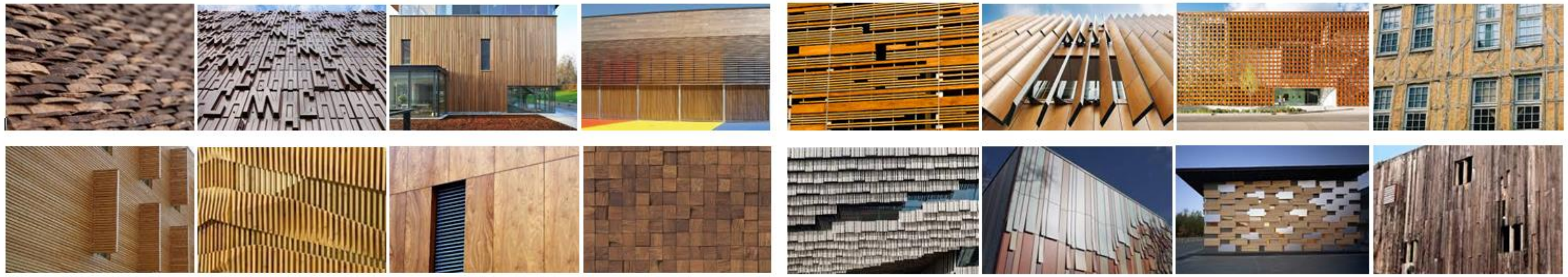
Understanding of biomaterials deterioration during service life



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FP1407 Training School: Service life of modified wood - Understanding Test Methodologies

Outline

- Wood as a building material
- Service life of buildings – definitions from various perspectives
- Criteria that Influence the End of the Service Life of Buildings
- Service life categories + examples
- Methodologies for Estimated Service Life calculation
- Normative Framework for the Service Life Prediction of Buildings
- How to improve durability in sustainable architecture

“*The Earth grows our food.* ***The earth can grow our homes****. It’s an ethical change that we have to go through*.”

Michael Green

“*The 18th century was about brick,*

the 19th about steel, the 20th about concrete,

and ***the 21st century is about wood***.”

Alex de Rijke

Timber offices: the time has come

How multidisciplinary engineering is unlocking the benefits of wood

Timber is the only renewable building material. It is strong and light, making it easy to transport and erect. It can also be machined to very high tolerances, making it ideal for prefabrication. New wood products such as CLT (cross laminated timber), and recent advances in computer-controlled manufacturing, now make it an attractive choice for office construction.

If acoustics, floor vibration and fire safety are addressed early in the design process, wood can be left exposed – saving on the cost of finishes and adding to the beauty of the interior. This is where our multidisciplinary approach can offer real cost savings. We believe that wood can create office buildings that are attractive, sustainable and affordable.

Why use timber?

These benefits of timber make it an ideal construction material. Richard Hough explains in this film what makes timber unique, and how that can radically change the construction process.

Designing with timber

Learn about the properties of wood as a material and see how it is being incorporated in design.

Download brochure

Arup's timber expertise

Why wood and other biomaterials?

- Wood has been used as a building material for thousands of years, being second only to stone in terms of its rich and storied history in the world of construction.
- This exceptionally versatile material is commonly used to build houses, shelters and boats, but it is also extensively used in the furniture and home decor industry as well.
- it is a natural resource, making it readily available and economically feasible.
- It is remarkably strong in relation to its weight, and it provides good insulation from the cold.
- Wood is highly machinable, and can be fabricated into all kinds of shapes and sizes to fit practically any construction need.
- Wood is an environmentally sustainable product; it is biodegradable and renewable, and carries the lowest carbon footprint of any comparable building material.
- No high-energy fossil fuels are required to produce wood, unlike other common building materials such as brick, steel or plastic.

