Plants can be divided into trees (one woody trunk), shrubs (multiple woody stems) and herbaceous plants (no persistent woody stem above ground). Plants can damage buildings and archaeological sites, but are not relevant to collections and will not, therefore, be discussed here.

This chapter focuses on *insects* in museums, archives, libraries and historic interiors. But the principles and the approach of integrated pest management can be used for all types of vermin and weed. For more detailed information about insects and integrated pest management see the references and further reading at the end of this chapter.

Insects belong to the invertebrates, they have an external skeleton and six legs. Some have one or two pairs of wings. When the front wings are hard, as in the case of beetles, they form the elytra (shields) that cover and protect the body. For a simple identification of insects, the external characteristics are important, such as size, shape, hairs, and the colours of the body, legs and antennae. Based on their development and growth, insects are divided into:

- Cockroaches, bristletails (silverfish, giant silverfish and fire-brats), lice, grasshoppers and crickets go through an **incomplete metamorphosis**. A small nymph, resembling the adult form, hatches from the egg and grows in stages, shedding its skin several times. After the last moult the insect has all the adult characteristics (wings, etc.) and is fertile. Both nymphs and adults feed and cause damage.
- Beetles, moths, butterflies, flies, mosquitos, bees and wasps go through a **complete metamorphosi**s. A small larva hatches from the egg, which feeds, grows and sheds its skin a number of times. It is the larva that causes damage (not the adult stage). When the larva is large enough, it changes into a pupa and during a period of apparent rest a complete transformation takes place after which the adult emerges from the cocoon. The adult insects have only one task: to ensure distribution and propagation of the species. Usually they do not feed and, therefore, hardly cause damage.

In order to survive, insects need the following:

Oxygen – Oxygen is needed during the metabolic process to generate energy. Insects do not have lungs, but take up oxygen directly through pores (spiracles) in their skin.
Nutrients – Insects feed on organic material. Some eat everything, such as cockroaches and the drugstore beetle, while woodborers and cigarette beetles have a preference for plant material (cellulose and carbohydrates). Carpet beetles and clothes moths prefer animal material (proteins). Dirt, grease, dust, sweat and urine provide additional nutrients and soiled materials are, therefore, usually more attractive than clean materials.
Warmth – Activity and development are determined by the

external temperature. Insects survive at temperatures of 5–45°C; their optimum development is at 15–35°C.
Moisture – Most insects are able to develop at a relative humidity (RH) of 50–90%; the optimum is around 70%. Some species have adapted to dry conditions, while for others a high RH is essential (silverfish). Woodborers require a wood moisture content of more than 10%. Other species need a high RH as they feed on the mould that grows on moist material.
Light – Light often determines the behaviour of insects. Adult carpet beetles fly towards the light and can be trapped on windowsills. Silverfish and moths shy away from light. Such behaviour can play an important role in detecting insects.
Shelter – The behaviour of insects is also determined by their need for shelter. Cockroaches crawl into cracks and crevices. Bristletails seek shelter, avoid open spaces and prefer to move along the skirting boards in a room.

Figure 71. The common furniture beetle (Anobium punctatum) (Source: Wikimedia)

Figure 72. Typical damage to wood caused by the larvae of the common furniture beetle

Insect types

Of the many thousands of insect species, it is fortunate that only about 30 species actually cause damage to collections. When insect damage is detected, or insects are found in the collection, one should first identify the species. This helps to assess the seriousness of the problem and to determine which measures should be taken. Based on their behaviour and the damage they inflict, insects can be divided in four types.

Woodborers

Borers are insects that penetrate deep into an object. The larvae live for some time, primarily in wood or paper, bore tunnels while they feed, until they pupate and fly out through exit holes as adult beetles (see Figure 72). Only adults are usually encountered; the larvae and pupae are hidden in the wood. The exit holes and the frass that falls out of the tunnels are the first clues to their presence and activity. Insects originating from construction wood and infested furniture will often spread to the collection. The control of woodborers requires a method that reaches the core of the object. Examples of this type of insect are common furniture beetle (Figure 71), death-watch beetle, other anobiid beetles, powder-post beetle and longhorn beetle.

Moth and beetles

These insects typically feed on the surface of objects (see Figures 75 and 76). The larvae live on top of, or sometimes slightly inside, the object. They gnaw through or graze over the material, which is mostly of animal origin but can be vegetable. However, they do not bore into wood. Damage is noticeable by the presence of holes and bare areas in the material, by the frass and waste that the larvae produce, and by webbing and cocoons on the object. Larvae, pupae and adults can all be found. To control these insects requires treating the object. Examples of this type of insect are clothes moths (Figure 73) and carpet beetles (Figure 74). The drugstore beetle and cigarette beetle belong to the Anobiid beetle family (they have the appearance of woodborers), but they are included in this type as they are found in materials other than wood.

Figure 73. Webbing clothing moth (Tineola bisselliella) (A. Photo Olaf Leillinger; B. Photo Guido Gerding)

Figure 74. Carpet beetle (Anthrenus variabile): larva ('woolly bear') and adult beetle (A. Photo Olaf Leillinger; B Photo André Karwath aka Aka)

Figure 75. Typical grazing damage on velvet upholstery caused by moth larvae

Figure 76. Typical damage to a stuffed bird by carpet beetle larvae

Figure 77. The giant silverfish (Ctenolepisma longicaudatum).

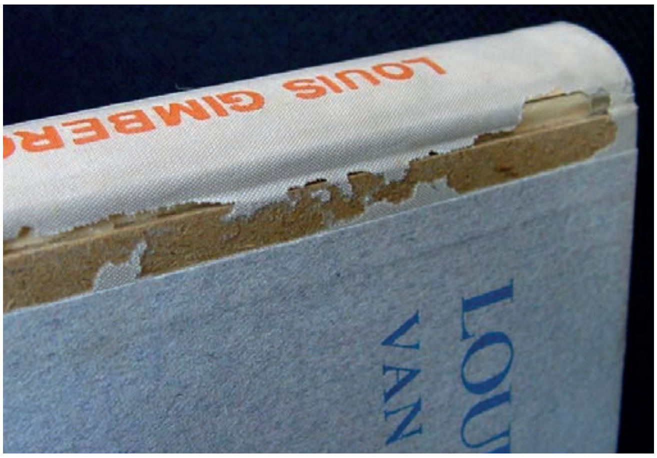


Figure 78. Typical damage to a book binding by normal and giant silverfish.

Residents

Residents are insects that live somewhere in a room, move around, and feed on collection material without actually living in or on the objects. These are mostly insects that go through an incomplete metamorphosis. They cause damage and soil the objects with excrement, frass and grease. They often also cause the collection to smell.

The presence of insects is usually related to the conditions in which the collection is stored, displayed or packed (micro-climate). Here, insects find an attractive climate with sufficient shelter and food (dirt, waste and mould). Often they only feed on the collection secondarily. Nymphs as well as adults are found in objects and within the building, although the small nymphs are usually difficult to see. All developmental stages feed and cause damage.

Control measures for this type focus on changing the conditions in the area so that the insects no longer feel at home. Usually this entails lowering the relative humidity (RH) and/or the temperature (T), and blocking the insects from entering the building. Objects and the area should be cleaned thoroughly and, if all else fails, treated. Examples of this type are the bristletails (silverfish, giant silverfish and firebrat) (Figures 77 and 78), cockroaches (Figure 79), booklice and dust lice.

Visitors

Insects that may be found in the building but do not cause direct feeding damage to the collection are so-called visitors. They enter coincidentally, searching for food or shelter, to stay the night or to hibernate. Their presence is an indication of 'leaks' in the building. If they are able to enter the building, then so can harmful insects. They can cause indirect damage through soiling and nesting. Furthermore, when they die they form a food source for moths, beetles and residents who may continue feeding on the collection. Dead insects also form a substrate for moulds. Usually the adult insects of this type are found. Pest control focuses on blocking the insects from entering the building. Examples of visitors are flies, lacewings, wasps and ladybirds (Figures 80 and 81).

Sources and entry routes

There are four ways in which insects can enter from the outside:

- creep, crawl or fly in;
- along with incoming objects or exhibition materials and props that act as 'Trojan horses';
- via related activities, such as shop supplies, with flowers, in packing and crating materials;
- along with food, restaurant and catering activities.

Objects can also be affected by insects already living in the building (in the area or in the building's construction, such as woodborers in beams or cockroaches under the floor) or by insects already active in other objects.
Different types of insects have their preferred entry route. Woodborers, beetles and moths usually hitch along with incoming objects or exhibition materials. Carpet beetles often live in bird's nests from which their larvae can crawl into the building; chimneys are a notorious entry route. Residents usually find their way into the building via related activities, with objects, object packaging and exhibition materials, or they creep, crawl or fly in. Visitors crawl, fly and tag along with food and catering supplies. Once in the building, insects go in search of good food sources: in the kitchens, rubbish bins and building fabric, as well as the collection.

Figure 79. The American cockroach (Periplaneta americana) in its various developmental stages (Wordpress).

Figure 80. Examples of visitors: dead flies and lacewings in the attic after winter

Figure 81. One of the best places to find intruders such as flies, mosquitos and wasps is the windowsill

Pathways and barriers

On their way from the source to the object, insects are blocked by physical or procedural barriers. The outer building envelope forms the first physical barrier. Each opening in that outer shell is a weakness. For instance, windows and doors, ventilation shafts, holes for pipes and wires, or cracks and crevices. These need to be sealed or closed off with gauze or a grill.

The building's inner walls form the next barrier. Doors and corridors between spaces form weak spots. They can be protected with adhesive mats in front of or behind the thresholds. The final barrier is near the object, varying from a showcase and a cabinet to a box or protective cover (or even a preventive treatment). Quarantine, cleaning and maintenance procedures form non-physical barriers that help prevent sources and block the pathway to the object.

Objects and their vulnerability

Although insects are able to make their way through the most unexpected materials to get to a good food source, they have specific preferences and requirements when it comes to feeding. Depending on their material composition objects have different vulnerabilities to insects. Provided their moisture content is high enough, wooden objects and constructions can be damaged by woodborers. Cellulose-containing materials such as books and paper are a good food source for woodborers, while wasps and bees can use these materials to build nests. Protein-containing materials such as wool, hair, fur, feather, leather and skin are attractive to the larvae of clothes moths and carpet beetles. Cotton and silk are not usually primary food sources, but can be damaged by moth and beetle larvae. Dirty objects are more vulnerable than clean objects. Objects that are kept in quiet, dark, warm places are more attractive than objects in busy surroundings.

Options for risk reduction

The physical barriers between source and object are only effective if they are insect-proof, closed and intact. Procedural barriers, such as maintenance plans, schedules for cleaning and waste disposal, considerate handling of packaging, protocols for inspection, and possible (preventive) treatment of objects and other materials that enter the building, only function if they are known to, and correctly applied by, staff. In general, the more people who are aware of the implementation of the integrated pest management approach (IPM-strategy), the lower the likelihood of an infestation and the smaller the damage in event of an infestation.

In the scenario scheme, possible measures to optimise the effectiveness of each barrier are described. They always comprise a combination of avoiding the presence of insects, blocking their entry and detecting them to monitor if the measures are adequate. To assess the likelihood of insect attack and the severity of resulting damage, four levels of control are distinguished.

No specific control measures

- Occasional housekeeping and building maintenance
- Building not sealed or screened
- Open storage racks and displays
- No inspection of incoming materials and objects
- No monitoring, with visual detection only when damage occurs
- No preventive treatment
- No special pest procedures or responsibilities

Low level of control

- Regular, average cleaning, average building maintenance
- One of the following:
  - Building sealed and screened
  - Closed cabinets and display cases
  - Inspection of incoming materials and objects
  - Regular visual inspections or monitoring
  - Preventive treatment, crevice spraying or freezing cycle
- Pest awareness and some procedures or responsibilities

Medium level of control

- Regular thorough cleaning, proper waste disposal, building maintenance
- Two of the following:
  - Building sealed and screened
  - Closed cabinets and display cases
  - Inspection of incoming materials and objects
  - Regular visual inspections or monitoring
  - Preventive treatment, crevice spraying, freezing cycle
- Pest awareness and some procedures or responsibilities

High level of control

- Regular thorough cleaning, proper daily waste disposal, good building maintenance
- Building sealed and screened, or closed cabinets and display cases
- Inspection of incoming materials and objects, with quarantine as needed
- Regular visual inspections and monitoring with insect traps
- Optional: preventive treatment, crevice spraying, freezing cycle
- Procedures and planning with allocated staff
- Documented procedure, supervision by allocated staff member, everybody has integrated pest management as part of their activities

Rules of thumb for determining the magnitude of risk for specific risk scenarios

Statistics for Dutch heritage intuitions show that, as the protection level of the institution increases and everybody deals with insect risks more consciously, the number of insects found might be higher but the resulting damage will be smaller (Brokerhof, 2013). Apparently, insects are detected in time, before they have reached the objects. On average, each institution has one insect incident per year, finding insects in places where they have not been detected before and may cause damage.

Almost half of these cases concern 'visitors' that will not cause direct damage. A quarter of cases concern woodborers that can cause small to significant damage if there is no – or a low – level of control. At high levels of control, damage is small or negligible. Moths and beetles account for a quarter of incidents. They can cause significant damage where there is a low level of control; at high levels of control damage is negligible. Incidents with 'residents' occur in less than 10% of cases. At low levels of control they can cause considerable damage, but at high levels of control the damage is negligible. The number of sightings of common and giant silverfish in collections and historical interiors has increased over the past few years, but fortunately their damage remains limited.

As the level of control is improved, the likelihood of insects entering the building, and of damage to the collection, decreases. In other words, the damage in a certain period decreases or the period in which a certain degree of damage is caused, gets longer. The rules of thumb to assess the average pest risk are listed in Table 31.

When insects have been detected or damaged objects in the collection have been found, the infestation needs to be confined. Subsequently, the appropriate pest control methods need to be chosen. These are described in *Buggy biz* (Brokerhof *et al*., 2007).

Level of control	Likelihood of damage in 100 years				Period in which considerable loss of material will occur
	Negligible Soiling and staining	**Small** Traces of grazing, holes, exit holes	**Considerable** Significant loss of material	**Large** Large loss of material	
None	Highly likely	Highly likely	Probable	Possible	1-10 years
Low	Highly likely	Probable	Probable	Not likely	10-30 years
Medium	Probable	Possible	Possible	Not likely	30-100 years
High	Probable	Possible	Not likely	Not likely	>100 years

Table 31. Likelihood of insect damage to objects in 100 years, depending on the level of control

Agent of Deterioration	Interaction
Physical forces	Damage weakens materials, making them more sensitive to physical forces. Handling objects for pest control treatments increases the likelihood of physical damage; frozen materials are extremely sensitive to handling. Heat treatment can soften materials, making them vulnerable to pressure and gravity.
Fire	Vermin can damage electric wiring and cause short-circuits.
Water	Warm air condenses to water droplets on cold surfaces treated by freezing.
Thieves and vandals	Pest control by an external company or off site treatment increases safety risks.
Contaminants	Vermin can cause soiling and staining. Pesticide treatments leave toxic and other residues.
Light, UV and IR radiation	Radiation treatment (UV or gamma) can cause molecular damage. UV traps can cause radiation damage.
Incorrect temperature	Lowering the temperature to avoid insects can lead to the crystallisation of oils and fats on objects. Heat treatment can soften materials, cause melting and promote deformation. (Accelerated ageing due to heat treatment is not relevant.)
Incorrect relative humidity (RH)	Lengthy treatment in a controlled atmosphere (nitrogen, argon, carbon dioxide) can lead to dehydration if the gas is not humidified. Packing objects in plastic bags or metal boxes can cause local high RH and mould growth as a result of temperature gradients.
Dissociation	Vermin can eat labels, gnaw them so they detach, or make them unreadable.

Table 32. Examples of the relationship between 'Pests and plants' and the other agents of deterioration

Relationship with other agents of deterioration

Measures that reduce one risk can have side effects on other risks. They can have a synergistic effect – a positive effect on reducing other risks – but they can also have a negative effect, leading to a (temporary) increase of other risks. Placing UV traps to detect insects can increase the risk of damage due to UV radiation. Treating an area with pesticide to reduce the risks of insect damage increases the risk of contaminants. Regular cleaning reduces the risk of contamination as well as that of pests.

Agents of deterioration may also follow on from each other. Infestation by woodborers may weaken an object causing it to collapse under physical forces.

Examples of the relationship between 'Pests and plants' and other agents of deterioration are listed in Table 32.

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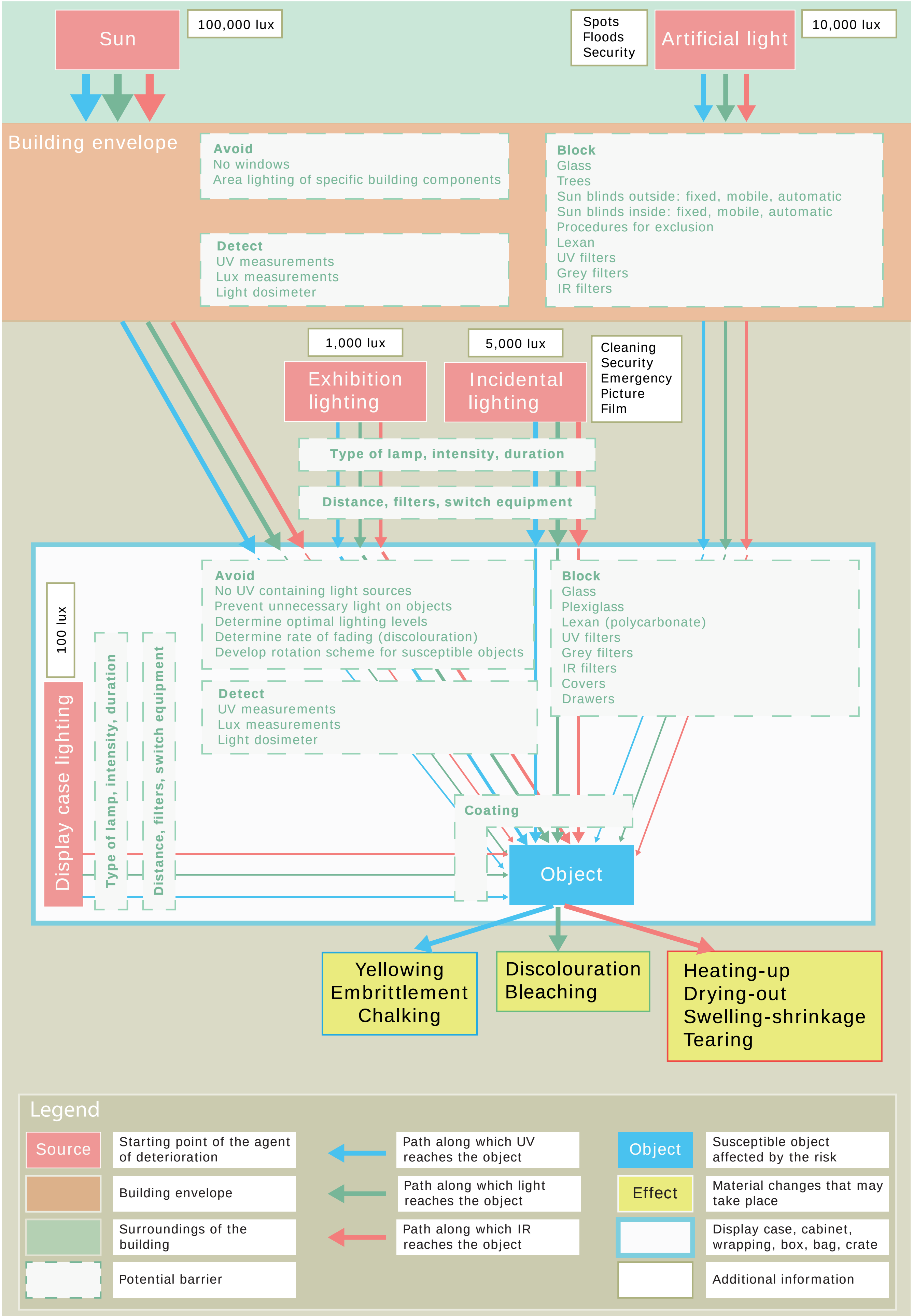
With the arrival of a new presentation – the Canon of Dutch History – the entrance building at the Open Air Museum was partly dismantled and refurbished. What had been a number of well-separated compartments are now connected to each other in order to make an attractive and coherent exhibition, and also provide an aesthetically appealing series of vistas from one space to the next. To create this new space, openings had to be made in several walls. Before the redevelopment began there were many discussions about how many openings should be created; no-one knew exactly and there were different interests. For an exhibition designer a hole in a wall meant less space for the collection, while a security officer immediately wonders whether it should be closed by a roller shutter or a sliding door in case of fire.

Together with colleagues from different departments, and facilitated by two RCE consultants, we discussed all the possibilities and risks. Those meetings were enlightening and gave us many new ideas. We also started to understand each other's point of view. After several sessions we noticed that everyone's ideas were starting to point in the same direction. To give an example: if a visitor can escape from one room to another in case of a fire, and a dividing door can close, then it improves safety. A fire resistance of, for instance, 60 minutes ensures that you have enough time to save the people as well as the collection. Hence both the curator and the security officer are happy. All manner of issues were discussed in a similar fashion and we also got some advice from RCE. We have installed the latest sprinklers that produce a high-pressure water mist – instead of the huge amounts of water that the old systems used. Fire is extinguished quickly without too much collateral damage.



Scenario scheme for the agent of deterioration 'Light, ultraviolet and infrared radiation'

Light, ultraviolet and infrared radiation

Scenarios for light, UV and IR radiation

This scenario scheme sketches all the scenarios for optical radiation. The red boxes represent the sources for light, ultraviolet (UV) and infrared (IR) radiation. These can be found outdoors, indoors, in a specific room or in a display case. The white boxes next to the red boxes give information about the typical properties and intensities that determine the radiation output of the source.