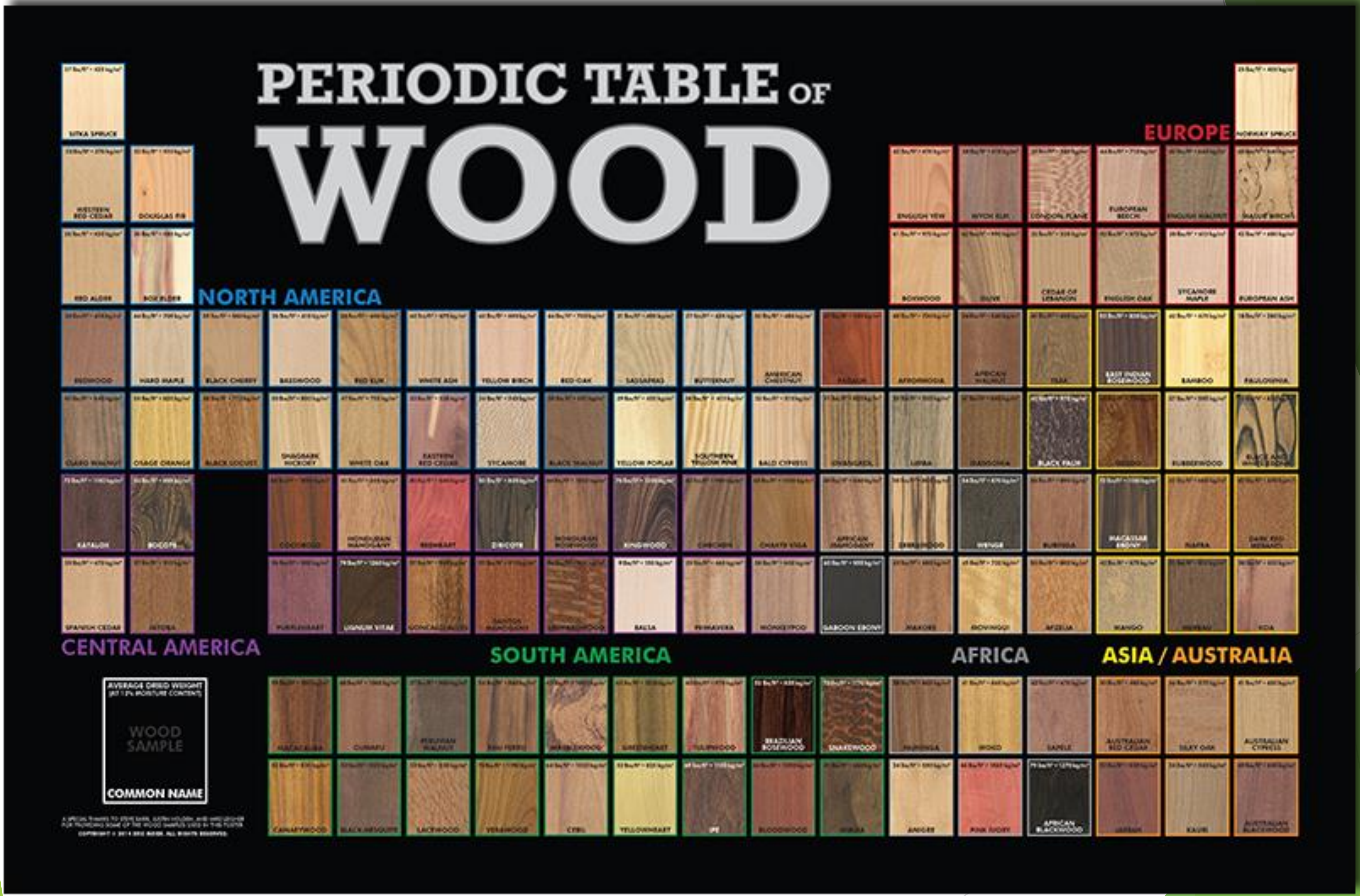










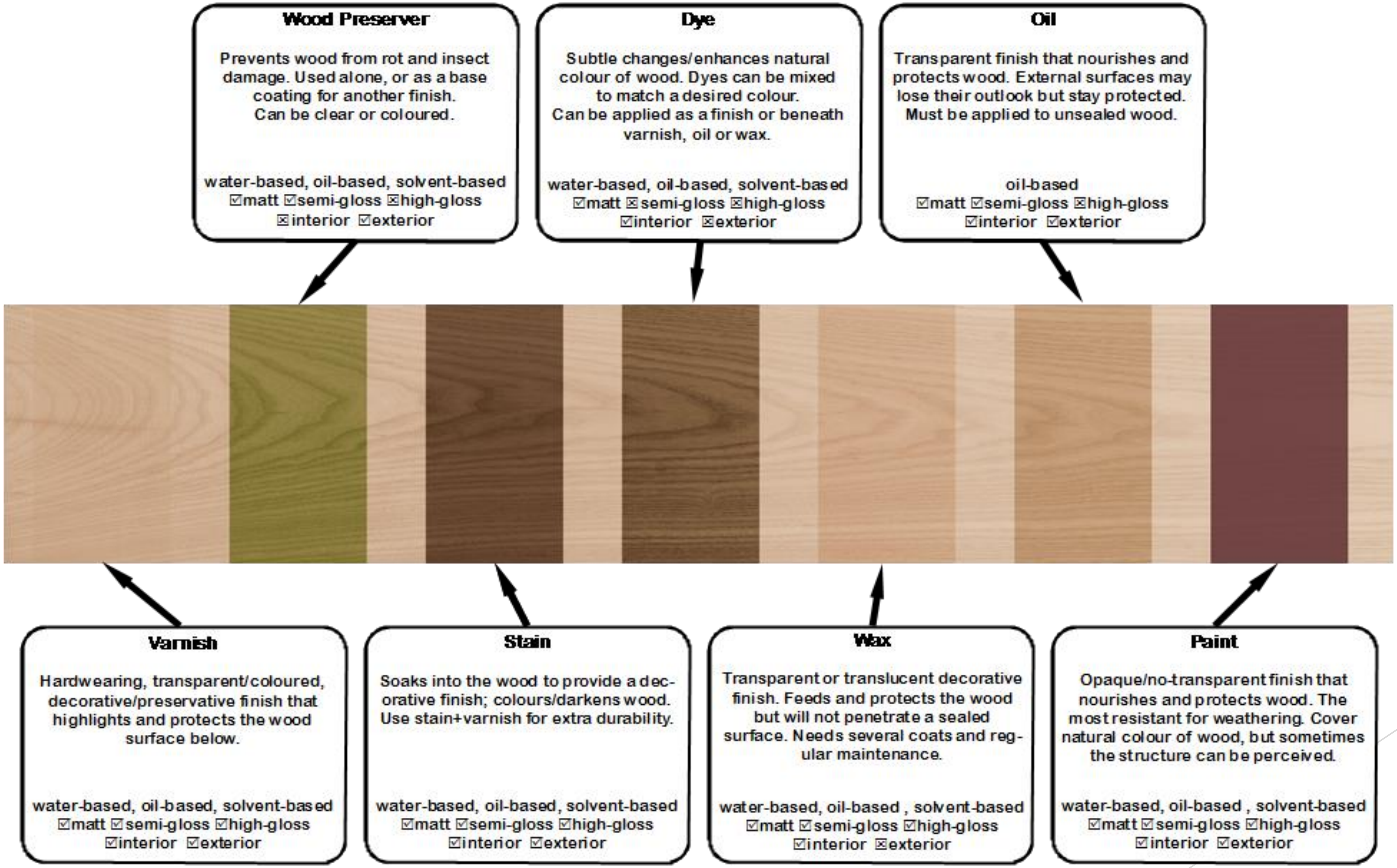


PERIODIC TABLE OF
WOOD
EUROPE
NORTH AMERICA
CENTRAL AMERICA
SOUTH AMERICA
AFRICA
ASIA / AUSTRALIA
AVERAGE DRIED WEIGHT
WOOD SAMPLE
COMMON NAME

Materials apperance – wood modification

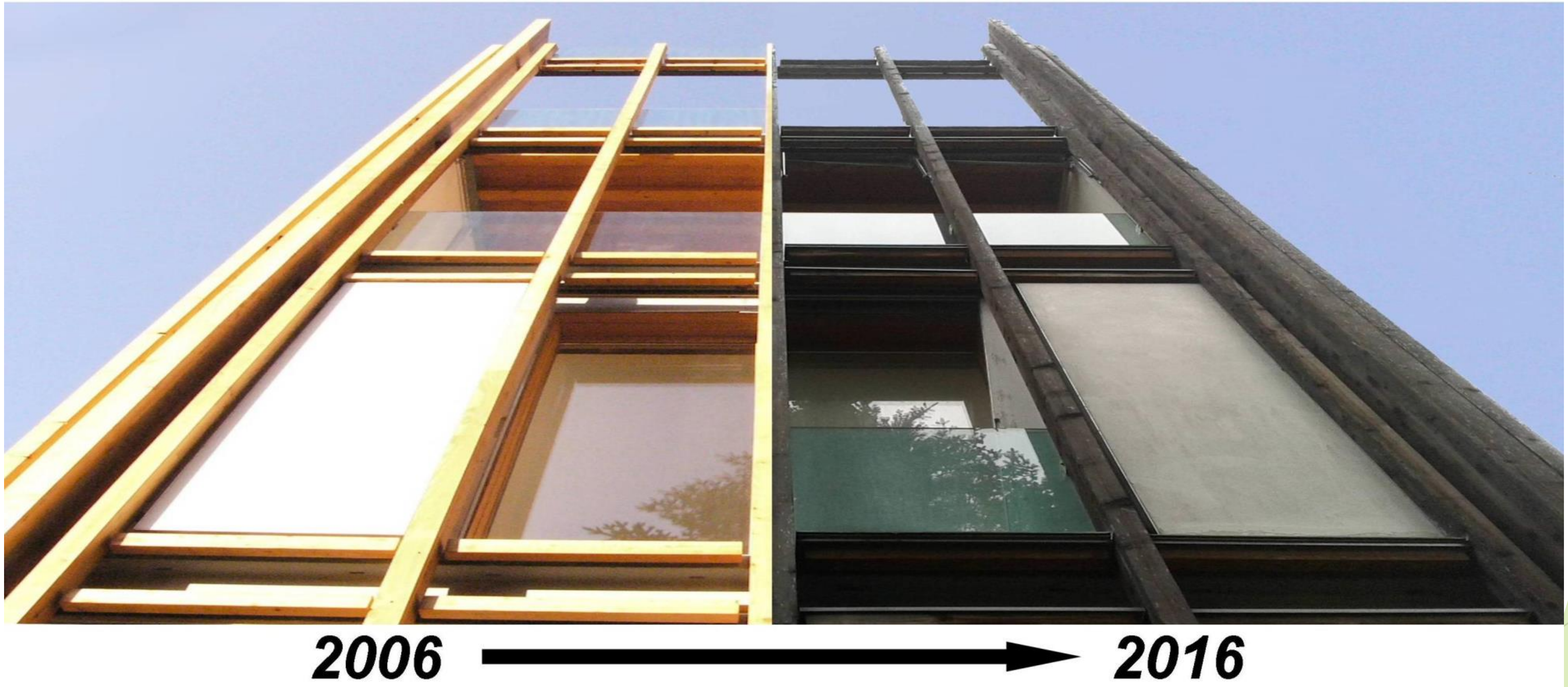





Materials apperance –finishing



Appearance change of the unprotected wooden structure in time: are we aware of that?



Unprotected cladding

https://russwood.co.uk/exteriors/cladding/weathering/

Norman Foster Chesa Futura - St. Moritz

Environment Centre Wales building in Bangor

A key issue in building construction: durability and performance










Service Life of Buildings

- **The building's life cycle comprises all stages of its life, i.e. the time elapsing since it is placed in use, after construction and ending at the instant from which it is unable to meet the acceptable minimum performance requirements**
- According to **ISO 15686: 2011** (Service life planning), service life can be defined as the period of time after installation in which the buildings or their parts meet or exceed the minimum performance requirements;
- **ASTM (1990)** shares the same definition of ISO 15686: 2011 and also mentions that during this period of time the building and its elements must be subjected to periodic maintenance;
- The Canadian standard **CSA S478-95** (Guideline on Durability in Buildings) refers that the service life can be described as the period of time during which the building or its components fulfil the requirements for which they were designed, without unexpected costs or maintenance and repair actions;
- EOTA, in the document Assumption of Working Life of Construction Products in Guideline for European Technical Approvals and Harmonized Standards (**EOTA 1999**), characterizes service life as the period of time during which the performance of the product is maintained at a level compatible with the fulfilment of the essential requirements.

Service life versus durability

- The concept of service life is often confused with that of durability, leading to the misuse of the terms.
- Contrary to the concept of service life, **durability** is not related to a period of time but instead corresponds to the **building's ability to show an adequate performance during their life cycle**
- Durability cannot be seen only as an intrinsic quality of a material
- **Simple changes in the construction details may promote a higher protection of a building element against the degradation agents, contributing to the increase of its service life**

Architectural and structural point of view

The capacity of buildings to offer functionally valuable spaces for a long time is defined as its durability or longevity. This parameter is usually used for determination of the real value of buildings, the rate of their depreciation and is included in insurance procedures.