The grey and orange bars represent the barriers that the radiation meets on its way from source to object. The green texts in the bars provide guidance for determining the performance of the barrier. When an object is placed outside, there are probably no barriers, except perhaps a protective coating on the object itself.

Each line that is drawn from a source to the object represents the pathway that the three types of radiation will take. The blue lines represent ultraviolet radiation; the green lines visible light; and the red lines infrared radiation. The thickness of the lines is indicative of the intensity or quantity of radiation. In general, each barrier will reduce the intensity somewhat.
The blue box represents the object, which has a particular sensitivity to light, ultraviolet and infrared radiation.

The three orange boxes with text at the bottom describe the most common effects of the three types of radiation. Each line drawn from a source, via one or more barriers, to the object where it causes an effect, represents the scenario for one specific risk. The page opposite shows the abstract scenario scheme. On the next page the same scheme is shown more realistically, within the setting of a building.

Introduction

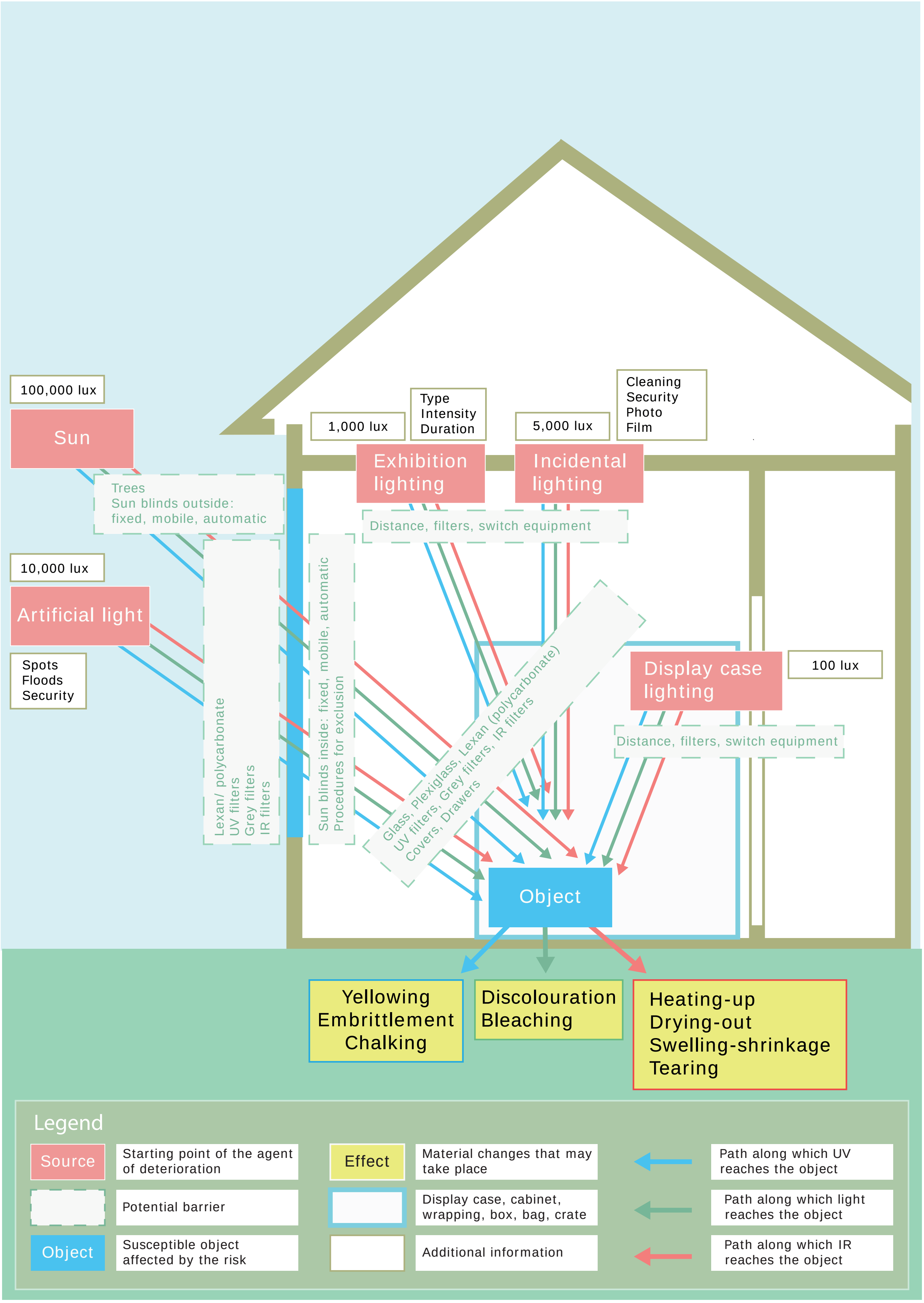
Optical radiation is the term applied to radiation in or near the region of the spectrum to which the eye is sensitive. It can be considered to consist of visible *light* – with a wavelength of 380 nm (violet) to 780 nm (red) – invisible *ultraviolet radiation* (UV, from 100 to 380 nm) and invisible *infrared radiation* (IR, from 780 to around 1,000,000 nm). Light is necessary to see form and colour, but it can also cause damage, even in small quantities; it simply takes longer before this damage is apparent. Damage by radiation is cumulative and irreversible; every bit of radiation that is absorbed by an object adds to the damage, which cannot be undone. The goal of museum lighting is, therefore, threefold: (1) to provide the visitor with sufficient light to be able to see the objects, (2) to offer an invitingly lit space, and (3) to minimise the damage caused by light and other radiation.

For a particular material, the damage caused by radiation depends on the type of radiation (how much energy it possesses; Padfield 2015), the level of illumination (measured in lux), and the exposure time (measured in hours). When UV and IR are reduced to the greatest extent possible, the cumulative light dose (measured in lux hours) determines the amount of damage caused and the rate at which damage will occur. Materials are classified according to their light sensitivity by dividing them into groups that show roughly the same amount of damage (usually discolouration) in response to a certain light dose. Indices of these materials can be found in, for example, CIE (2004), Ford and Smith (2011) and Michalski (2016).

Ultraviolet radiation (UV)

Daylight and many types of unfiltered electric light contain ultraviolet radiation. Because of the high energy of this radiation, it is the most damaging component in the spectrum. UV is responsible for reactions in which molecules break (for instance the breakdown of long-chain polymers) or join together (cross-linking, which often leads to yellowing). These reactions often involve the incorporation of oxygen into the molecules in so-called photo-oxidation. Damage by UV is frequently first apparent as a yellowing of the material or the fading of its colour. After that, the material tends to lose its strength, becomes brittle and starts to crumble. A good example is the effect of daylight on newspapers or certain plastic foams. The amount of UV present alongside light in the beam (the UV content) is frequently expressed in microwatts per lumen (µW/lm). By convention UV contents of 75 µW/lm (the level present in an old-fashioned incandescent lamp) or less are considered to be low, but by using modern electric lamps, or through filtering, it is possible to achieve UV contents of around 10 µW/lm.

Figure 82. Newspaper yellowed by the UV radiation present in daylight



Scenario scheme for the agent of deterioration 'Light, ultraviolet and infrared radiation' (alternative)

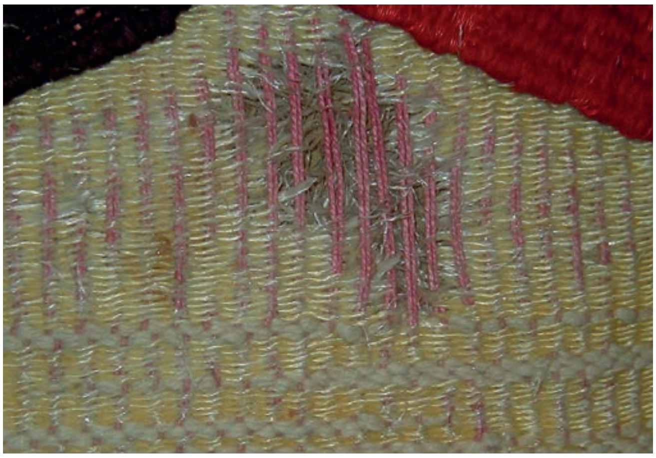


Figure 83. Crumbling of a plastic thread caused by UV radiation

Figure 84. Fading of a red colourant on the front of a rug exposed to light, the reverse is unchanged

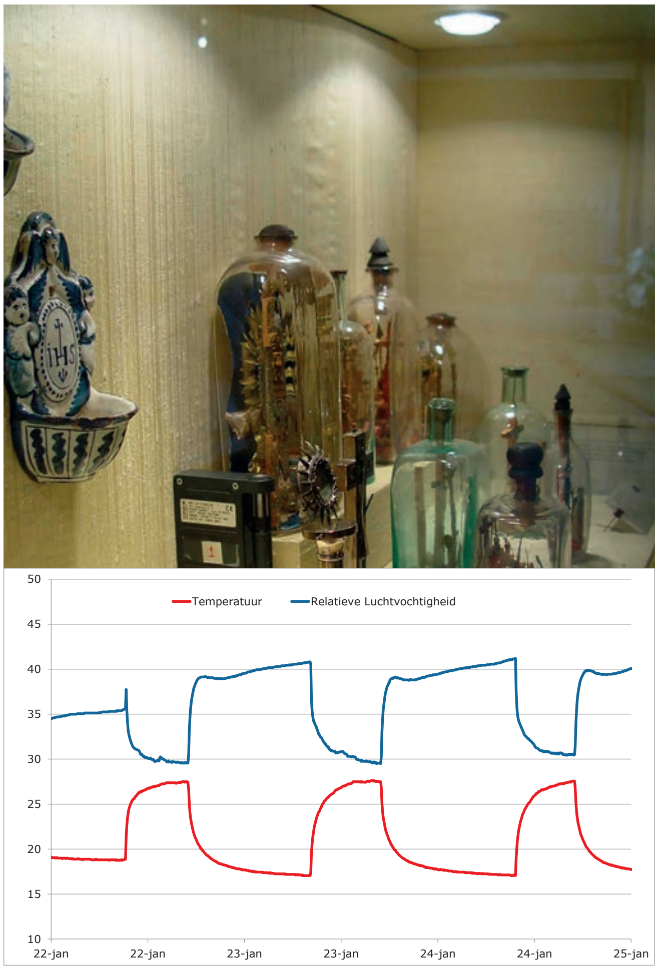


Figure 85. Daily temperature and relative humidity fluctuations due to the IR radiation from incandescent lamps in a display case

Light

We call the visible radiation to which our eyes are sensitive 'light'. It is the part of the spectrum that allows us to see the world around us. White light consists of all colours of the visible spectrum, the colours of the rainbow. We perceive objects because they emit or reflect light. The colour of an object is the result of selective absorption or reflection of certain wavelengths within the visible spectrum (for example a red object reflects red light while absorbing other parts of the visible spectrum). Even though light possesses less energy than UV, it can still cause damage, particularly discolouration or fading. A good example is offered by traditional red and yellow dyes, which often have a fragile molecular structure. These colourants absorb blue radiation, which is the part of the visible spectrum containing most energy, as a result of which they are often the first dyes to discolour. As light does not have enough energy to penetrate deeply into the materials, the damage that it causes is often only present at the surface (see Figure 84).

Infrared radiation (IR)

We are not able to see infrared radiation, but we can feel it as heat. This heat does usually not contain enough energy to initiate chemical reactions, but heat will generally accelerate reactions that have already started. IR radiation also causes surfaces to warm up, which can lead to dehydration, shrinkage, deformation and cracking. Objects composed of materials that have different expansion coefficients and which, therefore, shrink and expand differentially (e.g. layers of different materials, such as a veneer on wood), or objects that are restricted in their movement (fixed panels), can build up considerable stress and eventually crack as a result of heating. In particular, daily cycles of heating and cooling, when the lights are switched on and off in display cases, can cause cracks and tears (see Figure 85).

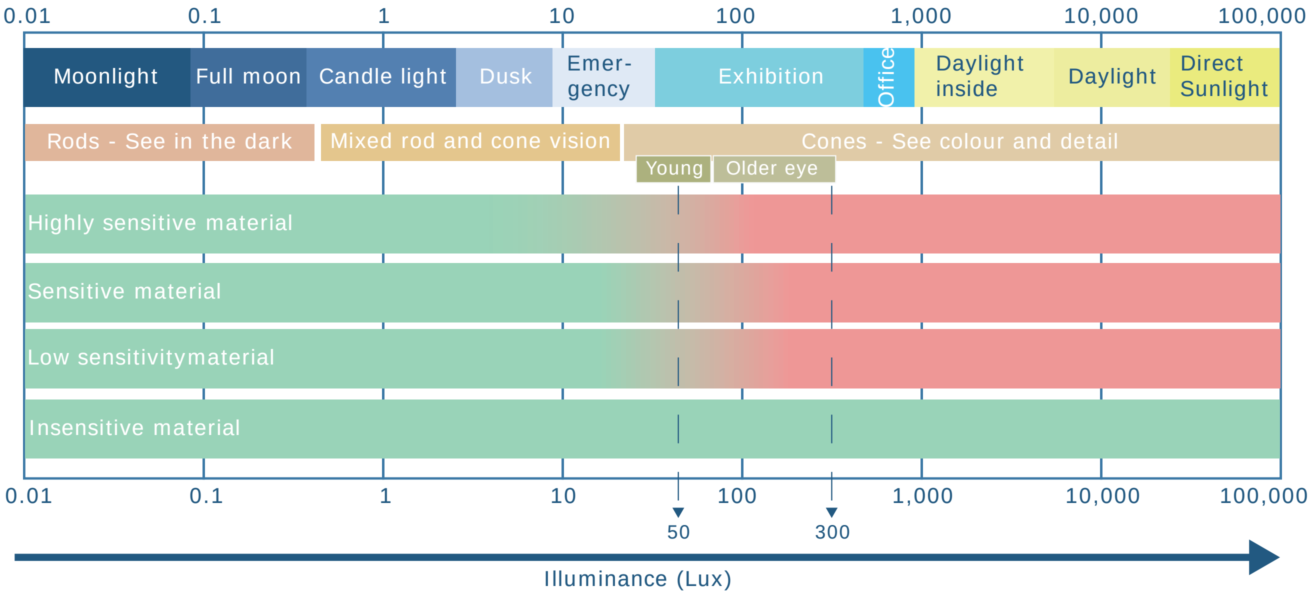


Figure 86. Light levels from different natural and electric light sources and guidelines for classes of object sensitivity

Sources and intensities

The most important outdoor source of radiation is the sun, which has high UV and IR contents in its emission. At night, buildings are often lit with outdoor spotlights and safety lights that also emit UV. Window glass blocks the most energetic UV radiation, but generally allows wavelengths longer than 320 nm to pass. Indoor electric light sources are needed to replace or supplement daylight for exhibition lighting (spotlights, display case lighting), room lighting (atmosphere and safety), work and cleaning lighting (before and after opening hours) and emergency lighting (escape routes and emergency back-up). Furthermore, there is incidental lighting, for example for filming and photography.
Typical light levels outdoors range from 10,000 to 100,000 lux; incoming daylight generates indoor levels ranging from 1,000 to 10,000 lux. Light levels provided for sensitive objects, whether on open display or in a showcase, range typically from 50 to 300 lux. At less than 50 lux many visitors will have difficulty distinguishing colour and detail. At 300 lux most people are able to see well.
For comparison, occupational health and safety requirements for office lighting typically specify 500 lux on the horizontal surface of a desk. Figure 86 provides an overview of typical light levels from different light sources.

Pathways and barriers

On its way from source to object, radiation may pass one or more barriers. Glazed skylights or windows form the first barrier for light, UV and IR radiation from outdoors. They offer several additional possibilities for blocking incoming radiation, such as curtains, screens, shutters and grey filters and/or UV filters applied to the glass (see Figure 87). The first barrier for electric light sources is their casing or fixture, which can be fitted with appropriate filters. Opaque internal walls can block radiation that enters from outside, but in this case, additional electric lighting is often needed for optimal visibility. A final barrier can be applied at object level, for example filtering glass in a showcase or a cover placed over an object when it is not being viewed (Figures 88 and 89).

Objects and their vulnerability

Radiation can cause damage either through the physical processes induced by heating or as a result of (photo)chemical reactions. The IR radiation reaching an object induces direct heating. Part of the light and UV radiation is absorbed by the object and may be converted into heat, inducing indirect heating. As dark materials absorb more radiation they are more likely to heat up than light-coloured materials. This heating can cause materials with a low melting point, such as waxes, resins and fats, to become soft, deform or even melt. The stress that can build up in objects that are constructed of materials with different thermal expansion coefficients, can be released by cracking and fracturing. Hygroscopic material can desiccate, shrink and tear. Chemical reactions that would not take place at normal temperatures, might be initiated at higher temperatures (see also 'Incorrect indoor climate').

Organic materials can undergo (photo)chemical reactions, which are activated by the energy of the absorbed radiation. The likelihood of such reactions depends, in part, on the composition and colour of the material and the presence of any protecting finish (for instance, black paint). Organic colourants and pigments (especially plant-based dyes), coloured textiles and paper, lignin-containing paper, colour photographs (prints and slides), felt-tip pen, coloured inks and plastics, are amongst the materials most sensitive to UV and light. Inorganic pigments, high quality rag paper, black pigments and carbon-based inks are not generally particularly sensitive.

Many light-sensitive colourants initially fade rapidly, after which the rate of fading decreases. This means that objects in which the colours are still pristine will suffer the most damage when they are exposed to light for the first time. They not only change colour quickly but they can also lose a relatively large proportion of their value when their 'as new' character is lost. The reduced fading in objects that have already been exhibited often, does not mean that they can be exposed to more light without risk. When little colour is left, small changes can appear even more striking. In addition, other less apparent types of damage – for example photochemical degradation of the textile or paper on which the colourant is applied – will continue, and may lead to damage to the support. More information about the light sensitivity of objects and materials, and their classification, can be found in CIE (2004), Ford and Smith (2011) and Michalski (2016).

Figure 87. Blocking radiation at a building level: screens on the outside of the façade

Figure 88. Blocking at object level: a showcase with a grey filter applied to the glass

Figure 89. Blocking at object level: covering an object when it is not being viewed

Options for risk reduction

Options to reduce the risks of light, UV and IR radiation focus on reducing the level of illumination (lux) and/or the duration of exposure (hours). Several options to block radiation and hence reduce intensity have already been mentioned under 'Pathways and barriers'. For electric light sources, increasing the distance between lamp and object will reduce the amount of light that reaches the object. Furthermore, the choice of light source is important, both the type of lamp and its power. Incandescent lamps emit low amounts of UV but high amounts of IR radiation.

Illumination	Number of jnc in 100 years			Period in which a colour change of 1 jnc occurs in highly sensitive material
	High sensitivity objects (ISO 1-3)	Medium sensitivity objects (ISO 4-6)	Low sensitivity objects (ISO 7-8)	
Up to 50 lux	5 - >30	1-2	<1	2 - 20 years
Up to 150 lux	15 - >30	1-5	<1	6 months - 7 years
Up to 300 lux	>30	1-9	<1	3 months – 3.5 years
Up to 1,000 lux	>30	3-30	1	1 month - 1 year

Table 33. Rules of thumb for the number of 'just noticeable change' (jnc) in 100 years and the period in which 1 jnc is expected at different levels of illumination

They can be dimmed to reduce the level of Illumination, but it is cheaper to use a less powerful lamp. Because of their inefficiency, incandescent lamps are being phased out.

Fluorescent lights (tubes and compact lamps) produce little heat but certain lamp types emit significant UV radiation, which can be blocked by filters (for instance Perspex or Plexiglass in luminaires). LED lamps emit neither UV or IR radiation, but the lamps and fittings can heat up and need to be cooled. The quality of light from LEDs continues to improve and they use less electricity than other lamps, which makes them attractive. As far as light damage is concerned, a warm white LED causes damage comparable that from an incandescent lamp at the same illumination. All light sources have their pros and cons and the conservation perspective is sometimes at variance with the interests of exhibition designers, who want to support a narrative using light, create an atmosphere and highlight certain aspects. More about this can be found in, for example, Brokerhof *et al*. (2008), Cuttle (2007), Michalski (2016), Saunders and Kirby (2008).

The duration of exposure can be reduced by switching off the lights or by closing the curtains when there is no-one near the objects. This can be done manually by staff or visitors, or automatically with movement sensors, contact mats or dedicated software. Objects can also be covered or placed in sliding drawers.

Rules of thumb for determining the magnitude of risk for specific risk scenarios

To express the degree of fading and discolouration, the unit 'just noticeable change' (jnc) has been introduced. This is the smallest change that the average viewer can see with the naked eye. A difference of 10 jnc represents a clear and distracting colour change. Objects that derive their significance from their colour have usually lost their exhibition value at that point. For objects with saturated colours, 30 jnc will correspond with complete loss of colour.

Assuming a typical light exposure of 3,000 hours per year and a low UV content (less than 75 µW/lm), the expected number of just noticeable changes in 100 years can be estimated, and is presented in Table 33.

Relationship with other agents of deterioration

Measures that reduce one risk can have side effects on other risks. They can have a positive synergistic effect, reducing other risks, but they can also have a negative effect, leading to a (temporary) increase of other risks. UV-absorbing film applied to window glass reduces UV radiation and will also provide some protection against falling fragments if the glass breaks. Placing objects in sliding drawers to reduce light exposure may increase the risk of damage due to vibration and shock.

Agents of deterioration may also act consecutively. The electricity that is needed for lighting can be a source of fire risks when short-circuits occur. Examples of relationships between 'Light, ultraviolet and infrared' and the other agents of deterioration are listed in Table 34.