Durability aspects:

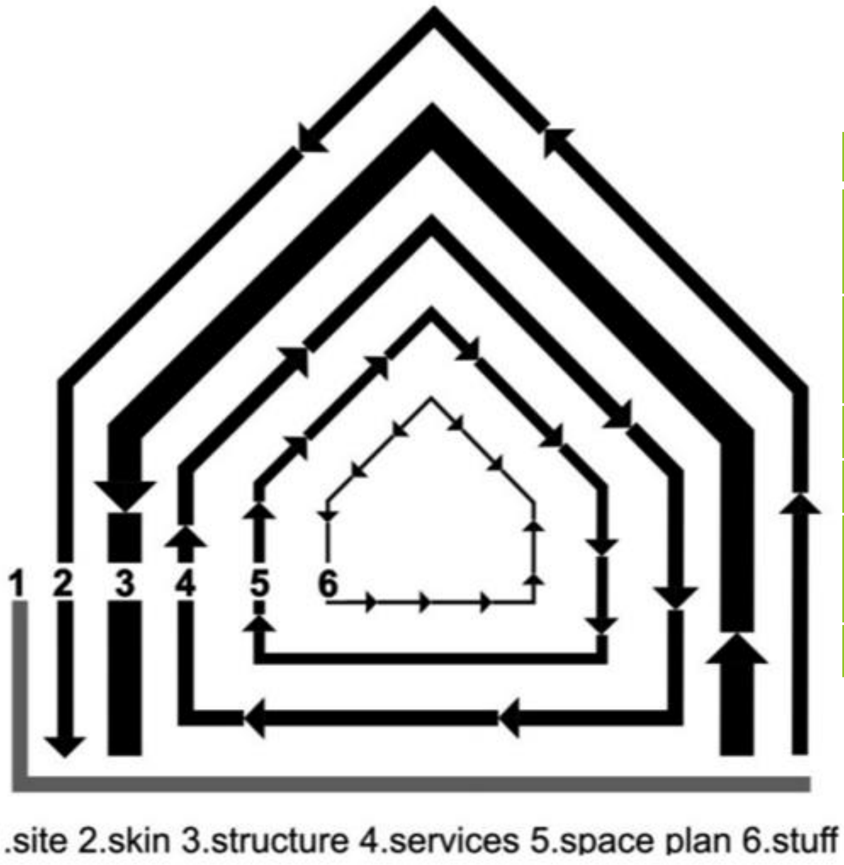
- technical durability,
- functional longevity,
- aesthetical longevity,
- operating durability,
- economic longevity

Celadyn (2014) DURABILITY OF BUILDINGS AND SUSTAINABLE ARCHITECTURE

Role of technical durability in architecture

- In Japan, the average durability of buildings reportedly comes to 30 years only
- Experts indicate that the exchange of houses every 25 years carries with it enormous social and environmental consequences and costs.
- Durability of commercial buildings is gradually getting lower in Europe
- The anticipated durability should be as long as 60 years
- The European trend to lessen the longevity of buildings to 50 years appears to be contradictory to the expected extension of their life- expectancy in sustainable architecture

The building as a system

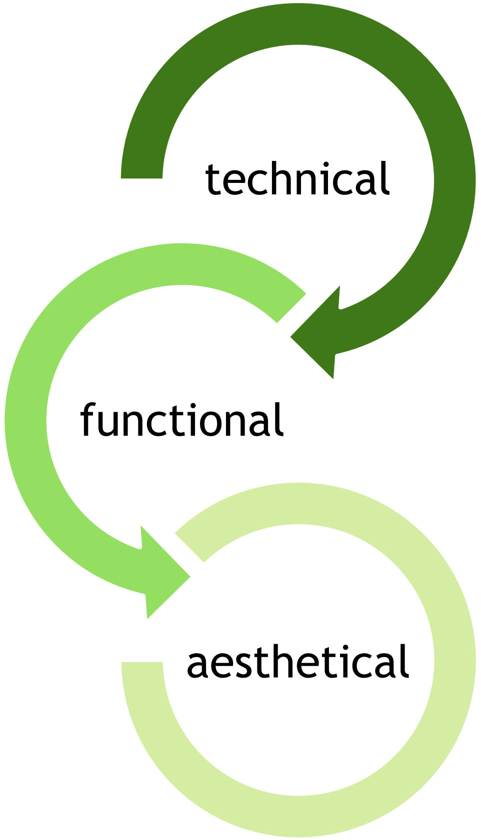


Layer	Components	Useful life (years)
Site	Geographical settings, urban location	Eternal
Structure	Foundation, load-bearing elements	30-300 (average 50-60)
Skin	Exterior surfaces	20
Service	Technical installation	7-15
Space plan	Interior walls, ceilings, floors, doors	Commercial – 3, home – 30
Stuff	Furniture	10-20

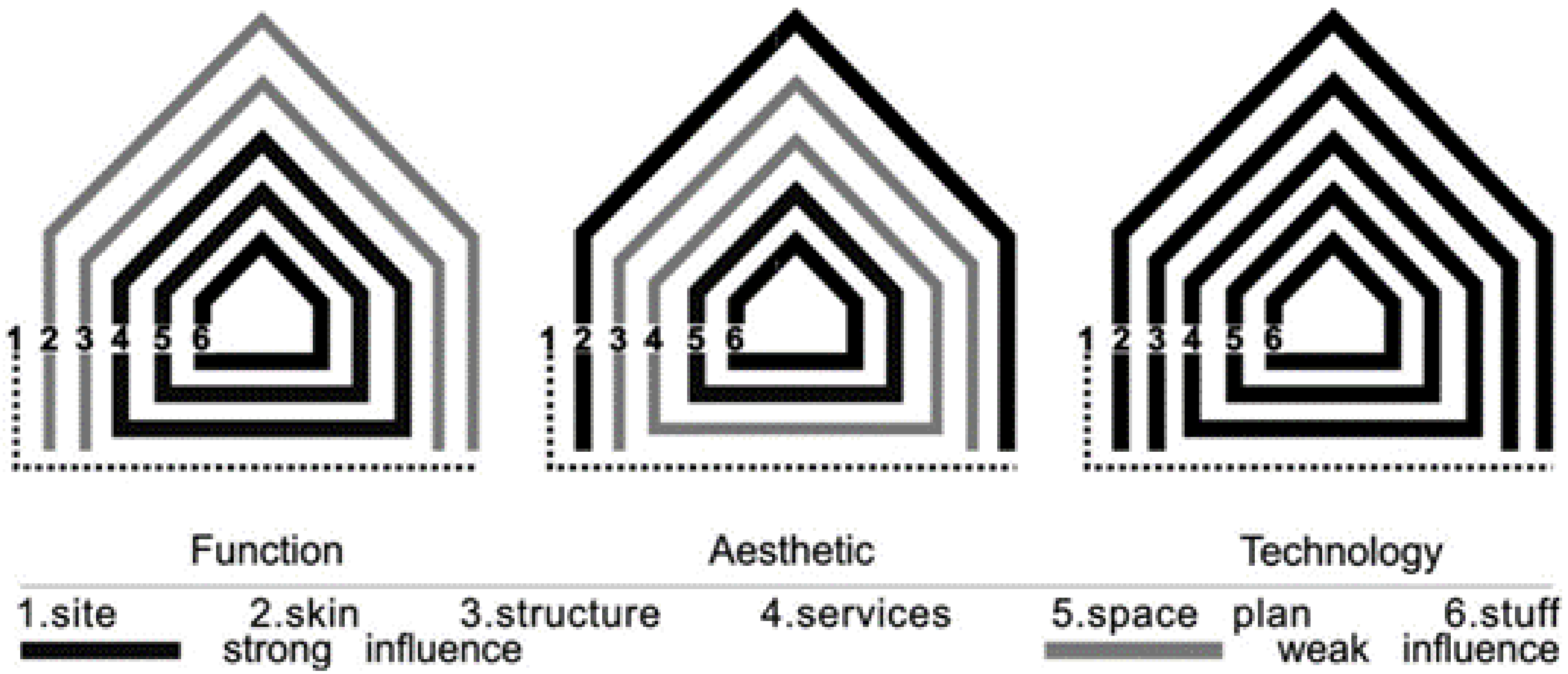
Brand S. (1994) How Buildings Learn. What Happens After They Are Built, Penguin, Books