Agents of Deterioration	Interaction
Physical forces	Placing objects in sliding drawers to reduce light exposure may increase the risk of vibrations and shock. Replacing lamps introduces the risk of knocking over objects or dropping tools. Handling equipment for photography and filming introduces a risk of scratching or knocking over objects.
Fire	Candles are a direct source of fire. Electricity can cause short-circuits. Light sources too close to objects might lead to extreme heating, searing and ignition. Glass objects can focus the sun's rays, which may cause searing or ignition Safety/security lighting reduces the chance of arson.
Water	The combination of electricity and water increases the risk of fire. Reflection of daylight on ponds may lead to unexpected entry of light.
Thieves and vandals	Safety/security lighting reduces the chance of theft and vandalism.
Pests	Spotlights on the building, emergency lighting and other light sources might attract insects; while other insects fear light and will hide from it.
Contaminants	Raking light, rays of sunlight and high light levels make dust and dirt more visible. Dust on lamps might increase the risk of overheating and fire.
Incorrect temperature	IR and absorption of radiation can heat up objects or showcases.
Incorrect relative humidity (RH)	An increase of temperature due to radiation can cause (local) dehydration, desiccation and cracking.
Dissociation	Fading of labels may lead to loss of information. Fading of texts or drawings leads to loss of readability.

Table 34. Examples of the relationship between 'Light, ultraviolet and infrared' and the other agents of deterioration

Daily temperature and relative humidity fluctuations due to the IR radiation from incandescent lamps in a display case

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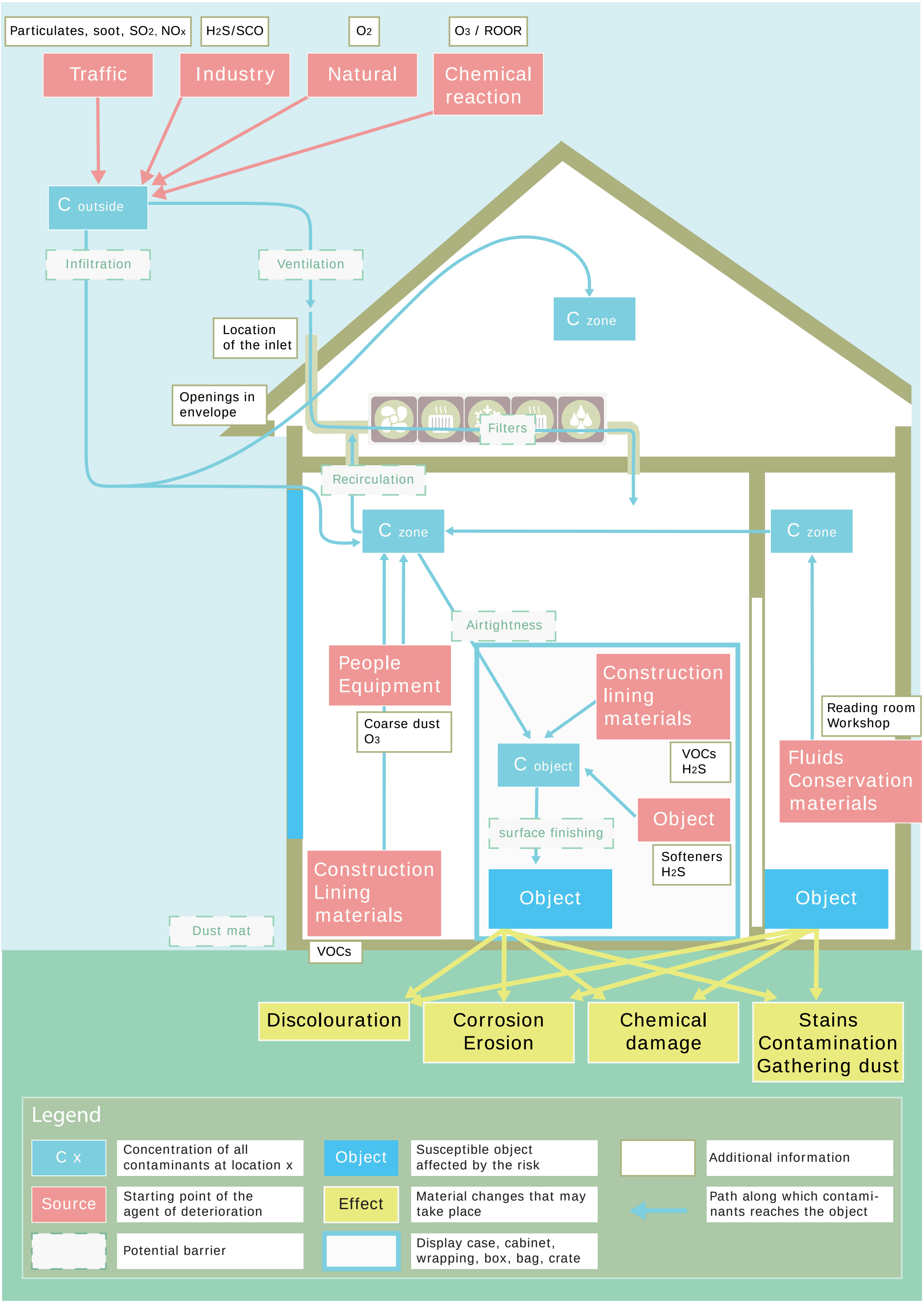


Scenario scheme for the agent of deterioration 'Contaminants'

Contaminants

Scenarios for contaminants

This scheme sketches the most common scenarios for contaminants. It represents a cross-section of a building and the layers around the object.
The red boxes are the sources for the different types of contaminants. They can be found inside or outside the building, in a certain room, or in a showcase. The white boxes outlined in blue provide additional information about the specific type of contaminant or situation.
The dark blue boxes indicate the total concentration of gaseous pollutants.

The possible barriers that a contaminant must pass on its way from the source to the object are indicated in the boxes outlined with a green dotted line. If the object is outside, there are probably no barriers to contaminants, except perhaps a protective coating on the object.

The red arrows indicate the pathways that contaminants typically take from a specific source to the object. Generally, each architectural or physical barrier reduces the concentration of pollutants in the air by a factor of 10. Filters can make this more efficient.

The pale blue boxes represent objects or collections that have a specific vulnerability to contaminants.
The orange boxes at the bottom describe the most common effects of contaminants on objects, such as soiling, discolouration, tarnishing, efflorescence, corrosion and chemical decay.
Each line drawn from a source, via one or more barrier, towards the object and an effect represents the scenario for one specific risk.

Introduction

The agent of deterioration 'Contaminants' describes the risks related to substances that come into contact with an object and that either leave behind traces or react with it in a manner that changes the appearance or properties of the object undesirably. There is a difference between harmful gases, aerosols (minuscule particles or droplets in the air), liquids and solids. These can be produced by human activities or natural processes outside the building (external sources), by activities or emissions from materials in the building (internal sources) or from the object itself (intrinsic sources).

It is impossible to describe every pollutant separately – where they come from, how they reach the objects and the damage they can cause. Therefore, only the most relevant and common pollutants encountered in museums are described here. They are representative of all the other pollutants, and the measures proposed to reduce their risks also apply to those other substances. Table 36 provides a summary of the information available from the literature. More detailed data can be found in, for example, Tétreault (2003) and ASHRAE (2007).

Air pollution (gases, vapours, particulates and dust)

The most common air pollutants from external sources are nitrogen oxides (NO, NO_2), sulphur dioxide (SO_2), ozone (O_3), hydrogen sulphide (H_2S) and carbonyl sulphide (OCS). Besides these reactive gases, particulates are also generated outside. Internal sources, such as visitors and construction materials mainly generate dust and volatile organic compounds (VOCs), of which acetic acid (HAc), formic acid (HCOOH) and formaldehyde (HCHO) are best known.

Nitrogen oxides (NO, NO_2)

Nitric oxide (NO) is generated by combustion processes in power plants, industry, heating and exhaust emissions. In the atmosphere, it reacts with ozone and is converted first into nitrogen dioxide (NO_2) and then into nitric acid (HNO_3). In warmer regions the NO_2 is visible as a brown smog (see Figure 90). Nitrogen dioxide causes fading of colours and degradation of textiles, paper, leather and photographic materials.

Sulphur dioxide (SO_2)

The most important source of sulphur dioxide is the burning of high-sulphur coal and oil products in power plants, industry and transportation. It reacts with water in the air to yield sulphuric acid (H_2SO_4), which causes corrosion of metals, fading of colours, and degradation of textiles, paper, leather and photographic materials.

Ozone (O_3)

Ozone is a strong oxidising agent. Outside, it is formed by electrical discharges such as lightning, or by the reaction between oxygen (O_2) and oxygen radicals (O•) that are formed by UV radiation in the stratosphere. Lower in the atmosphere, air pollution (nitrogen oxides and volatile organic compounds) is converted to ozone under the influence of sunlight. If there is little wind, the mixture of pollutants and ozone forms a photochemical smog. This happens only in spring and summer when the sun is at its most powerful. Sources for ozone inside buildings are photocopiers, laser printers, electronic filters and electric air-purifying systems. Ozone causes yellowing, fading of colours and degradation of polymers – especially rubber.

Figure 90. Smog over Los Angeles

Reduced sulphur gases (H_2S, OCS)

The reduced-sulphur-containing gases hydrogen sulphide (H_2S) and carbonyl sulphide (OCS) are generated by biodegradation processes (rotting organic matter, sewerage and marshes for example), in industrial processes (paper pulping), by the degradation of wool and vulcanised rubber, and by humans and animals. Their best-known effects are the tarnishing of silver and the blackening of lead-containing pigments.

Volatile Organic Compounds (VOCs)

Organic acids (formic and acetic acid) and aldehydes (formaldehyde and acetaldehyde) are released from wood and wood-based boards, such as plywood, medium-density fibreboard (MDF) and particle board.

Wood from the oak tree emits a considerable quantity of acetic acid and vulnerable materials kept in oak furniture are at risk. Classic examples of this interaction are the effects on shell and coin collections stored in specially-designed oak cabinets.

Engineered wood boards are regularly used in the construction or furnishing of buildings and showcases. Particle boards that incorporate wood chips, sawmill shavings or sawdust, release a relatively large amount of acetic acid. Depending on the type of adhesive or binder used in their production, they can also emit formaldehyde. Paints, glues and sealants can also be sources of gaseous contaminants. In enclosed environments, such as cabinets and showcases, a high concentration of these gases can build up. Lead is extremely sensitive to acetic acid and develops a white surface crust within a very short time when in contact with organic acids. Other metals and calcareous materials are also highly susceptible.

Dust

Fine dust (PM_{10}) is a collective name for airborne, inhalable particulate matter with a diameter of less than 10 micrometres. Particulates are produced by, amongst other sources, traffic (diesel soot, wear-and-tear of tyres) and industry. Fine dust can also contain pollen, desert sand and (sea) salt. The last of these is particularly aggressive and can cause corrosion. These small particles can settle into porous surfaces and thereby cause a discolouration of the surface, called ‘soiling’.

Large dust particles are generally generated indoors; examples of sources are combustion, which generates soot, loss of fibres

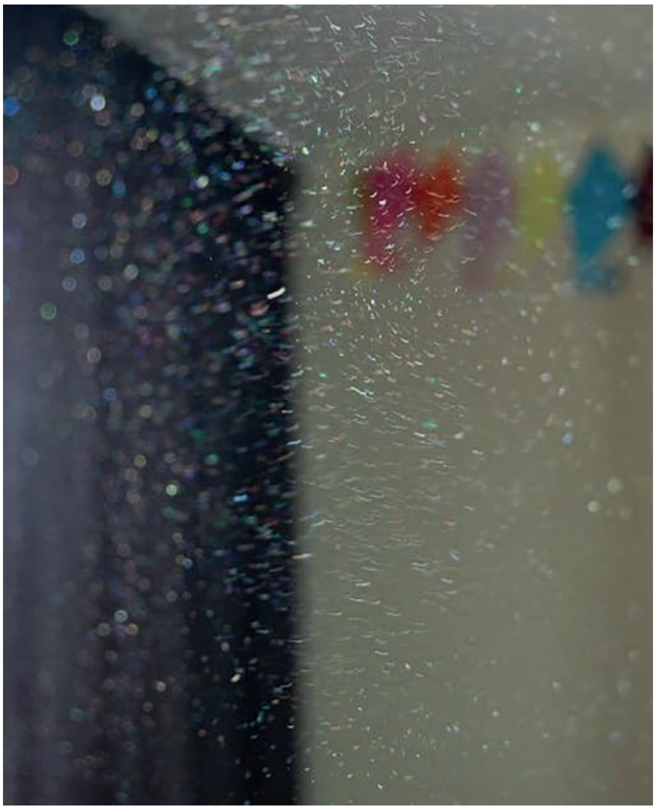


Figure 91. Dust particles in the air become visible in a beam of sunlight

Air pollutant	**Background levels in the outdoor air in the Netherlands**	
	µg/m³	**ppb**
NO_2*	10-40[1]	5-21
SO_2**	2[2]	0.8
O_3***	30-60[3]	15-30
H_2S§	0.1-0.3[4]	0.1-0.2
PM_{10}§§	10-30[5]	–

Table 35. Average background concentrations of outdoor air pollution in the Netherlands (data from the RIVM, 2015).

* *The NO_2 concentration is at its highest in the immediate vicinity of roads.*
** *The SO_2 concentrations throughout most of the Netherlands have decreased significantly over the past decade (current concentrations are just below the level of confidence in the measurements).*
*** *O_3 concentration measurements are based on the empirical relation between NO_x and O_3.*
§ *Measured in the SilProt project.*
§§ *The PM_{10} maps show a fairly homogeneous concentration over the Netherlands, with local highs near the harbours of Amsterdam and Rotterdam, where dry bulk goods are stored and shipped, and close to agricultural barns.*

from textiles, and humans, who shed hairs and flakes of skin. The main effect of the dust is that it creates a visually disturbing effect. Subsequent dusting and cleaning can lead to mechanical damage in the form of scratches, breaking or loss of material. Furthermore, it is especially difficult to remove dust from porous or sticky surfaces. Dust can attract moisture and is a good food source for fungi and insects. It can also absorb harmful gases from the air, which then cause corrosion or degradation. Over time, in combination with moisture, dust can harden (cementation), making it very difficult to remove. Dust released from unfinished concrete is alkaline and can be damaging to dyes and paint.

Concentration of air pollution

The quantity of air pollution is usually expressed as a concentration. This can be the weight of pollutant in a volume of air: in grams per litre (g/l), grams per cubic metre (g/m³), or micrograms per cubic metre (µg/m³). It can also be expressed as the number of particles of pollutant per total number of particles in the air – the number of particles per million air particles (ppm, parts per million, or 10^{-6}), per billion (ppb: parts per billion, 10^{-9}) or per trillion (ppt, parts per trillion, 10^{-12}).

The Dutch National Institute for Public Health and the Environment (RIVM) measures the air quality at a large number of locations in the Netherlands and publishes these data on a website (RIVM, 2015; 2016). The maps based on these measurements show the hourly values for different pollutants. In addition, it is possible to look back at 'validated data' for specific measurement locations.

Table 35 shows the average background levels for external air pollution in the Netherlands. The measured values can differ greatly, because the concentrations are dependent on local sources, wind direction, wind speed, rainfall and season.

Liquids

Liquids include paint, cleaning materials and solvents, as well as drinks near, or even on, objects. Spilt coffee, ink and felt-tip pens cause stains and can dissolve components in the object causing, for example, bleeding colours or inks. Plasticisers, for instance from soft PVC, can condense on cold surfaces in the area, making them sticky. Sweat, grease, oils, fats and acids from fingerprints can react with surfaces and leave stains or corrosion. Flooding usually goes hand-in-hand with contamination, because the water will contain dirt that remains on and in the surface after drying. Stains caused by urine from mice or other animals are discussed in the chapter on 'Pests and plants'.

Source	Group	Air pollutant	Vulnerable materials	Effect	LOAED (ug.m^{-3}.year)
Outside: Traffic Industry Manure Ground bacteria Inside: Silicone sealants Glues Cleaning products Visitors	Nitrogen	Nitrogen oxides (NO_x)	Silver with a high copper content	Corrosion	50
			Sulphur	Weakening	?
			Oxygen	Yellowing	10 – 50
			Volatile Organic Compounds	Decolourisation	1 – 10
		Particulates	Ebonite	Decolourisation	?
			Metal	Corrosion	?
			Nitro-cellulose	Crystallisation	?
			With sulphate- nitrate bonds	White efflorescence	?
		Other amines	Paintings	Decolourisation	?
			Copper, bronze	Corrosion	?
Outside: Burning of sulphur-containing fossil fuels (coals) Paper industry Decomposition (oceans, marshes) Inside: Degradation of proteins Minerals (e.g. pyrites) Vulcanised rubber	Sulphur	Sulphur oxides (SO_x)	Copper	Corrosion	50
			Leather	'Rotting'	
			Weakening	40	
			Paper	Acidification	10
			Some dyes	Decolourisation	10
		Reduced sulphur (OCS & H_2S)	Bronze, copper and silver	Corrosion	?
			Lead-containing pigments	Darkening	?
			Photographic prints	Decolourisation	1
Outside: 21% in atmosphere (O2) Photochemical smog Inside: Electronic air filters Electronic filters Laser printers Photocopiers Degradation of wood, rubber and oil paint	Oxygen	Oxygen (O_2)	Organic objects	Embrittlement and breakage	?
			Colouring	Decolourisation	?
		Ozone (O_3)	Some dyes and pigments	Decolourisation	1 – 60
			Organic objects	Oxidation (particularly rubber embrittlement)	< 0.005
		Peroxides (ROOR)	Photographs	Decolourisation	?
			Some dyes	Decolourisation	?
			Organic objects	Decolourisation	?
			Air pollution	Oxidation	?
Inside: Wood products Medium-density fibreboard (MDF) Dried paints Glues Smoke (candles, tobacco) Silicone sealant Degradation of oil paint Cleaning products	Volatile Organic Compounds	Acetaldehyde and formaldehyde	Copper, zinc	Transformed into organic acids	600 – 6,000
		Acetic and formic acids	Metal (copper alloys, lead, magnesium, zinc)	Corrosion	400 – 1,000
			Calcareous materials (shells, corals, limestone, fossils)	Salt efflorescence	10,000
			Sodium-rich glass	Salt crystallisation	?
			Cellulose	Reduced degree of polymerisation	4,000
		Fatty acids	Paintings	Decolourisation (and 'ghost images' on glass)	?
			Bronze, cadmium and lead	Corrosion	?
			Paper and photographs	Yellowing	?

Source	Group	Air pollutant	Vulnerable materials	Effect	LOAED (ug.m^{-3}.year)
Outside: Traffic Burning fossil fuels Industry Construction work Sea (salt) Inside: Burning candles Concrete Laser printers Textiles	Particulates	Particulates and dust	Magnetic media	Scratching	?
			Porous surfaces	Darkening (hardening)	10 – 50
		Soot	Metals	Corrosion	?
			Porous surfaces	Darkening	?
		Ammonium salt	Copper, nickel, silver and zinc	Corrosion	?
			Natural resins on furniture	Decolourisation	?
			Ebonite	Decolourisation	?
		Chloride	Metals	Increasing corrosion	?

Table 36. Sources for air pollutants relevant to heritage organisations, their effects, and their LOAED (lowest observable adverse effect dose): data from, amongst others, Tétreault, 2003 and 2013; BSI, 2012.

Solids

Apart from dust and particulates, there are other types of solid that can be deposited on objects. Their source often lies in one of the other agents of deterioration: excrement and frass from insects or fly and bird droppings ('Pests'); crystallising salts ('Incorrect indoor climate'); or chewing gum (possibly 'Thieves and vandals'). There are also materials applied to the objects; these include pesticide residues (DDT, lindane) and unstable (conservation) materials applied in the past, such as yellowing adhesives, consolidants, adhesive tape, (rusting) staples, paper clips and pencil marks. Although they were first applied with the best intentions, they can subsequently be perceived as contaminants.

Sources

In the scenario scheme, different external and internal sources for gases, liquids and solids are presented. Table 36 gives an overview of common air pollutants relevant for museums, their sources (of natural origin or due to human activity) and their effects on different materials. They can be generated internally or externally. Contamination by liquids and/or solids is often the result of human or animal contact between source and object. A very specific source is the object itself, in this case the contaminant originates from the materials from which the object is made. Examples include cellulose nitrate and acetate, which were used in early film and photographic material and fashion accessories; they produce nitric acid and acetic acid respectively upon degradation and the accumulation of these acids in the objects accelerates further degradation (autocatalysis), or corrodes other parts of the object, e.g. a copper handle on a cellulose acetate handbag.

Pathways and barriers

There are three pathways that contaminants can follow from the source to the object.

- Through the air: from high to low concentration by partial pressure differences, by random diffusion or by being carried in an air flow (gases, aerosols and particles).
- Flowing: from higher to lower areas (liquids).
- Direct contact: transfer through contact or direct application to a surface (liquids and solids).

Contamination from an intrinsic source can affect the object via all three pathways.