Aspects of durability

- Based on Brand`s diagram three derivative schemes can indicate the layers significant for the three aspects of durability:
  - technical
  - functional
  - aesthetical



Impact of building's layers on its functional, aesthetical and technical durability



Celadyn (2014) DURABILITY OF BUILDINGS AND SUSTAINABLE ARCHITECTURE

Average longevity of buildings

The average longevity of buildings depends on the following factors:

- function of the building,
- applied technology,
- environmental conditions,
- local culture,
- economic and political situation

Function of the building

This is the basic feature of buildings which is tightly linked to their durability.

category	description	building life (years)	examples
1	Temporary	Up to 10	Temporary exhibition buildings
2	Short life	Min 10	Temporary classroom
3	Medium life	Min. 30	Industrial buildings
4	Normal life	Min. 60	Health, housing, educational buildings
5	Long life	Min. 120	Civic and high quality buildings

Categories of Design Life for Buildings (BS 7543:1992)

Expo Milan, 2015

Vietnam

Slovenia

Poland

Estonia

China

Japan

Long life buildings

800 year old Church, BorgundStave, Norway

1400 year old Horyuji Temple, Nara, Japan

Applied technology

- **Optimal selection of materials and methods of their installation**, as well as initial state of the building structures, are crucial for their longevity.
- At the early operational stage the building can be subject to accelerated destruction due to such factors as for example, technological humidity contained within the materials freshly installed.
- The materials or components can perform satisfactorily for a long time if they are autonomous within the structure, but coupled with other materials they might make up a new less stable system.

Environmental influences

- Depending on the geographical location and climatic zone, buildings are subject to different rate of destruction, and in consequence, various technical durability.
- The most destructive relevant climatic factors are: precipitation, wind, solar radiation
- More details on “Modelling of weathering” presentation

Technical durability of some building materials and the impact of environmental factors

Case	Main Material	Environment	Useful Life (years)
Base Case	Reinforced concrete	dry[3] , non-aggressive	60
Variations in Material	Structural steel[1]	dry[3] , non-aggressive	80
	Masonry and/or Timber[2]	dry[3] , non-aggressive	100
Variations in Environment	Reinforced concrete	wet[4], non-aggressive	40
	Reinforced concrete	wet[4], aggressive[5]	30

1 - The steel should be readily inspectable and accessible for routine maintenance

2 - This indicates that there is sparing use of steel that is subject to corrosion

3 - This indicates that the main materials are protected against moisture, either by coverings (e.g. roofing sheets) or coatings (e.g. plasters)

4 - A wet environment indicates poor maintenance (e.g. leaking roofs or cracked plaster)

5 - The most pertinent aggressive environment for any steel in buildings is a chloride environment; sulphates can also attack the concrete itself.

Dias W.P.S., (2003) Useful Life of Buildings

Local culture

- the customary cycle of demolishing houses, which is followed by consecutive construction of new structures, is a phenomenon based on traditional cultural principles
- They are based upon modular construction techniques which enable easy dismantling and reuse of building components.
- the Japanese culture accepts the aesthetics of death whereas the western culture, the aesthetics of eternity, the latter resulting in long-lasting durable European architecture and the way of treatment of building materials