Gases enter a building or a space in different ways: *passively*, through openings, cracks, seams and holes in the building envelope, which is termed infiltration; or *actively*, perhaps with the help of a mechanical system or through an open door or window, termed ventilation. Gases can also penetrate through a material, called permeation, and then slowly spread through the air by diffusion. Diffusion and permeation are slow processes, while

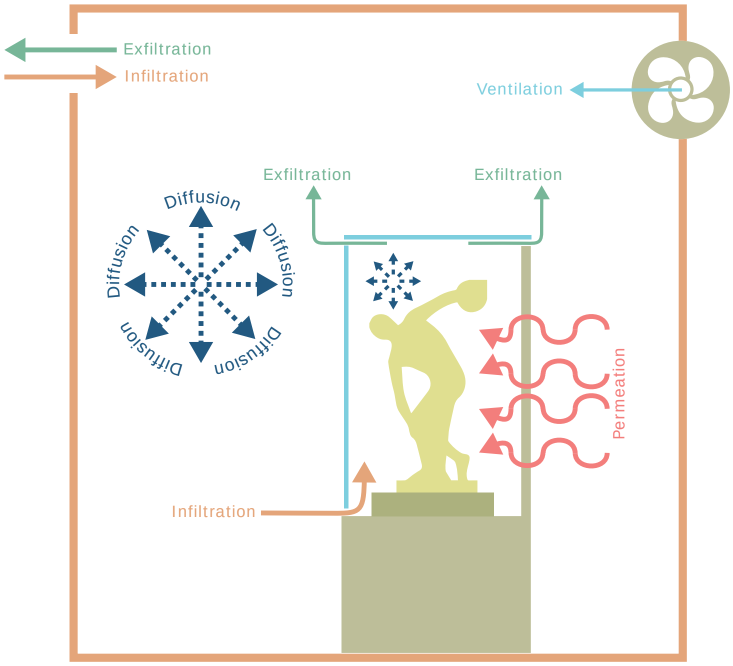


Figure 92. Different transport mechanisms into and inside a room and display case

infiltration and ventilation are rapid. See Figure 92 for a schematic visualisation of these transport processes. Air moves because of differences in pressure, which are caused in turn by temperature or atmospheric pressure differences that might lead to, for example, wind pressure on a façade. Sometimes this can be felt as a draught inside the building.

As human comfort requires optimal natural ventilation, openings are positioned in such a way that air can flow as efficiently as possible. With mechanical ventilation, air is pushed by the blades of a fan. The airflow is determined by the air speed and the size of the inlet.

For a material to change, the gas molecules or particulates should impact on an object's surface and be adsorbed or absorbed into the pores of the material.

Barriers that gases may encounter include architectural structures, furnishings, packaging or filters in the ventilation pathway. These barriers are located between the outside and inside (floors, roofs, walls, doors and windows), inside between different zones (interior walls, doors and windows), in rooms or galleries (cabinets and showcases) or at object level (bags and boxes). The ease with which a gas permeates these barriers depends on the type of material(s) and construction. Although polyethylene bags are waterproof and liquid water cannot penetrate the film, oxygen slowly permeates and water vapour passes through the film even more quickly.

To ensure that the air that is brought into the building by ventilation is free of pollution, different filters can be placed in the air stream. The most common are: particulate or dust filters, active carbon filters and impregnated media. The specific gases that are absorbed, and the degree of absorption, will depend on the type of filter; see Table 38 for a short overview.

Liquids flow over surfaces or drop from above onto the object; liquids always flow towards the lowest point. They can also reach the object directly, for example when drinks are spilt or as a result of wet cleaning. Clearly, the barriers used to block liquids must be impermeable to liquids. Plastic bags are waterproof, but offer less protection against organic solvents.

Solids are transferred through direct contact between a contaminating material and the object. Usually they cause stains or discolouration and the extent of damage depends on the amount of contamination, the mobility of the particles and the extent to which they adhere to, and penetrate, the surface, which is largely determined by its porosity. Wood resins are transferred through direct contact; acidic paper and cardboard can have an effect on photographic materials and works on paper when in direct contact. In time, PVC releases plasticisers that can dissolve the ink on papers stored in plastic folders. Skin grease and acids leave fingerprints on susceptible surfaces when touched with bare hands. Barriers in these cases include using gloves when handling objects, or placing (tissue) paper, polymeric film or cotton between the object and an emissive construction material.

In the case of intrinsic sources, the objects itself emits harmful gases. Some common examples are:

- Acetic acid emitted from wooden parts causing corrosion of lead components in the same object, for example lead organ pipes that show a white efflorescence.
- Organic acids emitted from ageing leather dressing or waxes causing brass handles to corrode.
- Salts and pesticides in porous materials migrating to a surface where they crystallise.
- Cellulose acetate and cellulose nitrate films and negatives give off acids that can damage the objects themselves or anything vulnerable in the vicinity.

Iron gall ink and copper-containing inks can accelerate the degradation of paper in damp environments or at high relative humidity. Since these inks are an original part of the object they could be considered an intrinsic source of contamination, but this degradation process is classed as 'autonomous decay'. In almost all cases, reducing the risks from intrinsic sources can only be achieved by reducing the temperature (and sometimes the RH) to slow down the reaction rate (see 'Incorrect indoor climate').

Objects and their vulnerability

The effects of contaminants on objects can be divided into four main groups.

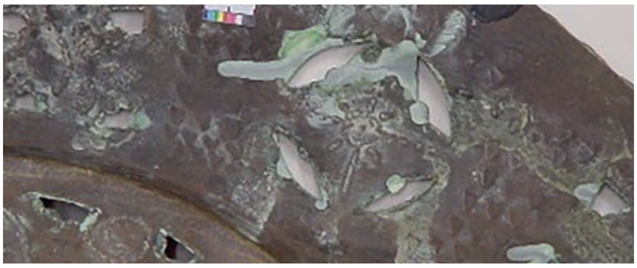
- Dirt, stains and dust, mostly on surfaces through direct contact and deposition of liquids and solids.
- Tarnishing and corrosion of inorganic materials by oxidative processes, which usually proceed faster at a higher relative humidity and temperature.
- Discolouration and yellowing of organic materials, which give a good first indication of chemical degradation due to oxidation (reaction with oxygen) or hydrolysis (reaction with water and/or acid).
- Embrittlement and loss of strength in organic materials due to further oxidation and hydrolysis, which generally occur after earlier discolouration and/or yellowing.

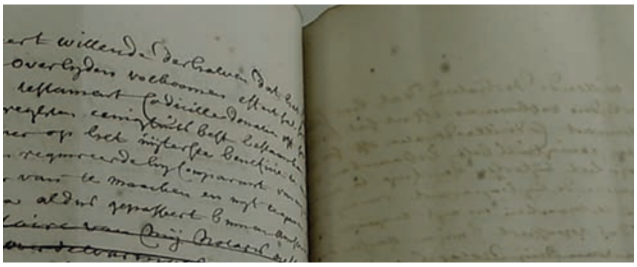
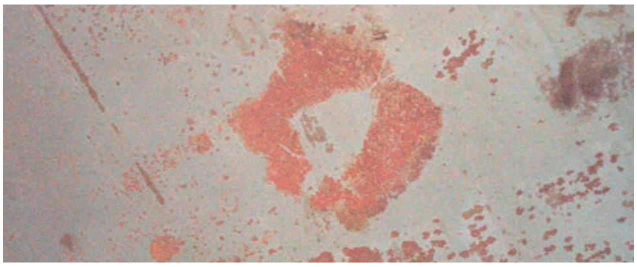
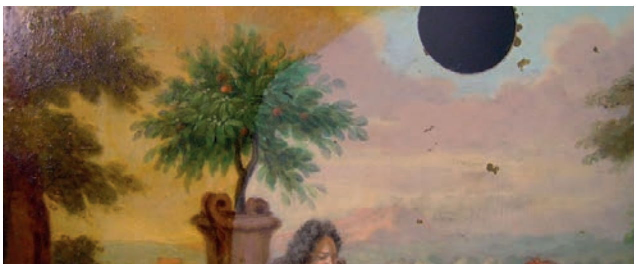
The last three processes involve chemical reactions. These will proceed more rapidly at higher temperatures and relative humidities (see also 'Incorrect indoor climate').

Whether an effect occurs depends on the susceptibility of the object on the one hand and the exposure on the other. In common with other degradation processes, assessing the exposure requires one to look at the dosage, which is related both to the amount of contamination and to the duration of the exposure. Laboratory experiments, observations and monitoring in everyday practice should give a better understanding of the dose to effect relationship. For some combinations of material and contaminant, these relationships have been established and expressed as a LOAED (lowest dosage at which an adverse effect is observed) or a NOAED (dosage below which no adverse effect is observed). Table 36 presents LOAEDs for a number of combinations of material and contaminant.

As there are many different combinations and interactions, and as many material changes, it is impossible to present a comprehensive overview of the great variety of risks due to contamination, so Table 37 summarises the most common damage found on museum objects.

Figure 93. Examples of damage caused by intrinsic sources of contamination

Example	Description
Dirt, stains and dust on surfaces through direct contact and deposition of liquids and solids.	
	*Figure 94.* Food or drink near objects may result in risks of spilling and staining. Therefore, in most institutions food and drink are not allowed. How often do you spill a cup of coffee or tea over something?
	*Figure 95.* Metal objects are sometimes cleaned with polishes that, if not removed completely after treatment, can cause local corrosion. In the image the brass was locally affected and turned green. Under normal museum conditions, this corrosion process becomes visible in three to six months.
	*Figure 96.* Conservation treatment using unstable materials that cause a colour change over time can be considered contamination due to solids.
	*Figure 97.* Dust deposited on the horizontal surfaces of porous materials is very hard to remove and can cause severe discolouration.
	*Figure 98.* The awareness of dust depends on lighting. The greatest risk from dust is mechanical damage caused by dusting. To a certain extent, dust gives an impression of antiquity, but too much simply makes an object look dirty.

<table>
<tr><td colspan="2">Tarnishing and corrosion of inorganic materials by oxidative processes that usually proceed more rapidly at a higher relative humidity and temperature.</td></tr>
<tr><td></td><td>Figure 99. Chemically-active components in iron gall ink have been transferred onto the page opposite, causing local discolouration. The transfer can only take place at high relative humidity or if the document has become wet (for more information, see the Iron Gall Ink Website, 2011).</td></tr>
<tr><td></td><td>Figure 100. When objects are touched with bare hands, skin oils and fatty acids can be transferred onto the surface. These chemically active compounds react locally with the surface and form corrosion on polished metals and stains on porous surfaces. Sometimes, a handprint may be visible. Corrosion on metals because of fingerprints is, under normal conditions, visible after three to nine months.</td></tr>
<tr><td></td><td>Figure 101. A lead musket ball was shot into a wooden board to study the penetration depth. The bullet has reacted locally to form lead carbonate. This is a good example of intrinsic contamination: the organic acid from the board reacts with the susceptible lead surface.</td></tr>
<tr><td></td><td>Figure 102. Silver objects tarnish and silver sulphide is formed. Because the concentrations of hydrogen sulphide (H_2S) and carbonyl sulphide (OCS) are very low and the reaction very fast, the reaction rate is completely determined by the speed at which the gases reach the surface. Under normal conditions, the first phase of tarnish, a pale-yellow surface, is visible in around six months to a year.</td></tr>
<tr><td colspan="2">Discolouration and yellowing of organic materials, which give a good first indication of chemical degradation due to oxidation (reaction with oxygen) or hydrolysis (reaction with water and/or acid).</td></tr>
<tr><td></td><td>Figure 103. Yellowing of varnish is the result of an interaction with different pollutants that can cause oxidation and hydrolysis of resins.</td></tr>
</table>

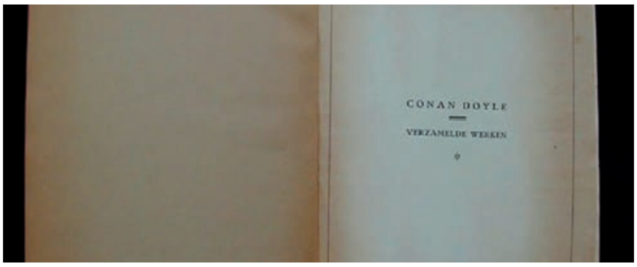
	*Figure 104*. Yellowing of paper is the first symptom of a reaction with acids that leads to the degradation of cellulose and hemicellulose. Later the paper becomes brittle and loses strength. Eventually it can no longer be handled. For books, the acidic card covers are the source of contaminants. The effect is limited to the pages at the front and back that are directly in contact with the covers.
Verzwakking en afbraak van organische materialen als gevolg van oxidatie en hydrolyse, wat meestal volgt op een eerdere verkleuring of vergeling.	
	*Figure 105*. Some materials emit harmful components and are also sensitive to them; they are both the source and the affected material. An example is the degradation of cellulose acetate. In an acid-catalysed reaction, cellulose acetate is converted to cellulose and acetic acid. The acetic acid further catalyses the reaction or migrates to the surface and slowly evaporates. Under normal circumstances, in a few decades, it can be smelt (known as vinegar syndrome) and seen (as sticky surfaces). The cellulose acetate becomes brittle and deformed.
	*Figure 106*. During the ageing of tracing paper, which is acidic and thin, it becomes brittle and breaks quickly when handled.

Table 37. Examples of damage found on museum objects caused by exposure to contaminants

Options for risk reduction

When taking measures to reduce the risks from contaminants, an integrated approach of five stages or steps can be used.

Avoid
By choosing the right location for the museum and appropriate construction materials and interior design, a number of sources can be avoided. The air inlets for the HVAC system should be located as high as possible to prevent particulates and gases from the street from entering and quickly saturating the filters.

Using inert construction materials for the exhibition and storage of susceptible materials further prevents damages. For instance, do not place any susceptible objects in showcases made of fibre board (MDF). Remove possible dust sources (large openings in the façade, visitors) from the vicinity of objects, or increase the distance between the source and object using, for example, barriers or ropes. Do not place objects that emit harmful components near susceptible objects.

Choose the right conservation and restoration methods and materials, and remove excess materials after treatment. Do not allow any food or drink near objects.

Block
If it is clear which are the most vulnerable materials (objects) in a collection, appropriate measures to block contaminants can be considered at a building level, room level and object level. If a source of contamination is present in the area surrounding the building or object, a physical barrier can be erected that blocks the path of the contaminant to the object. Options include placing filters in the air inlet for the building, an airtight or filtered showcase for the object, placing objects in cabinets or boxes to protect against dust or silver in plastic bags to protect against sulphur-containing gases.

As a rough guide, the concentration of external contaminants in the vicinity of objects decreases by a factor of 10 per functioning

Filter material	Impregnated with	Acetic acid	H_2S	NO_2	O_3	SO_2	NH_3
Active carbon	Nothing	Good	Poor	Poor	Good	Good	Poor
	Potassium carbonate (KCO_3) or Potassium hydroxide (KOH)	Good	Good	Good	Reasonable	Good	Poor
Active charcoal cloth	Nothing	Good	Poor	Poor	Good	Reasonable	Poor
Activated alumina	Potassium permanganate ($KMnO_4$)	Good	Very good	Reasonable	Good	Good	Poor
	Sodium bicarbonate ($NaHCO_3$)	Good	Reasonable	Good	Reasonable	Good	Poor
'Fixed-bed' composites	Nothing	Reasonable	Poor	Poor	Good	Good	Poor
	Potassium carbonate (KCO_3)	Good	Good	Good	Reasonable	Good	Poor
	Metal salt	Reasonable	Very good	Reasonable	Reasonable	Reasonable	Good
	Ion-exchange	Good	Reasonable	Reasonable	Reasonable	Reasonable	Very good

Table 38. Effectiveness of the most common filters for gas absorption

barrier. Thus, if the concentration of an air pollutant outside is 100%, it will be 10% inside a room (with no filtration) and 1% within a reasonably sealed display case.

Air pollutants can be absorbed with the help of dust filters for particles and specially-prepared chemical filters for specific gases (Table 38). The filters are usually incorporated into HVAC systems. As well as filtering the outside air drawn into the system, the air in the room can be filtered by installing filters in the recirculation system. Chemical filters absorb part of the air pollution, but lose their effectiveness over time and should, therefore, be replaced periodically.

For collections with many intrinsic sources (cellulose acetate, cellulose nitrate or strongly acidic paper), the filtering of ventilating and recirculating air merely offers a small risk reduction. Most of the contamination is already present in the collection. The costs of chemical air purification are high and the risk reduction small. A thorough analysis of the cost-effectiveness of these measures is therefore advisable (Porck, 2014; Di Pietro *et al.*, 2015).

Interaction between contaminant and object can also be blocked by placing a barrier over the object, such as a coating or lacquer. Wearing gloves when handling objects blocks grease and acids and prevents leaving fingerprints.

Dust mats by the entrance door prevent visitors from bringing in coarse dust on their shoes, while methods that maintain the distance between the visitors and objects also helps to limit dust deposition to a certain extent.

Detect

Detecting and monitoring pollutants can be carried out for different reasons. Firstly, to determine if the air is clean enough, or if measures need to be taken to avoid an expected effect. But they also help to determine the cause of damage that has been detected in objects, identifying potential sources and assessing whether the measures taken are effective. There are different ways to detect, monitor and measure.

Visual inspection

The objects form the basis for observation. The often-slow change in objects can be documented and followed with time to give a better idea of the changes that take place.

Indicators

Indicators are used to give an early warning, before damage affects an object. These early warning indicators are small pieces of materials that are more sensitive than most objects and which show a visible effect before it occurs to objects in the collection. They give an indication of the presence of pollutants, but they do not usually indicate the exact source. Examples include cleaned and polished copper or lead strips as an indicator of the presence of organic acids, silver coupons to detect sulphur-containing gases and glass slides to monitor dust. In about four weeks, the discolouration or other changes in these indicators reveal a certain degree of exposure to harmful substances at that location.

This principle is also used in the so-called Oddy-test. A small piece of potentially emissive material is placed in a sealed jar along with some moisture and coupons of three different metals. The jar is placed in an oven at high temperature (60°C). After four weeks, the degree of corrosion on the metals shows whether any harmful substances were released by the material under test.

Dosimetry
Dosimeters are advanced indicators that react to specific compounds, measuring changes that can be related to a particular dose.

An example is the commercially-available Onguard™ system. The thickness of the corrosion layer on a silver- or copper-coated silicate disc is measured continuously. The increase in corrosion over time can be related to the concentration of pollution in the air. The recently-developed MEMORI dosimeter measures both externally- and internally-generated air pollution and offers the possibility to interpret the outcomes in terms of risks (MEMORI, 2015).

Air concentration measurements
Measuring individual gases in the air is a specialised task that requires the collection and laboratory analysis of samples. All these methods are based on the principle that an air sample is taken from which the pollutant is captured and analysed. The simplest method is using so-called Dräger sampling tubes, in which air is pumped through a tube containing a reactive material that changes colour depending on the quantity of pollutant gas present. They generally work only at concentrations higher than those considered a risk for collections.
With more sophisticated, active sampling methods, a larger quantity of air is pumped through a filter and the pollutants trapped in this way are then taken to the laboratory for further analysis. This can only be carried out for spaces with large air volumes.
Areas with smaller volumes can sampled passively with so-called diffusion tubes. These tubes contain a compound that reacts specifically with the target pollutant (for example, an organic acid or hydrogen sulphide). After two to four weeks, the amount of pollutant can be determined by chemical analysis.

Deposition rate of dust
A decrease of gloss on a glass plate, due to the deposition of dust particles, can be determined at different times using gloss measurement. The loss of gloss gives the rate of deposition, which suggests how long it will take before an unacceptable amount of dust will be collected on objects (Wei *et al*., 2007 and 2016).

React
If the concentration of the contaminants is higher inside a particular space (a room or showcase) than outside there must be an internal source. The concentration can be lowered by increasing ventilation and thus diluting the amount of contaminant. Absorption measures, such as charcoal cloths (see Table 38) can also be used to reduce the concentration of certain gases. The process of passive absorption is a competition between object and absorbent, in which surface area is the critical factor: the larger surface absorbs most air pollution.

Treat
Objects that show rapid changes should be removed as quickly as possible and cleaned. However, before replacing the objects, the source of pollution must have been removed or appropriately blocked. It may be possible to place the object in a more suitable location, or to isolate it from its surroundings using a display case. If the source is present in the showcase, replacing the emissive material is preferred over covering or blocking the emissive surface.

Materials for storage and exhibition

Commercially-available materials used to furnish storage and exhibition spaces change regularly, without any information about their composition, which is why it is impossible to draw up a list of approved materials. There are, however, a number of general rules that can help to select materials or modify existing harmful situations (also see Tétreault, 1994).

- The harmful gases, such as VOCs and sulphur-containing gases, emitted by construction and finishing materials for rooms and showcases only form a risk for objects that are susceptible to those specific gases.
- The pollutant concentration in a space depends on the amount of gas emitted in a certain time, the volume of the space and the ventilation rate.
- When the source of harmful gases is in the same zone (room, cabinet, showcase) as the susceptible object, ventilation with clean air is an effective method to keep the concentration low.
- When the source of harmful gases is outside the zone in which the susceptible object is kept (room, cabinet, showcase), the zone needs to be sealed off as tightly as possible, or the air entering the zone should be filtered.
- Glass, metal, plaster and hard synthetic sheet materials do not emit harmful components.
- For wood and engineered wood boards the following applies: the smaller the wood fibres in the boards, the greater the emission of acetic acid. Solid wood emits the least, multiplex board more, chipboard more again and MDF the most. It is known that oak emits acetic acid upon ageing.
- MDF-ZF does not emit formaldehyde (from the glue), but emits acetic acid (from the wood fibres).
- Engineered wood boards with a synthetic finish or surface layer may not emit such high levels of VOCs from the surface, but pollutants can be emitted from the saw cuts and sides.

Level of control	Examples	Risk
None No barriers or measures between source and object	Object placed outside or in open structures such as sheds. Building equipped with active ventilation or an air handling unit without (chemical) filtering.	Exposure to full amount of pollutant present outside (see Table 35). If the air handling system has a high flow rate the exposure can be even higher than outside. The risk of soiling and/or corrosion is high.
Low One barrier or measure between source and object	Old buildings with high infiltration (no sealing of seams and cracks). Doors and windows are often open. Objects in leaky, wooden showcases.	The concentration of harmful gases inside is lower than outside by a factor of about 10. If the air pollution concentration is (very) high (city centre, industrial environment, the coast), the risk of soiling and/or corrosion will be significant. In a cleaner environment, the risk is moderate.
Moderate Two effective barriers or measures between source and object	Old buildings with normal infiltration (large seams and cracks sealed). Objects in showcases and attention is paid to materials used. Buildings equipped with active ventilation or an air handling unit with coarse and fine dust filters.	The concentration of harmful gases in the showcase is lower than in outside air by a factor of 100. If the air pollution concentration is (very) high (city centre, industrial environment, the coast), then the risk of soiling and/or corrosion will be significant in the room and low in the showcase.
High Three effective barriers or measures between source and object	Airtight building with (very) low infiltration. Sensitive objects are placed in airtight showcases or microclimate boxes. The building is equipped with an air handling unit with coarse and fine dust filters, and chemical filters.	The concentration of harmful gases inside is low and at object level about 1,000 times lower than outside. If the air pollution concentration is (very) high (city centre, industrial environment, the coast), then the risk of contamination and/or corrosion will be low in the room and very low in the showcase.

Table 39. Indication of the magnitude of risk for susceptible materials at different levels of control for contaminants from outside. See examples of vulnerable objects in Table 36.

- The emission of gases from wood and boards can be reduced by applying an impermeable film to the surface, such as a heat-sealed laminate of polyethylene-aluminium-polyethylene, by covering it with an absorber such as copy paper or *Artsorb*, or with a lacquer.
- Suitable lacquer and paint systems are: two-component epoxy- and polyurethane varnish (catalysed polymerisation, without alkyd polyols or acids) and water-based latex with a large amount of chalk filler (calcium carbonate). Allow airtight display cases to dry for at least four weeks; all other applications require a one week drying time.
- Paints, adhesives and sealants can emit harmful vapours when drying and upon ageing. High emissions characterise paints that dry by oxidative polymerisation (oil paint, alkyd paint, epoxy esters, oil-modified urethane paint) and sealants that harden with acid (for instance, silicone sealant with acetic acid).
- At low temperatures, emission and reaction of harmful gases with objects occur more slowly. However, as a fresh coat of paint also takes longer to dry, more time is needed before a room or showcase can be used.
- At low relative humidity the reaction rate of organic acids is significantly reduced. Below 30% reactions hardly take place.

Rules of thumb for determining the magnitude of risk for specific risk scenarios

To assess risks, ambitions for preservation should first be formulated. Is the silver allowed to show visible tarnishing in one, 10 or 50 years? Usually the lifetime of permanent displays is used: 10 to 20 years. Once this ambition or goal has been determined, the risks for different levels of control can be considered. It is not easy to make general estimates of contamination risks. It might seem best to control contaminants at building level control, making extensive use of filters, but this has little effect at object level if the display cases are made from emissive materials, e.g. silicone sealants, wool or MDF.

Primary air pollution

Pollutants generated outdoors will form the greatest risk to unprotected susceptible objects outdoors. Metal sculptures are generally protected from these pollutants by a surface coating such as a wax, lacquer or paint. For objects placed inside, the risk depends on the building physics. How much polluted air can enter the building by infiltration? In other words, how leaky is the building? Table 39 gives an overview of risks at different levels of control. A relatively closed building will have approximately 10%

Protection level	Examples	Risk
Low No barriers or measures between source and object	Long-term exhibition in (enclosed) display cases made of emissive materials. For example, those containing oak, MDF, oil paint, alkyd, epoxy esters, oil-modified urethane paint, acid-cured sealants, wool-containing textiles and untreated archaeological objects.	Prolonged exposure to all those compounds emitted from the materials. The risk of pollutants causing corrosion, discolouration and embrittlement is high.
Moderate One effective barrier or measure between source and object	For temporary exhibitions, rather leaky display cases are used, which may contain emissive materials. For long-term exhibitions, rather leaky showcases are used with less emissive materials (MDF-ZF) or materials with a surface coating.	Temporary exposure to high levels of pollutants or prolonged exposure to lower concentrations. The risk of pollutants causing corrosion, discolouration and embrittlement is moderate.
High No sources in the direct vicinity of the vulnerable object	For exhibitions, airtight inert showcases are used, made of glass and steel. New exhibition materials are tested and used only if they do not emit contaminants.	Hardly any exposure. The risk of pollutants causing corrosion, discolouration and embrittlement is very low.

Table 40. Indication of the magnitude of risk for susceptible materials at different levels of control for contaminants emitted from construction materials. For examples of vulnerable objects see Table 36.

of the outdoor pollutant concentration in the indoor air; yet if doors and windows are opened regularly the indoor concentration will be closer to that outdoors.

Secondary air pollution
The gases emitted by materials used in the construction of the building, the room or the display cases form the greatest risk for unprotected susceptible objects indoors. Sealed spaces, such as display cases containing emissive materials, can allow harmful gases to accumulate, forming a high-risk environment for susceptible objects. At room level, the (natural) ventilation is generally sufficient to keep the concentration of harmful components at an acceptable level. In Table 40, three levels of control are distinguished.

Relationship with other agents of deterioration

Measures that reduce one risk can have side effects on other risks. They can have a synergistic effect with a positive reducing effect on other risks, but they can also have a negative effect leading to a (temporary) increase of other risks. Installing an air handling system involves handling objects, tools and equipment, which can result in objects being knocked over. A pesticide treatment leads to contamination, leaving solvents and residues on the object.

Agents of deterioration may also act sequentially. During a fire, smoke and soot particles are formed, which will subsequently contaminate the objects.

Examples of the relationship between 'Contaminants' and other agents of deterioration are listed in Table 41.

Agent of deterioration	Interaction
Physical forces	Wear-and-tear of the coatings on emissive materials can allow pollutant concentrations to increase. Removing dust can cause scratches. Earthquakes or collapse of constructions cause dust and debris.
Fire	The release of soot can cause great surface changes. When soot deposited on a porous surface gets wet, it will penetrate into the pores. Powder extinguishers cause contamination that is very difficult to remove.
Water	Water from floods and leaks is never clean. Water transported through salt-containing walls will deposit salts on the surface and possibly on objects hanging on the wall.
Thieves and vandals	Reactive substances left on the surface of objects after an act of vandalism can cause serious damage. Dirty objects or graffiti attract further vandalism. A protective showcase may be airtight, producing a corrosive environment if emissive materials have been used in its construction.
Pests	Excrement from vermin can be visibly disturbing (e.g. fly specks) and may contain chemically-active contaminants that can react with susceptible surfaces. Pesticides remain as contaminating residues on or in the object.
Light, UV and IR radiation	Light and UV radiation accelerate photo-oxidation processes that involve pollutants.
Incorrect temperature	The rate of chemical reactions with pollutants is primarily determined by the temperature. A rule of thumb is that when the temperature increases by 5ºC, the reaction rate doubles. Temperature gradients and fluctuations cause air movement: the larger the gradients or fluctuations, the faster the air moves. Air transport is responsible for the deposition of particulates and dust, and for the transport of harmful external gases.
Incorrect relative humidity (RH)	The reaction rate of some chemical processes is affected by the relative humidity. A high relative humidity will increase the reaction rate. Dust in combination with a high relative humidity forms an attractive food source for moulds. At high relative humidity, cementing of dust may occur.
Dissociation	Contaminants can cause labels to become illegible. While cleaning or dusting objects, labels may become unfastened.

Table 41. Examples of the relationship between 'Contaminants' and other agents of deterioration

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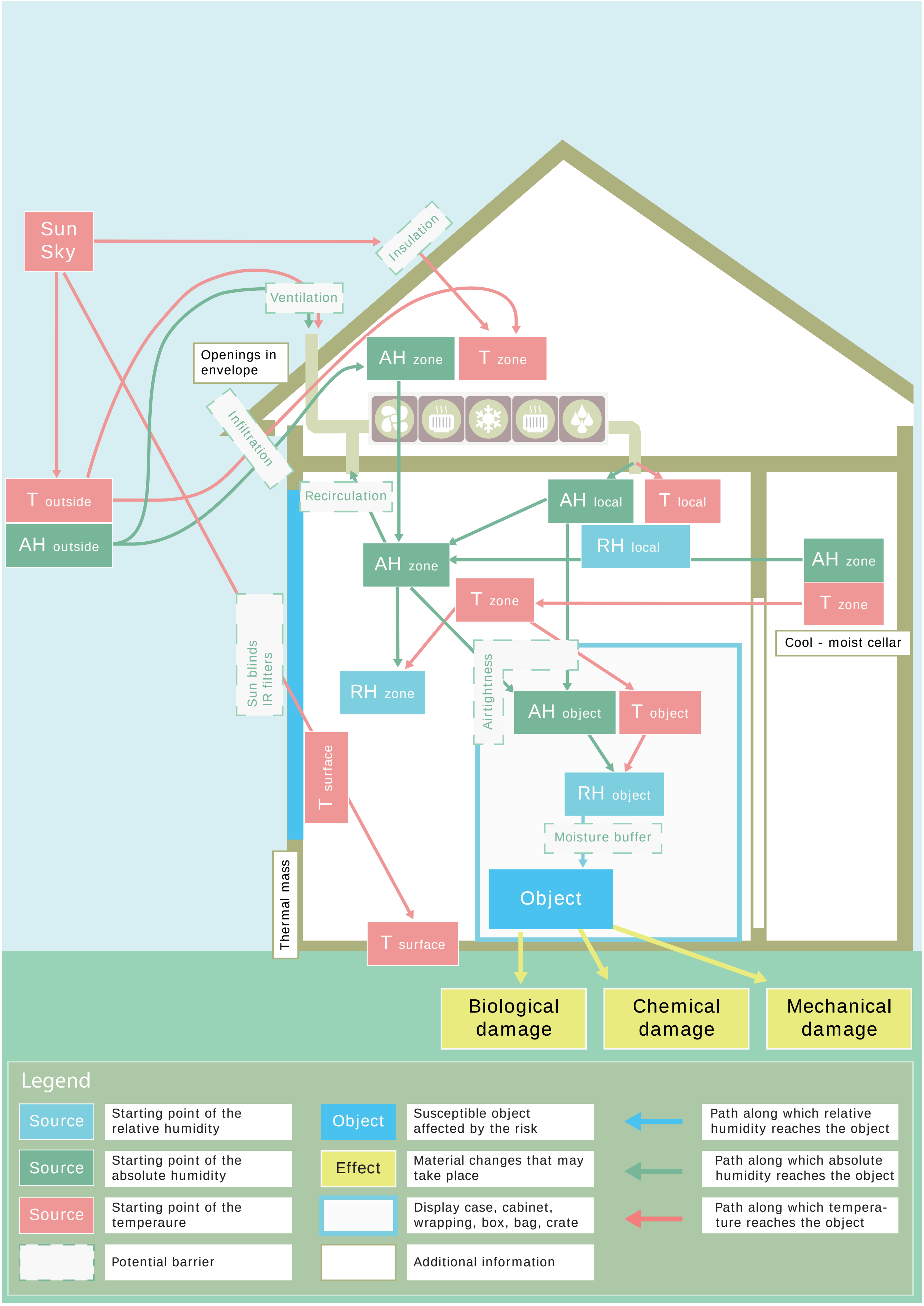
Margrit Reuss
Conservator, National Museum of World Cultures / National Museum of Ethnology, Leiden, the Netherlands

'Our museum manages a collection of prints collected by Jan Cock Blomhoff, Johannes van Overmeer Fisscher and Philipp Franz Von Siebold in 1818, 1822 and 1826, when they were stationed in the Dutch trading colony of Deshima in Japan, from which they travelled to Edo – now the modern city of Tokyo. It is a special collection as the prints are still in exceptionally good condition. Furthermore, these gentlemen collected large quantities of prints, usually buying several versions of the same design with different colour nuances directly over the counter. Since these Japanese prints, along with other objects from our collection, were to be shown to the public in the Siebold House Museum, we had to devise a method to deal with this unique resource. Therefore, we formed a risk assessment team comprising the curator and conservators of our museum, as well as representatives of the Siebold House Museum and the RCE. One of the most important outcomes of the process was the shared value assessment of the prints. It quickly became apparent that their high value results from their unique and almost pristine condition. Many still had their original colours and were barely, if at all, faded – as is the case with many Japanese prints. In addition, much is known about their collection history.

The risk assessment showed that light would pose the greatest threat. The colours, especially the purple and blue, can fade so rapidly when exposed to light that it was decided to impose a zero-tolerance policy for the prints in the best condition. They remain locked away and have a limited access for study only. For the prints in 'less perfect condition' – but still almost of the same quality as the pristine material – an exhibition strategy was developed that stipulates that they must be rotated regularly during exhibitions and that the exposure to light must be limited as much as possible.'



Scenario scheme for the agent of deterioration 'Incorrect indoor climate'

Incorrect indoor climate

Scenarios for incorrect indoor climate

This scheme sketches the most common scenarios for incorrect temperature (T) and incorrect relative humidity (RH). It shows a cross-section of a building and the layers around the object. The orange-brown lines represent the roof, ceiling and floor, and the thick grey lines the walls; together they form the 'building envelope'. They provide a physical separation between the outdoor and indoor climate. A practical approach to gain a better understanding of how the climate in the building, room, and near the object is created, is to look from the outside in.

Because an incorrect RH (the blue boxes and arrows) causes several important risks to the collection and sometimes to the building itself, the derivation of RH is visualised by considering the absolute air humidity (AH) in green and the temperature (T) in red.

The blue, green and red boxes indicate the sources for RH, AH and T respectively. The arrows show how moisture and heat flow from the source to the object, and how they influence each other.

The text in the white boxes gives additional information about the sources and the barriers. The pale blue box represents the object. The orange boxes describe the three main processes in which T and RH affect the object. Each line drawn from a source, via one or more barrier, towards the object and an effect, represents a specific scenario for 'Incorrect relative humidity' or 'Incorrect temperature'.

Introduction

In contrast to other agents of deterioration, an indoor climate cannot be avoided. Fire, thieves, vandals and pollutants can be avoided to some extent, but a space will always have a certain relative humidity and temperature. Accordingly, the risks related to climate will always be due to an incorrect relative humidity (RH) and/or an incorrect temperature (T). In this chapter these two agents of deterioration are discussed in combination under the title 'Incorrect indoor climate'.

Based on the type of degradation process that they cause, different incorrect indoor climates can be distinguished.

1. The relative humidity is higher than 75% (very humid).
2. The relative humidity/temperature is too low or too high.
3. The relative humidity/temperature fluctuates too greatly.

Ultimately, the material characteristics of an object or collection define the extent to which an incorrect indoor climate leads to damage. There are three degradation processes that can take place:

Biological – At high relative humidity fungi can germinate and grow on the surface of materials. The relative humidity at the surface is in equilibrium with the relative humidity and temperature of the air close to the surface. The rate at which fungal spores germinate and colonies grow depends on the temperature and the nutritional quality of the substrate.

Chemical – Degradation processes such as hydrolysis, oxidation and corrosion are accelerated by higher relative humidity or temperature. Temperature has a particularly large influence on the rate of chemical reactions. In principle, the lower the temperature, the slower the reaction rate and the longer the expected useful life of chemically unstable materials and objects in the museum context. A lower relative humidity is generally favourable for many objects, although it should not be too low (see below).

Physical – Hygroscopic materials, such as wood, paper and textiles, will absorb or desorb moisture upon changes in relative humidity and temperature. As a result, these materials will shrink or expand, generating strain that can result in stress in the object depending on its construction. If these stresses are too great, objects, or parts of them, can deform or crack. A secondary effect of a high temperature is localised low relative humidity that may cause drying of hygroscopic materials. In addition, phase changes such as melting or evaporation may occur, which can lead to deformation.

It is important to realise that it is difficult to create an indoor climate in which all the objects in a mixed collection can be stored or displayed without risk and which also provides comfort for visitors. The optimum will be a balance between acceptable risk, comfort and resources.

Sources and pathways

Air can enter a building through openings in the building envelope in two ways: controlled (ventilation) or uncontrolled (in- or exfiltration). Outside air entering the building has a certain temperature and contains a specific amount of moisture, the specific or absolute humidity (AH). The specific humidity indoors might differ because of sources of additional humidity or so-called moisture 'sinks', which extract humidity. Ultimately, the total capacity of the humidity sources and sinks determines whether

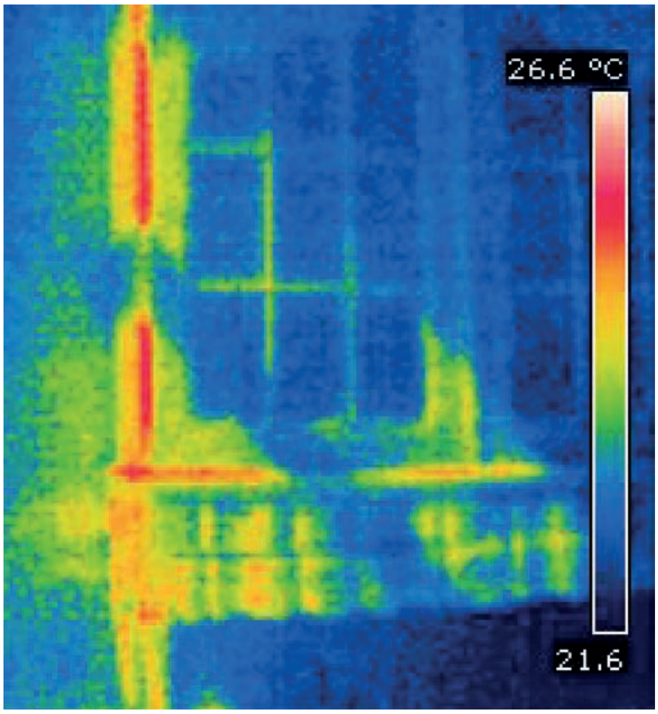


Figure 107. Incoming sunlight can influence local temperature and consequently local relative humidity. The infrared image at the right shows the local temperatures for the cabinet illustrated to the left. The different colours indicate different temperatures, red at the sunlit side being the warmest

the specific humidity inside will be higher or lower than outside. Indoors, the specific humidity is mixed efficiently by differences in pressure so that the humidity gradients in rooms, and even across the building, are minimal. Thus, the relative humidity at a surface ($RH_{surface}$ in the scenario scheme) is the product of the absolute humidity in the zone (AH_{zone}) and the surface temperature ($T_{surface}$).

The absolute humidity inside may differ from that outside because of a delay in reaching an equilibrium. This might be caused by the low volume of incoming air and the buffering capacity of the building structure, interior furnishings and collection.

The average air temperature (T_{zone}) is influenced by the local temperatures in a room, including radiation from hot or cold surfaces ($T_{surface}$) and the movement of air from adjacent rooms (T_{zone2}). At a local level, there can be great differences in temperature due to the presence of heat sources such as radiators, sunlit surfaces, or cold spots at the walls, windows, floors and roof. As a result there may also be local differences in relative humidity. The (local) relative humidity is, apart from small variations due to specific humidity, primarily defined by the (locally deviating) temperature.

Psychometric chart

A psychometric chart (Figure 108) shows the relationship between temperature (x-axis), specific humidity (y-axis), and relative humidity (the curved lines). The blue dots indicate the outside climate throughout the year in the Netherlands. When outside air enters a building the temperature, and sometimes the specific humidity, of the air will change, with consequent changes to the relative humidity. There are three different scenarios illustrated.

- When the temperature changes while the specific humidity remains constant (line A ↔ B), the relative humidity will change. As temperature increases the relative humidity drops; upon cooling the relative humidity rises.
- When the temperature remains the same and the air is humidified or dehumidified (line C ↔ D), the relative humidity will change. Humidification increases the relative humidity while dehumidification decreases the relative humidity.
- When cold outside air with a high relative humidity enters a building, and is heated without humidification, the relative humidity inside will be lower than outside (line E ↔ F).

Moisture sources humidify the air, and the extent to which this

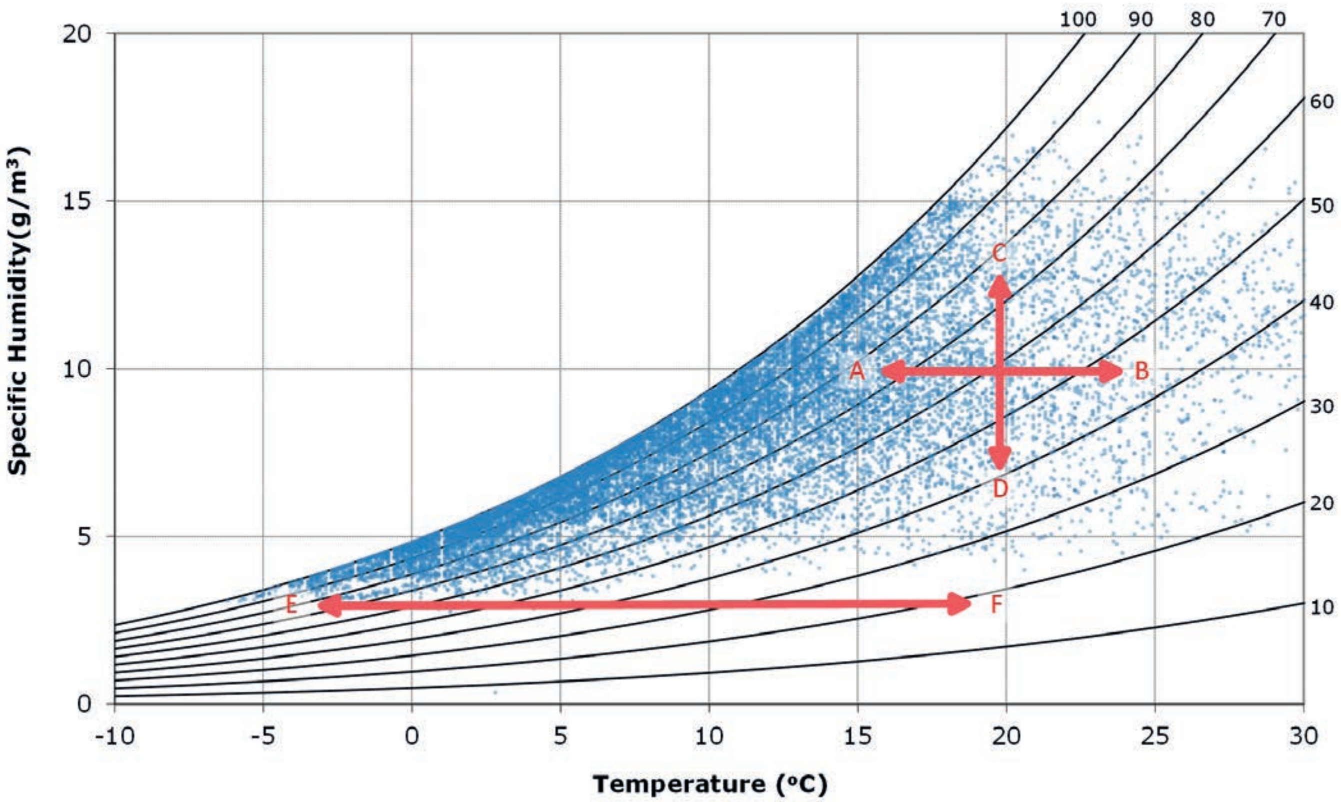


Figure 108. Psychometric chart showing the relation between specific humidity, temperature and relative humidity

occurs depends on the capacity of the source. Known moisture sources are rising damp, leaking gutters and rainwater drains, visitors and humidifiers. Each visitor will generate 50 to 100 ml water per hour (roughly a small glass) and a mobile humidifier 0.5 to 1 litre per hour (roughly a bottle). The building, or a part of it, may also be a source of moisture, for instance damp basements (AV_{zone2}).