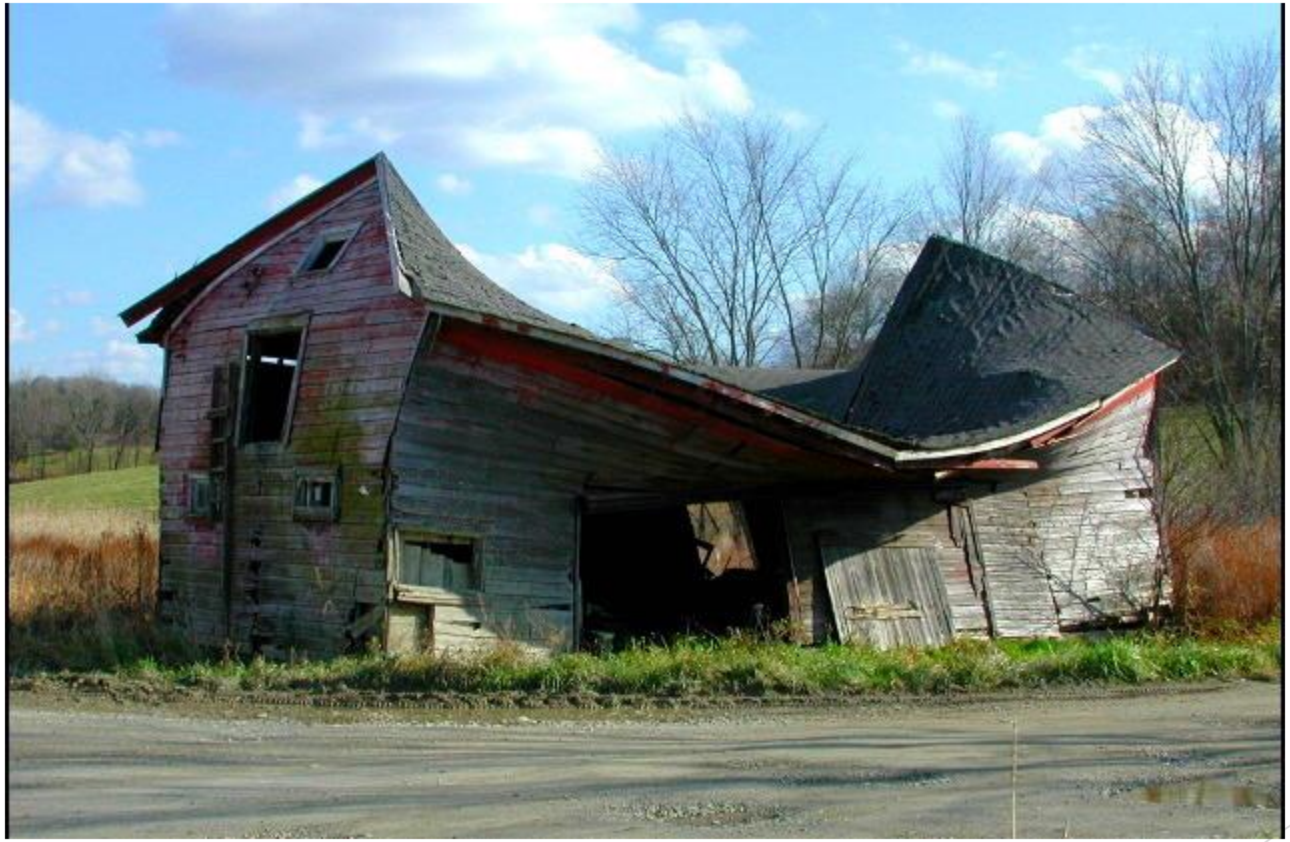
Flager F.L. (2003) The Design of Building Structures for Improved Life-Cycle Performance

Economic and political conditions

- The dismantling of building structures is most frequently caused by nontechnical factors like:
  - change in the value of land and new investments (34%),
  - inappropriate function for new emerging needs (22%),
  - insufficient energy and ecological parameters, shortage of appropriate maintenance (24%)
- East European countries where the intensified construction industry brought significant deterioration of the buildings' quality as well as the diminution of their durability

End of Service Life

the point in time, when the foreseen function is no longer fulfilled



Criteria that Influence the End of the Service Life of Buildings

- During its life cycle, a building should meet a set of performance requirements, e.g. safety, compatibility to the substrate, visual comfort, durability, among others. However, in some situations, the building's components fail to fulfil these requirements after some time.
- The usefulness of the buildings may also be compromised by their inability to accommodate changes over time.
- Throughout their life cycle, all the buildings experience changes, e.g. changes in its occupants or their needs and expectations, renovations and/or extensions, the ageing and replacement of components and systems

Depreciation during life cycle

Depreciation of constrtuction due to several factors:

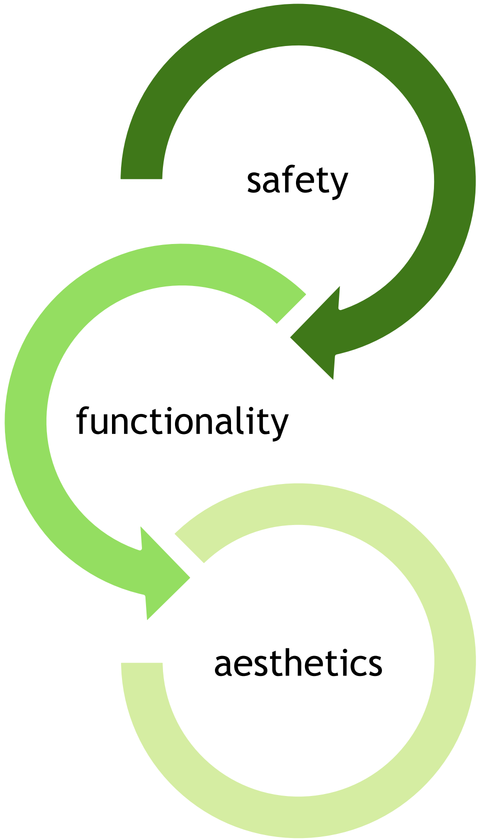
- physical deterioration;
- economic obsolescence;
- functional obsolescence;
- technological obsolescence;
- changes in the social context;
- obsolescence due to the building envelope;
- legal obsolescence;
- aesthetic obsolescence; and
- environmental obsolescence

Reasons to establish end of service life of buildings (Hovde, 2002)