Moisture can be removed from the air by moisture sinks. Examples of sinks are (mobile) dehumidifiers (with a capacity of 0.1 to 0.3 litre per hour) and condensation processes, for example those that occur at (single) panes of glass in the winter. Condensation can also occur in the building envelope at locations that are not directly visible, such as cold spots behind wall hangings or wood panelling. The building mass, the furniture and the collection also form important moisture sources or sinks. Every hygroscopic material in a zone affects the relative humidity and the equilibrium moisture content of each hygroscopic material varies with changing relative humidity. The collections in libraries and archives are, for instance, large buffering masses.

Exposure

As can be seen in the scenario scheme, the indoor climate depends on the degree to which the building envelope buffers the (fluctuating) outdoor climate. Also, any equipment used to heat, cool, humidify or dehumidify will determine the properties of the inside air.

Not every building is the same: the quality of the building envelope (or the building physics) and the quality of climate control will determine whether a particular indoor climate can be generated and sustainably maintained. The matrix below (Figure 109) gives examples of buildings with poor to high quality building envelopes equipped with a range of heating/cooling and (de)humidification equipment, and describes the indoor climate for each.

Examples with ‘poor-quality building physics’ refer to (historical) buildings that are not insulated, have single glazed windows and contain many seams and cracks in the building envelope. Examples include barns, ships and historic buildings that have not been customised as museums. A building to which

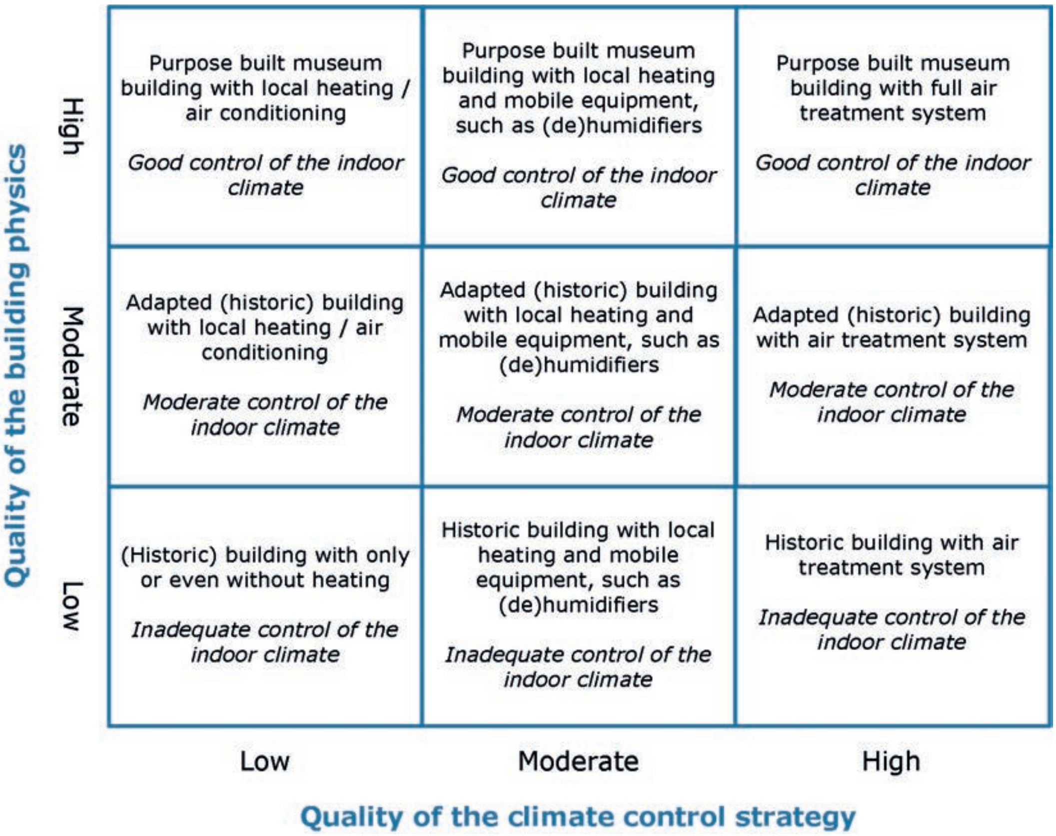


Figure 109. Examples of buildings with different qualities of building physics and climate control strategy, and the consequent level of control over the indoor climate

adjustments have been made in the past decades (through insulation, double-glazing and possibly draught proofing) will have better physical properties. Examples are castles, canal houses, manor houses and old schools to which improvements for comfort have been made.

In a purpose-built or fully adapted museum building, every part has been fully customised to provide a stable indoor climate. It will be difficult for air to enter, the walls will be appropriately insulated, the envelope draught free, and insulating glass of high quality will have been installed. Examples are newly-built storage facilities and recently-built museums.

The term 'low climate control quality' refers to a building that does not have any heating or has only central heating; there is no cooling or forced ventilation. In a situation with moderate control over the indoor climate, humidifiers and dehumidifiers are used alongside central heating. High quality climate control implies that the air quality is controlled and conditioned to the appropriate temperature and relative humidity by HVAC (Heating Ventilation and Air Conditioning) equipment.

It is evident that it is impossible to control the climate inside buildings with a poor-quality building envelope, even with an advanced air treatment system. On the other hand, a building with high-quality building physics, barely requires climate control to create a stable climate inside. This is the starting point for sustainability.

Effects

The publication *Managing Indoor Climate Risks* (Ankersmit and Stappers, 2016) gives an extensive overview of the risks to materials and objects due to an incorrect indoor climate. They are summarised in Table 42.

Table 43 presents some examples of common damage observed in collections as a result of incorrect (local) indoor climate. Materials, constructions and finishes all have different vulnerabilities to

	Too high	Too low	Too much fluctuation
Relative humidity	*Biological* Fungal growth *Chemical* Hydrolysis: acidification Oxidation: yellowing Corrosion: rust formation *Physical* Uptake of water, swelling, expansion Deformation	*Physical* Dehydration, embrittlement Shrinking, cracking, tearing Delamination Salt efflorescence	*Physical* Deformation Cracking, tearing, fracture Delamination
Temperature	*Chemical* Accelerated oxidation, corrosion and hydrolysis reactions *Physical* Softening, melting, evaporation Deformation Loss of water of crystallisation	*Physical* Dropping below glass transition temperature, becoming glassy and brittle Condensation Crystallisation of fatty acids	*Physical* Expansion and shrinkage of metal Swelling and shrinkage of objects with air pockets

Table 42. Effects caused by incorrect relative humidity and incorrect temperature

their environment. For materials whose crystal structure contains water molecules (such as minerals) or organic materials (such as parchment), the relative humidity should not drop below a critical minimum level (to prevent irreversible dehydration), nor should it exceed a critical maximum (to prevent gel formation, deliquescence and expansion).

Options for risk reduction

In the scenario scheme, different measures to control the indoor climate are indicated. When considering measures to improve an incorrect indoor climate, the five stages of the integrated approach can be used. In *Managing Indoor Climate Risks* (Ankersmit and Stappers, 2016) different mitigating strategies are described in detail. Here only a brief summary is provided.

Avoid

Do not store or display susceptible objects in warm attics, direct sunlight, cold and damp basements, or near cold or warm surfaces. Place light sources outside display cases, or prevent the heat from reaching the object. Sensitive constructions of hygroscopic materials may be at risk from large relative humidity fluctuations. This can be the case when the space that contains the collection is heated during special events to provide a comfortable environment for visitors. In this case, it is recommended to (temporarily) move any highly susceptible objects to a stable climate. Maintain lower indoor temperatures during winter to prevent the relative humidity from becoming too low.

Block

Good insulation can block moisture and heat, preventing the formation of hot and cold surfaces. However, it should be noted that in cold climates the risk of thermal bridges within walls increases when insulation is installed. Damp-proof finishes on walls and floors can block moisture sources. Airtight (inert) showcases, microclimate boxes, bags and cabinets can be used to protect vulnerable objects that are kept in areas with unsuitable climatic conditions. Outside air can be partially blocked and controlled by an air handling unit that can heat, cool, humidify or dehumidify the incoming air to meet indoor requirements (see Figure 2).

Detect

Monitor the indoor climate over a prolonged period using data loggers that measure temperature and relative humidity, and analyse and interpret the data. See also appendix 4 in the publication *Managing Indoor Climate Risks* (Ankersmit and Stappers, 2016).

Respond

Buffering materials can be used to maintain a specific relative humidity level in the vicinity of objects kept in (airtight) showcases. If an incorrect relative humidity has been detected near an object, the object should be moved to a more favourable climate or the climate should be adjusted, at object level

	*Figure 110.* Because the relative humidity was too low these book bindings dried out, which caused the backs to break upon opening.
	*Figure 111.* As a result of acid catalysed hydrolysis of cellulose, this newspaper has become brittle. When the pages are handled and turned, small tears may form, which could cause material loss. The higher the temperature and relative humidity, the more rapid the degradation process.
	*Figure 112.* Fluctuations in relative humidity cause wood to expand and contract continuously, causing stress between the paint layer and the wooden support. If the stress is too high, the paint will crack and paint loss may occur in time. In addition, the joins in the wood may open.
	*Figure 113.* Thermoplastics, such as this LP (a mixture of polyvinyl chloride and polyvinyl acetate) will soften if the temperature is too high and deform if placed under pressure.
	*Figure 114.* These books have developed mould after being exposed to an excessively high local (surface) relative humidity. The book blocks have been damaged and discoloured.
	*Figure 115.* Even under 'normal' conditions, chemically unstable cellulose acetate will last only a few decades. Such objects can only be preserved by keeping them at low temperatures.

Table 43. Examples of damage due to an incorrect indoor climate

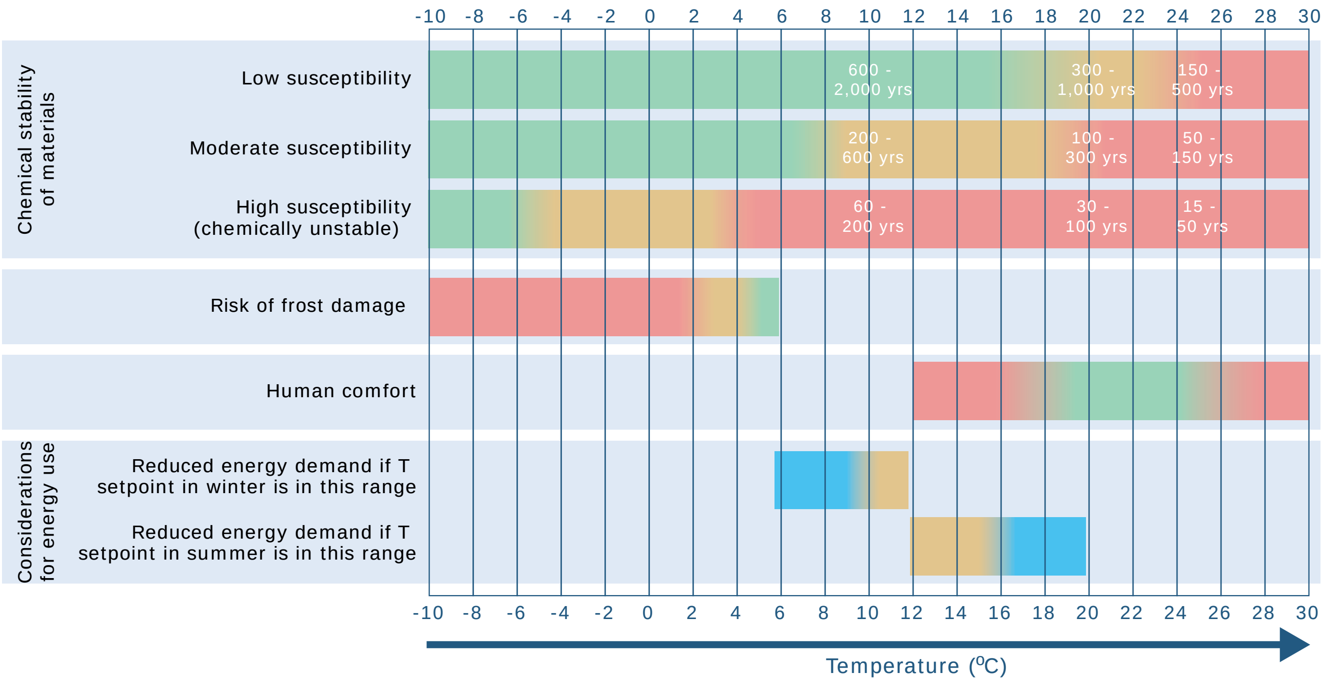


Figure 116. Safe (green) and dangerous (red) temperatures for materials with different susceptibilities to chemical degradation. The estimated lifetimes for the different chemical stability classes are indicated in years. Light blue shows the human comfort temperature zone. The bottom two bars show the energy considerations for summer and winter (based on PAS 198:2012).

(showcase, box, bag), at zone level (mobile devices), or at building level (climate control system). After a flood or other water-related disaster, mobile dryers, dehumidifiers and fans can be used to reduce the relative humidity as quickly as possible.

Treat

Objects that respond rapidly to changes in climate should be removed from an incorrect indoor climate. If damage has occurred, the objects will need to undergo treatment. The treatment should be tailored to the climatic conditions to which the object will return. A treated object is generally more susceptible to relative humidity fluctuations than an untreated object (see ‘Proofed relative humidity fluctuation’ below).

Rules of thumb for determining the magnitude of risk for specific risk scenarios

Risks due to incorrect temperature

The higher the temperature, the faster the rate of chemical degradation (hydrolysis, oxidation, and corrosion) and the shorter the expected usability (lifetime) of chemically unstable objects. For a number of (chemically unstable) materials, such as cellulose acetate and cellulose nitrate negatives, (acidic) paper, textiles and photographs, even normal room temperature can be too high if we want to preserve them longer than a few decades. If the relative humidity is also higher, chemical degradation reactions involving water are accelerated at higher temperatures. Examples for inorganic materials are corrosion reactions for metals, such as rusting of iron, or the effects of air pollution on minerals, including damage to limestone or shells by acetic acid. Examples for organic materials are, the (acidic) hydrolysis of paper and the effects of SO_2 on leather (red rot). The Dew Point Calculator provided by the Image Permanence Institute (IPI, 2016) gives a good impression of the influence of relative humidity and temperature on degradation processes and the expected life expectancy of organic materials. Figure 116 gives ranges of safe and dangerous temperature for different materials.

Risks due to incorrect relative humidity

At relative humidities above 65%, the risk of biological degradation (mould growth) and corrosion of metals is significant (Figure 117). Such a high relative humidity can be expected near cold surfaces in the building envelope, such as basement floors, exterior walls and windows. This is an example of a situation in which a primary effect, an incorrect temperature (too low), causes a secondary effect, an incorrect relative humidity, which

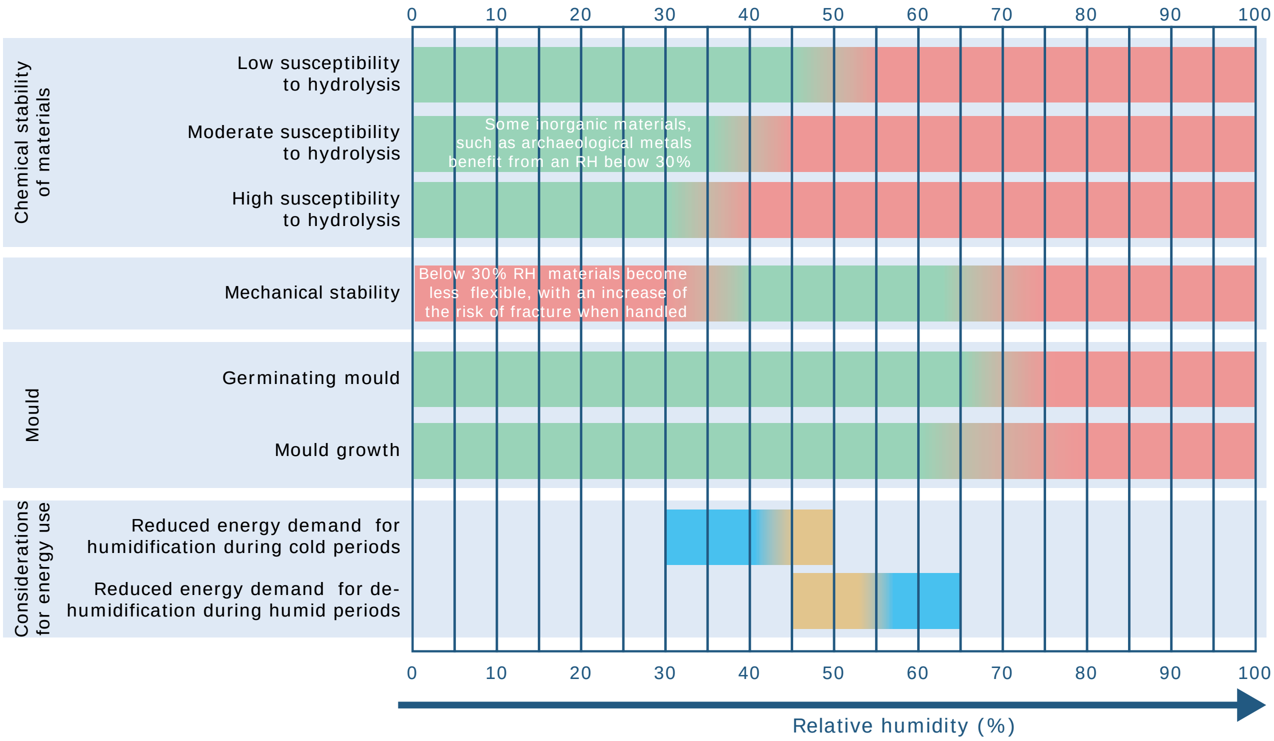


Figure 117. Safe (green) and dangerous (red) relative humidity ranges for materials with different chemical and mechanical susceptibilities, and the ranges for mould germination and growth. The energy considerations for summer and winter are given in the bottom two bars (based on PAS 198:2012).

Material	Reaction upon fluctuating relative humidity
Traditional paintings Oil paint, egg tempera, or mixed binding media on wood, canvas, linen or other support.	Expansion and contraction of structural components can create stress in the paint layers. This can cause delamination and cracking of layers. Fluctuations around lower (40%) or higher (60%) relative humidity will give a higher risk than the same fluctuation around 50%.
Modern paintings (20^{th} and 21^{st} century) oil paint, mixed media, synthetic resins (acrylic acetate or polyvinyl acetate) on different supports.	Expansion and contraction of rigid components, such as wood and boards, can create stress on the paint layers. This can cause delamination and cracking of layers. Fluctuations around lower (40%) or higher (60%) relative humidity will give a higher risk than the same fluctuation around 50%.
Ceramics	Some ceramic objects contain salts. With a fluctuating relative humidity, efflorescence can occur on the surface or in the core, which can cause mechanical damage.
Ivory	Ivory expands and contracts as it absorbs and desorbs moisture. It does so differently longitudinally and radially (i.e. it is anisotropic), which leads to uneven stress and can cause cracking. Thin layers can deform or split.
Leather	Due to absorption and release of moisture, stress can build up in stretched leather (drums, book bindings), causing deformation, cracks and eventually tears.
Parchment	Due to the absorption and desorption of moisture, stress can build up between a parchment support and a text or decoration. Upon deformation of the parchment, loss of information can occur.
Photographs	Images on paper, film, gelatine and albumen prints can undergo unequal expansion and contraction due to relative humidity fluctuations. This can cause the photograph to deform and/or hairline cracks to appear.
Wooden objects	Wood expands and contracts as it absorbs and desorbs moisture. It does so differently longitudinally and radially (anisotropic) which leads to uneven stress resulting in deformation, cracks and breakage.

Table 44. Risk of mechanical damage to (highly) susceptible objects due to relative humidity fluctuations

Quality of building physics ↓ / Quality of climate control strategy →	Low	Moderate	High
High	Without central heating: cooling in winter. With central heating: local high T and local low RH. Seasonal and small diurnal RH fluctuations	With central heating: local high T and local low RH. Local high or low RH from mobile conditioning equipment. Seasonal and small short-term RH fluctuations	Stable T. Small seasonal and short-term RH fluctuations
Moderate	Without central heating: low T in winter. With central heating: local high T and local low RH. Significant seasonal and diurnal RH fluctuations	With central heating: local high T and local low RH. Local high or low RH from mobile conditioning equipment. Seasonal and large diurnal RH fluctuations	Stable T. Seasonal and short-term RH fluctuations. Risk of condensation in the building envelope
Low	Without central heating: low T in winter. With central heating: local high T and local low RH. Large seasonal and diurnal RH fluctuations	With central heating: local high T and local low RH. Local high or low RH from mobile conditioning equipment. Large seasonal and diurnal RH fluctuations	Stable T. Large seasonal and short-term RH fluctuations. High risk of condensation in the building envelope

Figure 118. The magnitude of risks for mechanical damage due to fluctuating climate for different levels of building physics and climate control strategy. Green indicates (very) small risks, such as deformation or cracking; orange indicates significant climatic risks; and red indicates large risks.

eventually leads to damage. An example of this in cold climates is the accelerated rotting of window frames and the ends of beams. Objects on or near an uninsulated exterior wall will have a colder verso and the pocket of cold air here will have a higher relative humidity than the air in the main zone.

Risk of mechanical damage

Fluctuations in temperature can lead to immediate expansion and contraction of materials, such as metals. As the temperature varies, the air pressure also changes, which will affect objects with air pockets.

Large temperature fluctuations can lead to large relative humidity fluctuations and consequently cause damage indirectly. For example halogen lighting inside a display case that is switched on and off daily, causing the temperature to rise during the day and cool at night, will trigger relative humidity fluctuations inside the display case. Hygroscopic objects will absorb and release moisture and swell and shrink accordingly. Fluctuations that take longer than the hygroscopic response time (the time an object needs to reach equilibrium with a new relative humidity) of the most sensitive objects must be avoided.

The risks due to relative humidity fluctuations are directly related to the quality of the building envelope and the preventive measures taken (level of control). Both can vary from low

Agent of deterioration	Interaction
Physical forces	Hygroscopic materials become brittle at low relative humidity, making them become more susceptible to breaking. Below their glass transition temperatures, polymers (binding media, plastics) become glassy and less flexible, increasing the risk of fracture significantly.
Thieves and vandals	Opening doors and windows for ventilation on hot summer days increases the risk of theft.
Fire	An HVAC system (or other climate control system that uses electricity) increases the risk of short-circuits and fire. In a long, dry and warm period, the risk of (forest) fire increases.
Water	Using (mobile) humidifiers increases the risk of leaks. Condensation can form on cold surfaces.
Pests and plants	Insects thrive at certain relative humidities and temperatures. High and low temperatures can be used to kill insects.
Contaminants	At high temperatures, transport processes are accelerated. The release of gaseous pollutants from materials increases at high temperatures. Temperature differences create air movement, which causes the displacement of particles. At high relative humidity, reactions with pollutants such as ozone, sulphur dioxide and organic acids are accelerated.
Light, UV and IR radiation	Infrared radiation is absorbed by surfaces, causing their temperature to rise; this can result in a decrease in the relative humidity and desiccation.
Dissociation	High relative humidities and/or low temperatures can cause glued labels that bear information to become detached and lost.

Table 45. Examples of relationships between 'Incorrect indoor climate' and the other agents of deterioration

to high, see Figure 118. As the quality of the building physics and of the climate control strategy increases, the risk of large relative humidity fluctuations decreases. As a result, the risk of mechanical damage will be less where there is improved climate control and a better building envelope. It should be noted that the risk of failure of the control measures, e.g. failure of the air conditioning during extreme weather conditions, is not considered. For a number of materials and objects, the risk of mechanical damage is described in Table 44.

Proofed fluctuations

In conservation practice, the current state of a collection is used in many cases as an indicator of the risks to the collection. Cracks, fractures and paint losses are considered direct evidence of a poor indoor climate, and decisions to improve the environmental conditions are often made based on these observations. The fact that the current state of an object is a result of all the environmental conditions it has been exposed to since the moment of its production, or since it was last treated, is often not taken into account. A relatively simple estimate of the risk of mechanical damage to a collection can be made, based on the so-called 'proofed relative humidity fluctuation'. Future relative humidity fluctuations do not pose a significant risk for the fracture or detachment of layers (delamination) if these fluctuations are expected to be smaller than – and centred on approximately the same value as – the relative humidity fluctuations to which the object has already been exposed.

Relationship with other agents of deterioration

Measures that reduce one risk can have side effects on other risks. They can have a synergistic effect with a positive reducing effect on other risks, but they can also have a negative effect leading to a (temporary) increase of other risks. Temperature and relative humidity go hand in hand. In an open space, reducing the temperature leads to an increase in the relative humidity. In a small, enclosed space containing organic material (an object in a bag or box), the relative humidity increases as soon as the temperature rises. Protecting a painting from an incorrect indoor climate by using a microclimate box will also reduce the impact of a fire risk.

Agents of deterioration may also act sequentially. While extinguishing a fire or after a water-related incident, objects may be exposed to high relative humidity. Examples of relationships between 'Incorrect indoor climate' and other agents of deterioration are listed in Table 45.

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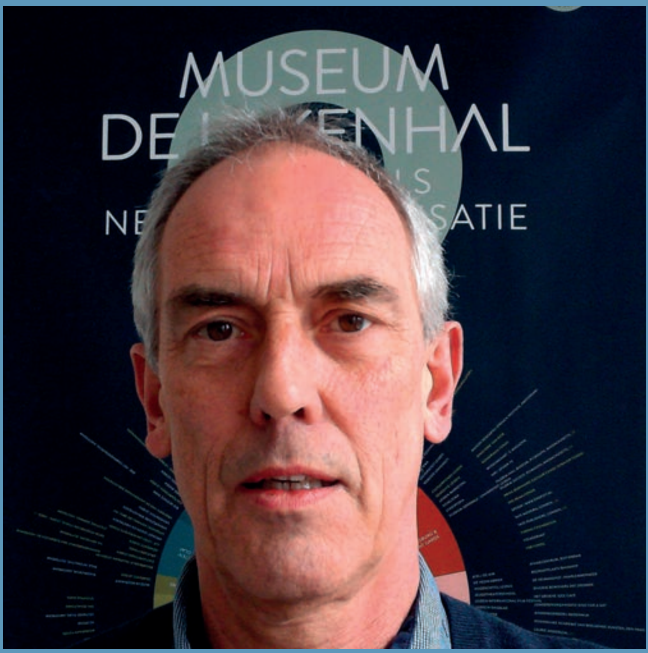
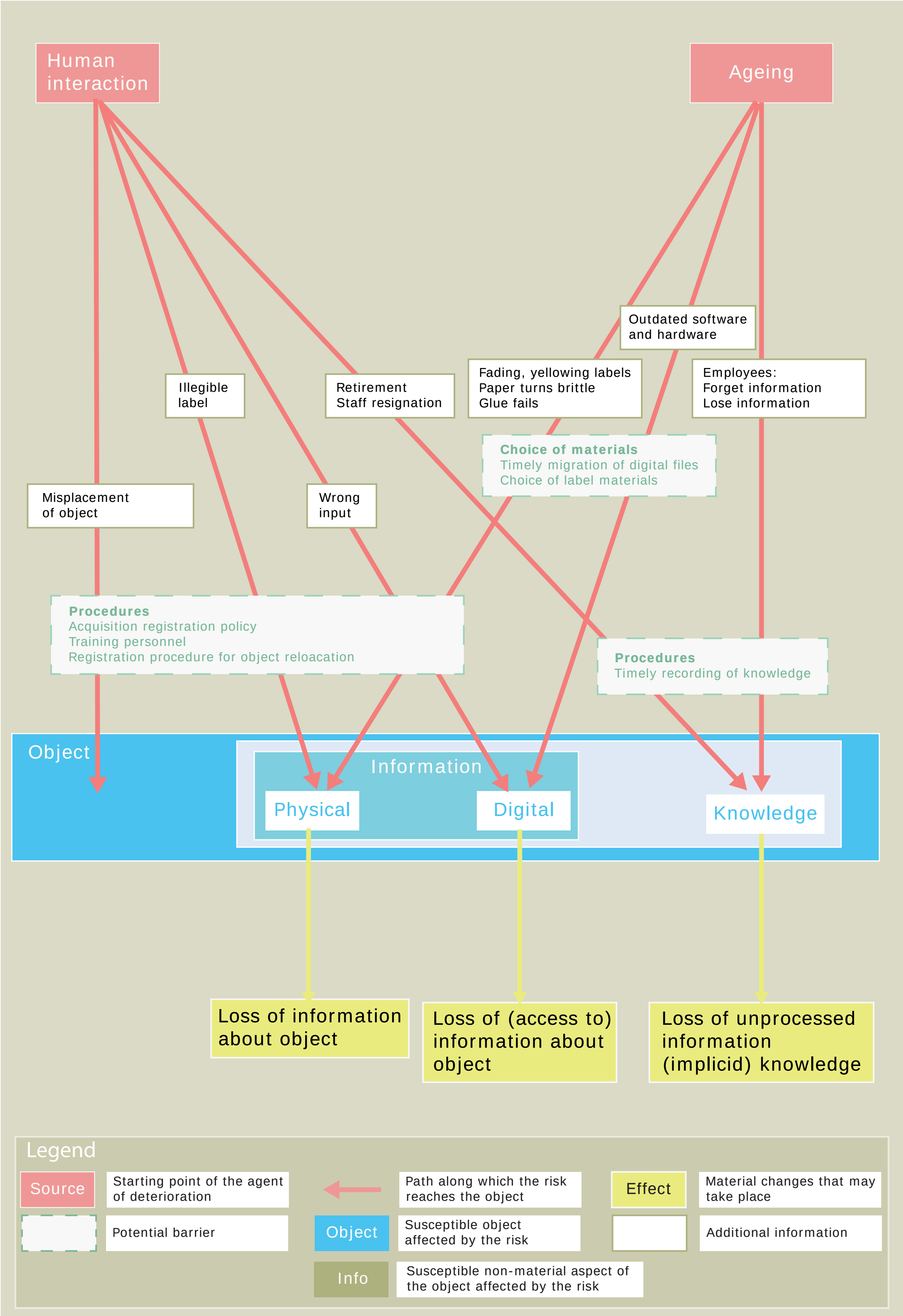
Covers, such as these sheets, offer effective protection against dust



Rob Wolthoorn
Head of Collections, Museum De Lakenhal,
Leiden, the Netherlands

Museum De Lakenhal used a risk assessment to investigate which objects in our collection should be insured. We used QuiskScan to identify the most vulnerable objects in our A-collection. By only insuring those we hoped that we might save the cost of the insurance premium for the less vulnerable objects in our collection. Our idea was to have smarter insurance and to use the money we saved to pay for measures to protect the less vulnerable objects in different ways – with a new climate control system, additional guards, and so on. A well-conceived plan perhaps, but it was not so clear-cut in reality.

When we assessed the value of our paintings, drawings, handicrafts and objects related to the history of Leyden, it became clear that our most precious possessions – the 16th century panel paintings, including the altarpiece with the Last Judgement by Lucas van Leyden – were also our most vulnerable possessions. Seeking the most comprehensive insurance for these objects alone would account for our entire insurance budget, and leave nothing for the preventive measures for the other collections. The risk assessment did not provide the final answer, but it was an eye-opener for us in our discussions about collection management. For instance, it showed that the most important paintings in our stores should be kept in a location from which they can be evacuated easily in case of fire or flood. It is also refreshing to be able to talk about loss when deciding what constitutes the core collection. A curator may be inclined to think that the objects in their own department are the most important, or everyone finds every object equally valuable. It is good that the risk assessment forces you to make choices together.



Scenario scheme for the agent of deterioration 'Dissociation'

Dissociation

Scenarios for dissociation

This scenario scheme sketches the most common scenarios for dissociation. It is an abstract representation of the ways in which an object can be separated from the knowledge or information about it. As a result of that detachment, the object loses meaning and value.
The red boxes at the top of the scheme show the two main sources for dissociation: human conduct and ageing of the supports for, or carriers of, knowledge and information. The white boxes with blue borders and black text give examples of processes.

The blue and white boxes beneath represent the complex interrelationship of the physical object (light blue) with knowledge (mid-blue) and information and documentation (dark blue) about that object: the so-called 'object complex'. Information and documentation for an object can be physical (analogue) or digital. The boxes with green text are the possible barriers that can reduce the effect of the processes on the object complex.

The orange boxes are the effects that processes can have on the object complex. These encompass loss of value due to loss of the physical object, knowledge, information, documentation, meaning or understanding about the object.

The blue arrows represent the processes that can lead to a loss of value. The arrows run from the source to the object complex with its material and non-material aspects. Each line drawn from a source, via one or more barriers, to the object to which it causes an effect, represents the scenario for one specific risk.

Introduction

Dissociation occurs when the link between an object or collection and the associated knowledge, information or documentation is broken. The association between the physical object and its non-material attributes is lost, or the object and its context are separated. This can happen, for example, because an object is put in the wrong place and is thus separated from its registered location. It is still located within the institution but cannot be found (temporarily) and is consequently of no use. An object can lose significance when it is placed out of context, when knowledge or information about the object have disappeared (or are no longer accessible), or when certain intangible aspects such as odour, sound or 'atmosphere' change or are lost.

Of the ten agents of deterioration, dissociation is the only one that describes the loss of value due to non-material changes. It is an agent that is closely related to registration and documentation activities within an institution, often sharing their procedures and data management processes. Various scenarios can lead to a loss of access to an object, collection and/or collection information.

An undocumented relocation of objects that renders them untraceable (Figure 119).
- Labels or tags that detach from objects or become illegible, so that the objects cannot be linked to the registration data.
- Inaccessible digital information because software or hardware have become obsolete.
- Unrecorded knowledge that resides with an employee, which is

Figure 119. A non-registered or undocumented object in a museum collection (left) and mediocre collection care (right) eventually lead to an increased risk of neglect, physical decay and loss of value.

lost when there is no access to the person because of retirement, resignation or death.

When so much information is lost that the object loses its meaning and nobody recognises what it is, there is a chance that the object is no longer worth keeping. 'The unknown is unloved' as the Dutch say, and during a period of neglect, the chances of de-accessioning increase.

From source to effect

The scenario scheme is based on two main causes or sources for dissociation.

- Human conduct (everything related to moving, registration and documentation).
- Ageing of the supports for, or carriers of, knowledge and information (employees, labels, documentation and computer systems).

Those two sources can act upon various aspects of the object complex: the physical object, implicit knowledge about it (in the minds and experiences of people) and explicit information about it (whether recorded in documentary form or in information systems).

The information and documentation can be analogue records (e.g. inventories, labels, tags, object numbering, registration cards, acquisition data, notebooks, catalogues, field journals, research data, photographs, microfilms, video and audio tapes, or samples) or digital (including all types of information systems, computer files or digital versions of analogue data). The effect of the two sources acting on the object complex can eventually result in the loss of the object's meaning, which consequently leads to loss of value, neglect and even de-accessioning.

The first stage at which a loss of information can occur is upon acquisition, when the registration data for the object entered into the collection system are incorrect, incomplete or absent. For instance, the object details may have been registered in an unreadable, ambiguous or impermanent way. This can be because fading ink or crumbling brittle paper render labels, tags or notes illegible, or result from the total loss of labels once an adhesive fails. When registration is incomplete, the identification of objects is tenuous and significance can become unclear.

As objects are used their labels may be removed and objects may be placed in a location other than that at which they are registered. In this way objects can become (temporarily) lost.

Figure 120. Without additional information we cannot know that this stuffed pigeon is the now-extinct American passenger pigeon (Source: www.wikipedia.org).

Information may be lost in transcription or translation or when analogue information is transferred to a digital record. Digital data and documentation need to be updated regularly and reformatted to guarantee accessibility using new systems or software. If a computer crashes, backups ensure that not all information is lost. Knowledge about objects or the collection that is only available in the memories of staff can disappear when people leave the organisation, for example because of retirement, resignation or death.

An example that is frequently used to explain 'dissociation' is the loss of object information for a specimen in a natural history collection. Together with its information, the specimen forms the evidence for the presence of that species in a specific place at a particular time, which gives it a scientific value. Without the information, it is merely a dead animal (Figure 120). Field journals and additional information increase the scientific value, but if they are lost, for whatever reason, the specimen loses value (Figure 121).

When its associated records are lost, an oil painting with a

Figure 121. This fluid-preserved collection has little scientific value within the context of café De Kroon in Amsterdam, yet it does have decorative and aesthetic value.

Figure 122. Ernst Casimir's felt hat with the hole from the lead musket ball that killed him in 1632 during the Siege of Roermond (Source: Rijksmuseum Amsterdam).

Figure 123. The bed in The Blue Chamber of Duivenvoorde Castle would lose artistic and historical value outside the context of the ensemble.

recognisable image that tells its own story will lose less value than an object that does not speak for itself. For example, it is important to know that a hat with a hole is not simply an example of insect damage to the fabric, but is significant because of who was wearing it when they were shot in the head (Figure 122).

A collection for which all provenance data have been lost, loses its credibility and value as a research resource. Distinctive forms of dissociation occur for objects that have significance in a specific context. Religious objects or objects with a high symbolic value lose their value outside the context for which they were intended. In addition, handling such objects without due respect can make them worthless to the original owners.

Figure 124. Documentation of installation art is crucial for its correct interpretation during re-installation, in this case Jeffrey Shaw's Revolution.

When several objects form an ensemble or when there is a connection between, for example, the objects, the interior in which they stand and the garden visible through the window, the value will be diminished once the objects are taken out of their context (Figure 123).

With modern installation art, the volume of the sound, the light intensity or the speed at which images change, can be essential for the experience and significance of the object. If these aspects are not documented properly, the object can lose value when re-installed for exhibition (Inside Installations, 2007).

Installations usually consist of a number of components. When one or more of the parts are lost or missing, it is another form of dissociation. Adding components that were not originally part of the installation can also be regarded as a form of dissociation (Figure 124).

Options for risk reduction

Managing dissociation risks is mainly a matter of effective policy. Agreed procedures for registration, documentation, relocation and displacement should be drawn up and complied with. The risk is reduced significantly when incoming objects are registered meticulously and where knowledge and information are recorded in a well-structured documentation system.

Acquisition of objects into a collection begins with clarifying the legal responsibility for the objects, which must be clear and preferably in the hands of the heritage institution. The object must then be related to all available information, which is generally achieved by assigning it the unique identification number by which it is registered (Lebeer, 2008).

When a registration code is connected to an object physically, it is important to choose the correct method and material for labelling (Powerhouse Museum, 2007). Currently, digital collection information systems, which run software such as Adlib, TMS and Emu, are the predominant means of registering and documenting objects. The files require adequate maintenance and regular updates. Databases should be safely archived, backups should be available, and files should be transferred to new, accessible formats before old systems become obsolete.

Barcoding has become popular to monitor the relocation of objects, and there are modern alternative techniques such as radio frequency identification (RFID), as well as chips in the object that contain identification details that can be recognised by detection gates at entrances and exits or emit a signal that indicates the location of the object.

If all is arranged well, with appropriate policies and procedures, then all that remains is a reliance on individual staff to follow the procedures rigorously so that dissociation risks stay as low as possible.

Dissociation risks are very sensitive to magnifying and mitigating factors such as the lack of personnel and resources, training of staff and technical limitations. In their chapter about dissociation, Waller and Cato (2016) present a number of factors that increase the risk of dissociation. In Table 46 these are shown in combination with some mitigating factors.

To limit dissociation risks, the five stages from the integrated approach in the *Framework for Preservation of Museum Collections* (CCI, 1994) can be applied.

Avoid
Ensure adequate registration upon entering the collection. Objects that are not registered or catalogued on arrival are placed on a waiting list. Make regular backups of the information systems. Make sure staff members are trained sufficiently and are aware of risks and procedures.

Block
Whenever handling objects, information and documentation, make sure that the association between them remains intact. Keep track of objects and enter changes into the registration system immediately. Ensure that identification numbers and labels are properly attached to the object.

Detect
Check regularly to ensure that the data are still correct and that labels remain adhered. Perform random sampling to make sure that objects are in the right place, check that transcribed data are correct, and ensure that digital formats are still readable. Ask users to report threats of dissociation to staff.

Respond
Create procedures to replace labels in good time, well before they are lost. Transfer digital files and train staff. Interview employees before they leave their job.

Treat
Create a procedure to deal with dissociated parts, information or labels. Ask users to be attentive and to report any instances of dissociation to staff and ensure re-association.

Level	Magnifying factors	Mitigating factors
Object	Obtained illegally Ambiguous ownership Small (difficult to label) Susceptible (difficult to label) Consists of multiple parts 'Out of fashion' Differs significantly from the collection Destructive research on object In poor condition	Acquisition policy with criteria Tells own story Maker is still alive Is widely known Catches the eye In good condition All the parts in the same packaging
Collection	Large number of objects Great diversity of objects Collection data from various sources Collection badly ordered Outdated carriers and media for information and documentation	Clear collection policy Collection preservation plan
Procedures	Staff are not aware how storage is organised Staff do not realise the importance of location registration Cultural value insufficiently recognised by keepers Untrained volunteers who are unaware of proper procedures Separated storage of parts of objects and collections	Access to collections regulated Control of provenance upon acquisition Durable labelling materials and methods Collection value assessed and known Used for research
Management	Unclear responsibilities Insufficient staff Tight deadlines for projects, which could lead to carelessness Insufficient resources	Value assessment part of collection management Education and further collection management training of permanent staff and volunteers

Table 46. Magnifying and mitigating factors for dissociation risks (after Waller and Cato, 2016).

Level of control	Probability of loss of value in 100 years				Period within which loss of value for an object occurs
	Minimum part of collection	Small part of collection	Considerable part of collection	Large part of collection	
Low	Highly likely	Highly likely	Likely	Possibly	1–10 years
Medium	Highly likely	Likely	Possibly	Unlikely	10–100 years
High	Likely	Possibly	Unlikely	Unlikely	>100 years

Table 47. The probability of loss in value in 100 years as a result of dissociation for the different levels of control.