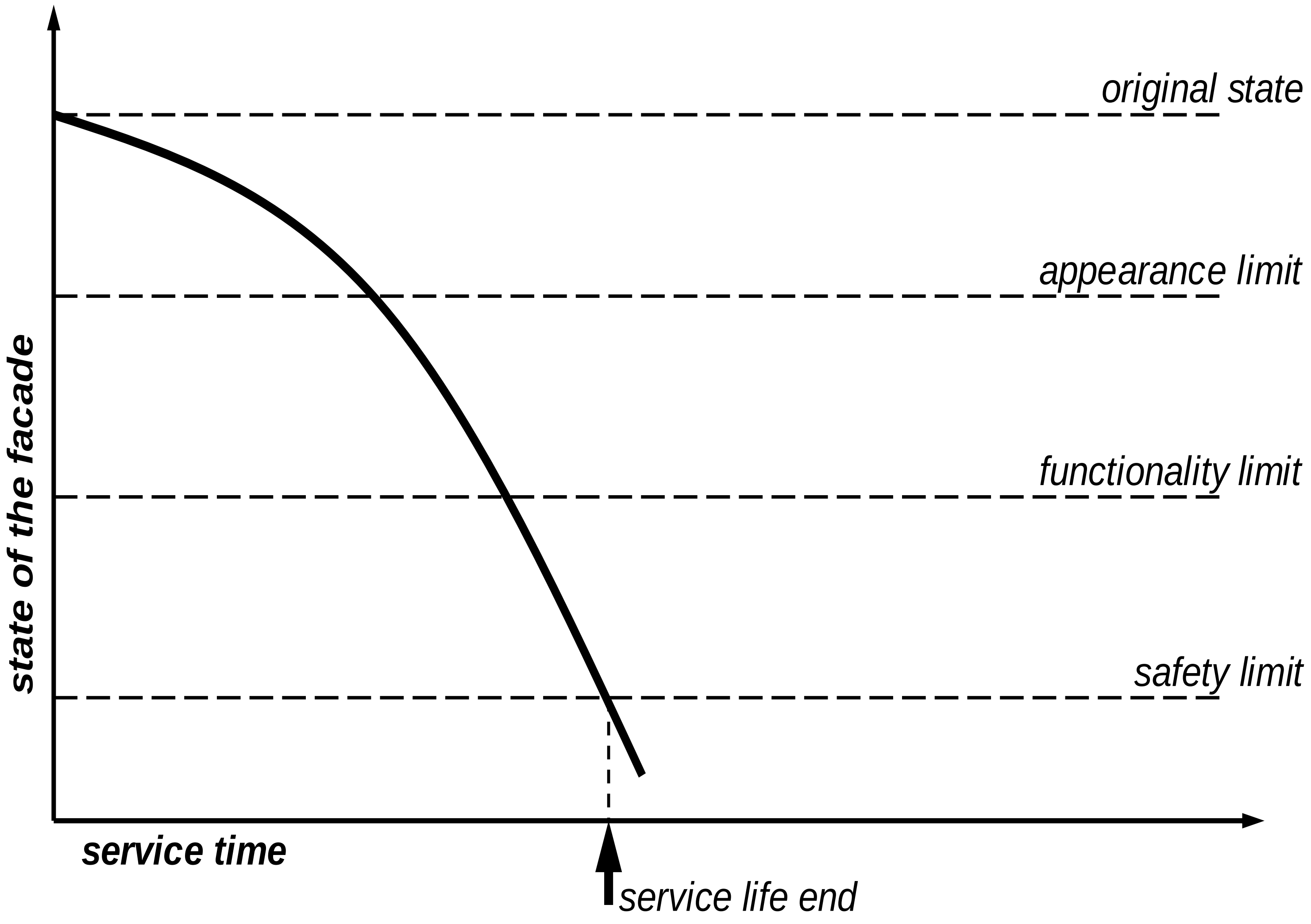
- technical aspects;
- economic aspects;
- environmental reasons;
- planning reasons— e.g. when the demolition of a building or a structure leads to the construction of a railway or other construction for public service;
- society requirements or technological development

Reasons to establish end of service life of buildings (Moser, 2004)

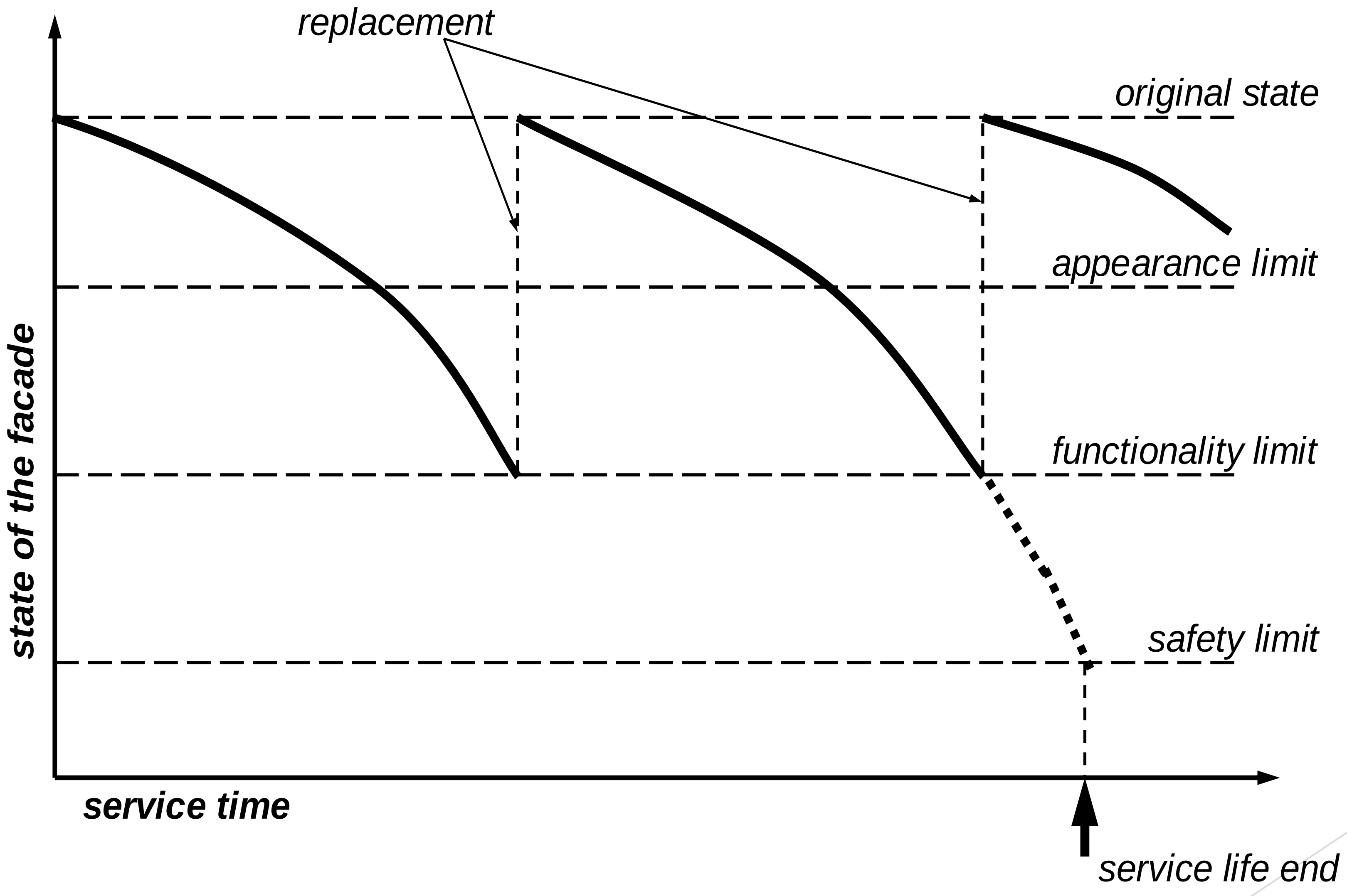
- safety;
- functionality;
- aesthetics;