Rules of thumb for determining the magnitude of risk for specific risk scenarios

The dissociation risk will decrease as the level of control in the institution increases and everyone becomes aware of the risk of losing knowledge and information; as a result, the loss of value over a given time will be smaller or the period over which a particular loss of value occurs will be longer. Three levels of control can be distinguished:

- Low: a part of the collection is registered and entered into a registration and documentation system, different labels are attached to objects in various ways, relocation of the object is not always registered, procedures are not always followed (this level will be insufficient for most museum accreditation schemes).
- Medium: most of the collection is entered into an appropriate registration and documentation system, objects are properly labelled, relocation of objects is registered, procedures are usually respected (a level that is sufficient for museum accreditation schemes).
- High: the whole collection is registered in a sustainable registration and documentation system, objects are properly labelled, possibly with barcodes or tags, relocation of objects is registered, all procedures are followed thoroughly (high professional level).

Agent of Deterioration	Interaction
Physical forces	Registration, relocation and assessment procedures can raise awareness of sources of damage and thus reduce future risks of physical forces. Handling of the object during registration, numbering and photography can lead to physical damage. Frequent handling can cause object numbers or labels to wear off or become unreadable.
Fire	Registration, relocation and assessment procedures can raise awareness of fire risks and so improve maintenance and emergency planning procedures. During the evacuation of objects labels may detach. During an evacuation the location registration is disrupted.
Water	Registration, relocation and assessment procedures can raise awareness of water-related risks and so improve maintenance and emergency planning procedures. Wet labels may detach. During an evacuation the location registration is disrupted.
Thieves and vandals	Unregistered objects disappear more easily than those that are registered. A high registration rate lowers the chances of (internal) theft because the lost objects are noticed at an earlier stage. Hiring employees for collection registration and documentation, introduces new people, which increases the risk of theft. Objects of which the meaning is unknown can easily become victims of vandalism.
Contaminants	Random checks on object location can help to identify dirty or contaminated areas. The use of unsuitable media to number objects is a form of contamination. Labels can become unreadable because of contamination.
Light, UV and IR radiation	Dissociated information about the meaning and character-defining features of objects can lead to irresponsible exposure to radiation. Objects of which the meaning is unknown will be exhibited less often. Labels may fade or become unreadable due to light damage.
Pests and plants	Random checks on object location can help to identify insect damage. Mice and insects may attack labels.
Incorrect temperature	Procedures for the proper use of the collection may reduce the risk of exposure to incorrect temperatures. At high temperatures, chemically unstable labels and information carriers age faster.
Incorrect relative humidity (RH)	Procedures for the proper use of the collection may reduce the risk of exposure to an incorrect relative humidity. At high relative humidity, labels may detach or degrade.

Table 48. Examples of the relationship between 'Dissociation' and the other agents of deterioration

Table 47 lists estimates for the probability of loss of value of particular parts of the collection in 100 years at the three levels of control. The last column gives the period within which an object is expected to lose value at the three levels of control.

To determine how great the loss of value will be, it is necessary to have a good understanding of the relationship between the physical object and the knowledge, information and documentation that belong to it. It can be useful to think about this in the light of the questions presented below – alone or together with a colleague or users of the collection. The schematic in Figure 125 may also be helpful; it presents the object complex from the scenario scheme (which consists of the physical object, unrecorded knowledge, and recorded information and documentation) and applies a so-called thought experiment.

1. Suppose the complex of tangible and intangible aspects of object, knowledge, information and documentation currently has a value of 100% (bar 1 in Figure 125), and that the value will be 0% if everything is lost (bar 8). What will be the value of the different combinations of parts in the complex?
2. If the recorded information and documentation are lost (but remain present as unrecorded knowledge)?
3. If the unrecorded knowledge is lost?
4. If there is neither knowledge nor information about the object available (does the object explain itself)?
5. If there is only knowledge, information and documentation but no object?
6. If there is only unrecorded knowledge and information retained in the minds of staff?
7. If there is only recorded information and documentation available?

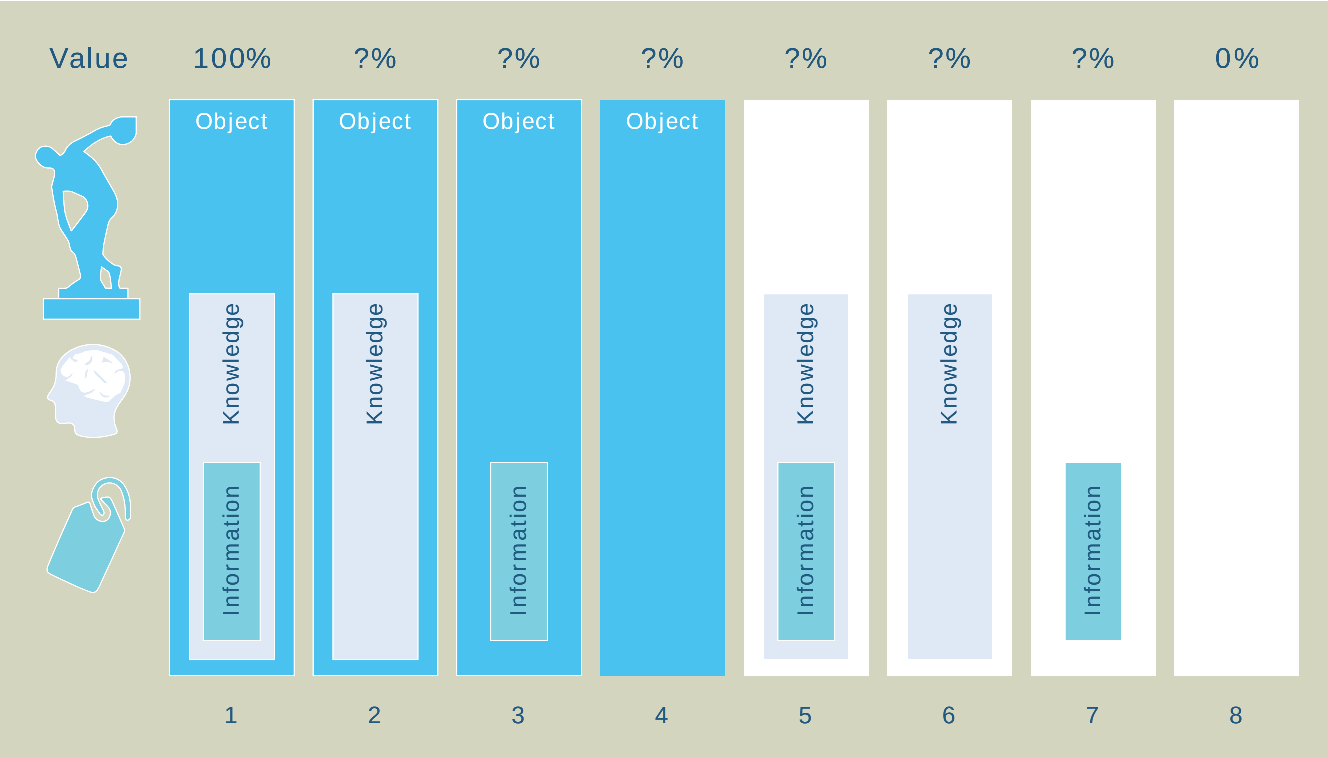


Figure 125. Schematic for the thought experiment to determine the value of the object complex when it is subjected to different forms of dissociation.

Also, what if certain intangible properties such as sound, odour, light intensity and atmosphere change?

For the various scenarios presented above, the loss of value will differ greatly for each object or (part of the) collection. It is valuable, therefore, to talk to several colleagues about the different scenarios and to determine together how great the loss of value will be.

Relationship with other agents of deterioration

Measures that reduce one risk can have side effects on other risks. They can have a synergistic effect with a positive reducing effect on other risks, but they can also have a negative effect leading to a (temporary) increase of other risks. Storing parts of objects with different susceptibilities to incorrect indoor climatic conditions in different locations could lead to an increased dissociation risk. Regular location checks help signal dissociation risks but also help to reduce risks from theft and pests.
Agents of deterioration may also act sequentially. A label that comes off an object due to the action of physical forces, leads to dissociation. Loose labels may detach during a fire evacuation, which increases the risk of dissociation. Examples of relationships between 'Dissociation' and the other agents of deterioration are listed in Table 48.

References and further reading

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Simmons, J.E. (2006) *Things Great and Small: Collections Management Policies*, American Association of Museums, Washington DC, 208 pp.

Waller, R.R. and P.S. Cato (2016) 'Agent of Deterioration: Dissociation', Canadian Conservation Institute, Ottawa. http://canada.pch.gc.ca/eng/1444924574622 (Accessed 27 January 2017)

The walls of De Haar Castle in Haarzuilens (the Netherlands) showed large cracks. Substantial restoration was needed to preserve the castle. Between 2006 and 2009 the external shell was restored in a phased project and the foundations of the leaning Knight's tower were strengthened.

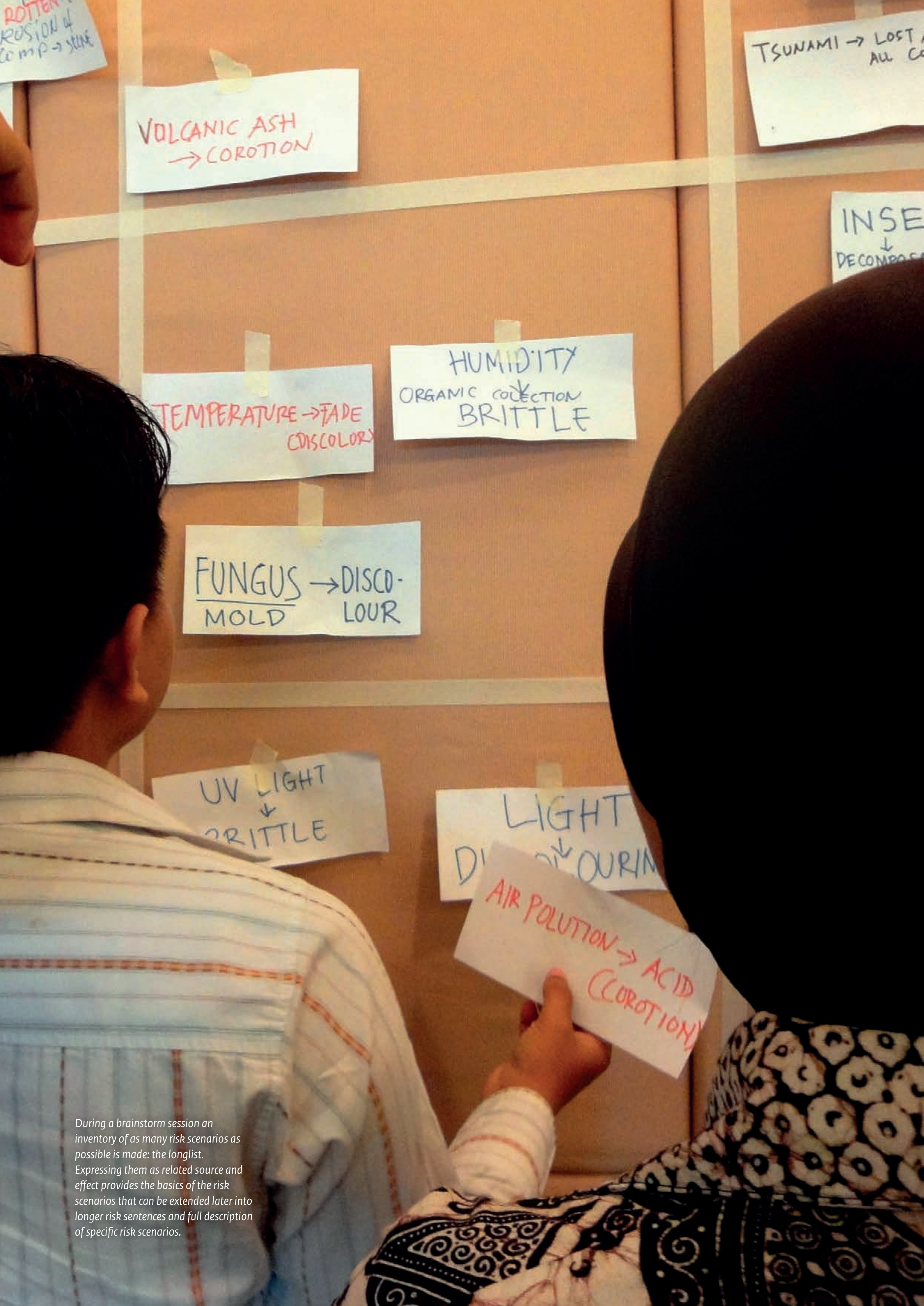
Other agents of deterioration

An agent of deterioration that is missing from the ten agents is 'autonomous' or 'inherent' decay. Examples of this deterioration process are the degradation of early photographic and film materials such as cellulose acetate or cellulose nitrate, and thermal printing paper. Since these deteriorate through chemical processes, the general rule that reaction rates are slower at low temperatures applies. The associated risks are, therefore, usually identified under 'Incorrect temperature', and for these particular materials, room temperature is too high to ensure their preservation for very long. This risk can be reduced by using cool or cold storage. When identifying risks, we should remember to consider autonomous decay under 'Incorrect temperature'.

When we are dealing with electronics, including industrial collections, computers and video installations, capacitors could leak and fail. This autonomous decay process does not seem to be affected by the temperature, and neither can the cause be traced back to one of the other agents of deterioration. The measures needed to reduce this risk are not covered within the usual options applied to any of the ten agents. Therefore, an eleventh 'other' agent can be introduced, to which we must apply our knowledge, experience and creativity to produce a risk analysis and develop risk reduction measures.

Other examples of additional agents include electricity/power, computer failures and computer virus infections. These could be considered under 'Dissociation' or 'Contaminants', but it is probably more practical to give them separate status.

Figure 126A and B: Revolution by Jeffery Shaw (top) is an installation that comprises a rotating framework supporting a monitor. Depending on the direction in which the construction is manually rotated, the monitors displays images either of revolutions over the years or of a millstone. The electronic components (bottom) are vulnerable to decay and may become irreplaceable in a few years.



During a brainstorm session an inventory of as many risk scenarios as possible is made: the longlist. Expressing them as related source and effect provides the basics of the risk scenarios that can be extended later into longer risk sentences and full description of specific risk scenarios.

Appendix 1: QuiskScan form

QuiskScan form

I Collection anatomy		II Value		III Vulnerability for agent of deterioration [1]									
Collection unit	Quantuty (Number of objects)	Relative value [1]	Weight	Physical Forces [2]	Water	Fire	Thieves & Vandals	Pests	Contaminants	Light, UV, IR	Incorrect temperature	Incorrect relative humidity	Dissociation

[1] Indicate, using High (H), Moderate (M), Low (L)

[2] color code the cell indicating value x susceptibility:
- H x H = red
- H x M & M x H = orange
- M x M = yellow
- H x L = L x H = M x L = L x M = green
- L x L = blue

Appendix 2: ABC-scores

ABC-scores

A — How often or how soon?

	Event: The probability or frequency with which an event takes place and leads to a loss of value	Process: The rate at which a process leads to a loss of value. The loss of value from the B-score will occur in:
5	Once every year	Approximately 1 year
4½	Once every 3 years	Approximately 3 years
4	Once every 10 years	Approximately 10 years
3½	Once every 30 years	Approximately 30 years
3	Once every 100 years	Approximately 100 years
2½	Once every 300 years	Approximately 300 years
2	Once every 1,000 years	Approximately 1,000 years
1½	Once every 3,000 years	Approximately 3,000 years
1	Once every 10,000 years	Approximately 10,000 years

B — What is the loss of value to each affected object?

5	100%	Total or almost total loss of value for each affected object
4½	30%	
4	10%	Significant loss of value for each affected object
3½	3%	
3	1%	Small loss of value for each affected object
2½	0.3%	
2	0.1%	Very small loss of value for each affected object
1½	0.3%	
1	0.001%	Just noticeable loss of value for each affected object

C — How much of the total collection value is involved?

If all objects are of equal value: How many objects are affected
If there is a value pie with objects of varying value: Which part of the pie is affected?

5	100%	All or most of the collection value
4½	30%	
4	10%	A significant part of the collection value
3½	3%	
3	1%	A small part of the collection value
2½	0.3%	
2	0.1%	A very small part of the collection value
1½	0.03%	
1	0.001%	A minute part of the collection value

Appendix 3: Scenario form

Scenario form

Agent of deterioration

☐ Physical forces	☐ Light, UV, IR	☐ Fire	☐ Thieves & Vandals	☐ Pests
☐ Contaminants	☐ Water	☐ Incorr Temp	☐ Incorr RH	☐ Dissociation

Type

☐ Event ☐ Process

Risk

Provide a short sentence to describe the risk.

Source

Provide relevant information about the source. What is it? where is it? how often or how long is this source active?
What is the intensity and /or frequency?

Path

Provide relevant information about the pathway that is followed between source and object. Are there any barriers?
Where are these barriers? How effective are these barriers? Are there barriers lacking?

Effect (object)

Describe what happens to the objects that are affected. How much of their value is lost?

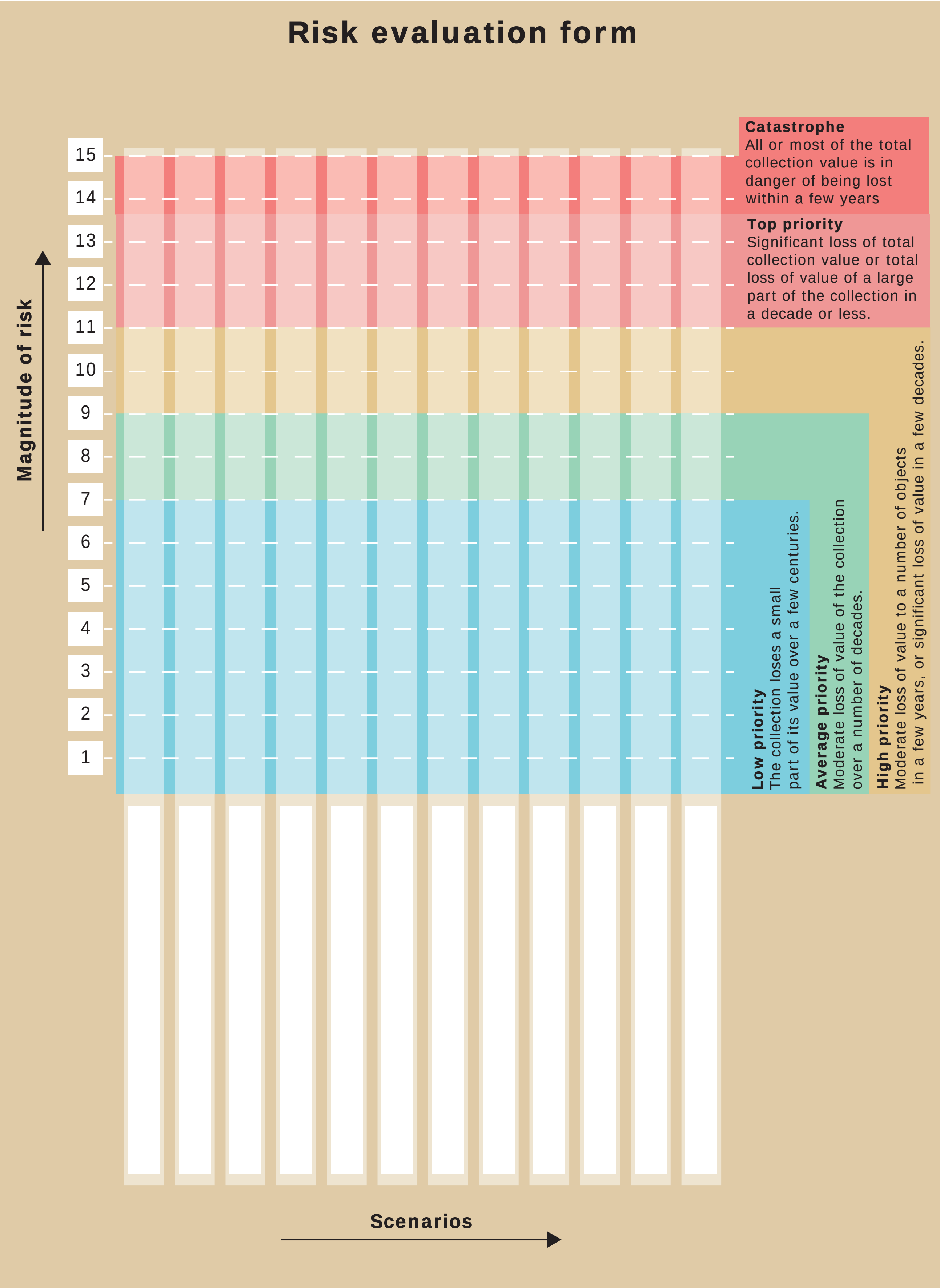
Consequences (collection)

Describe which objects from the collection show the effect described above. How much value do these objects represent?

SCORES

	A-score (How often, how soon?)	B-score (What is the loss in value for each affected object?)	C-score (How much of the total collection value is affected?)	Total score A + B + C
Lowest score				
Expected score				
Highest score				

Appendix 4: Risk evalution form



Which measures are most effective to reduce the likelihood of water damage in the museum? Does the lighting of the print collection need adjusting? Does the museum really need complete climate control?

Every day collection managers have to decide how to best let the public enjoy our cultural heritage. They weigh the benefits of collection use against the risks for preservation. When resources are limited it is essential to allocate them such that threats of degradation can be minimalized as effectively as possible. Risk management offers a practical and useful approach for comparing the options and setting priorities. With this publication the Cultural Heritage Agency of the Netherlands hopes to provide the knowledge that is required to analyse and manage risks to collections.