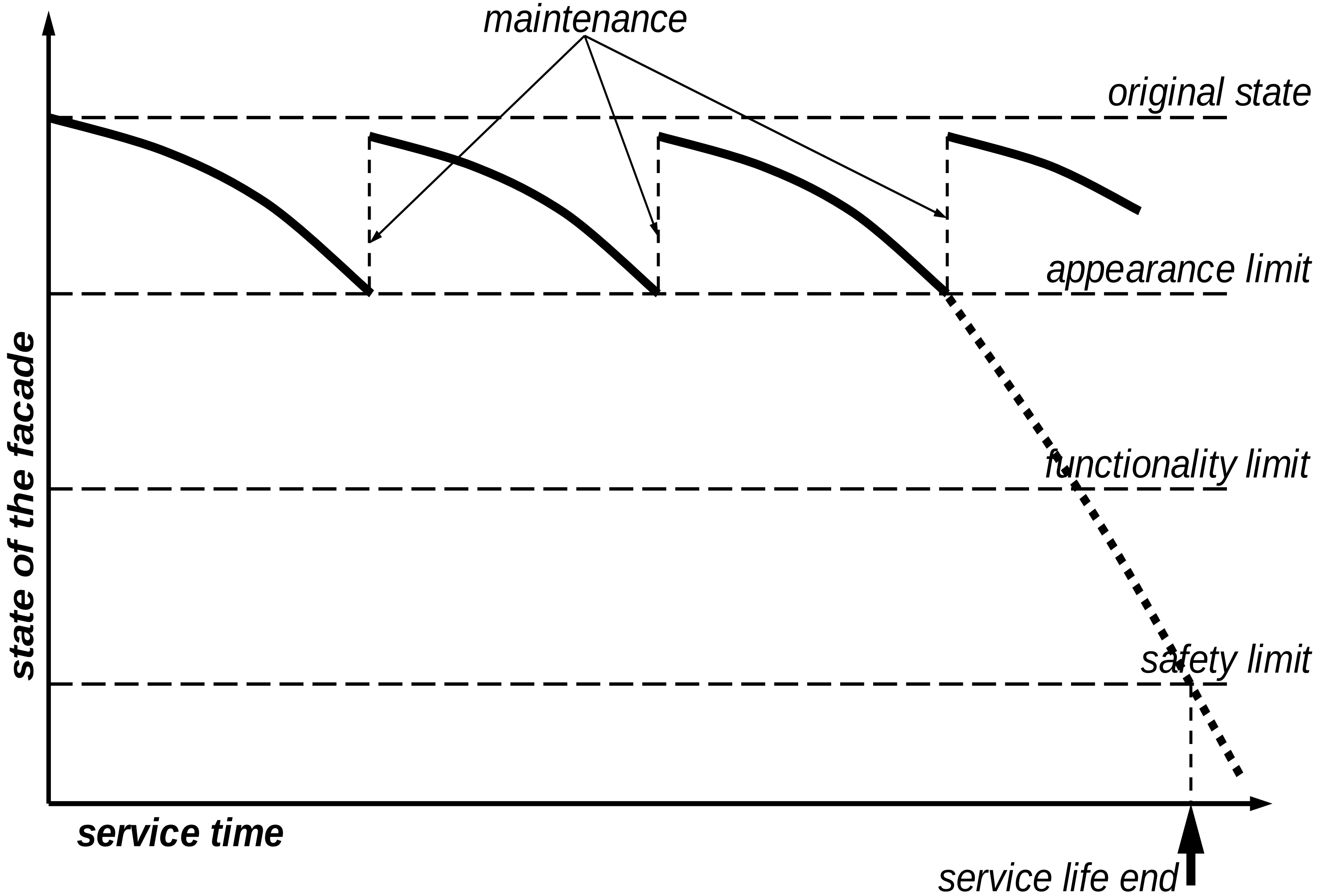
Scenario #1 – no any repairs



Scenario #2 – replacement



Scenario #3 – regualr maintenance



Some concerns

- Gaspar (2009) refers that despite the relative simplicity of the service life concept, the service life is extremely difficult to predict or simulate through models, since it **“depends on the definition of acceptance criteria, which varies to the time, place and the stakeholder and even with the social, economic, political, aesthetic, environmental context of the building under analysis”.**

In real life....

- A study performed by Aikivuori (1999) shows that in only 17 % of the situations, the decision to intervene is taken based on the building's deterioration and in 44 % of cases maintenance actions are performed based on subjective criteria.
- This study also concludes that, when the decision to intervene is based on technical criteria only, depending on the building's degradation condition, the rehabilitation action takes place later than it would if the criteria were subjective (e.g. due to the aesthetic criteria).

Service life categories

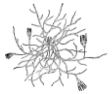
Regardless of the variability of the acceptance criteria, the service life of buildings can be distinguished into three main categories:

- physical service life;
- functional service life;
- economic service life (Marteinsson 2003).

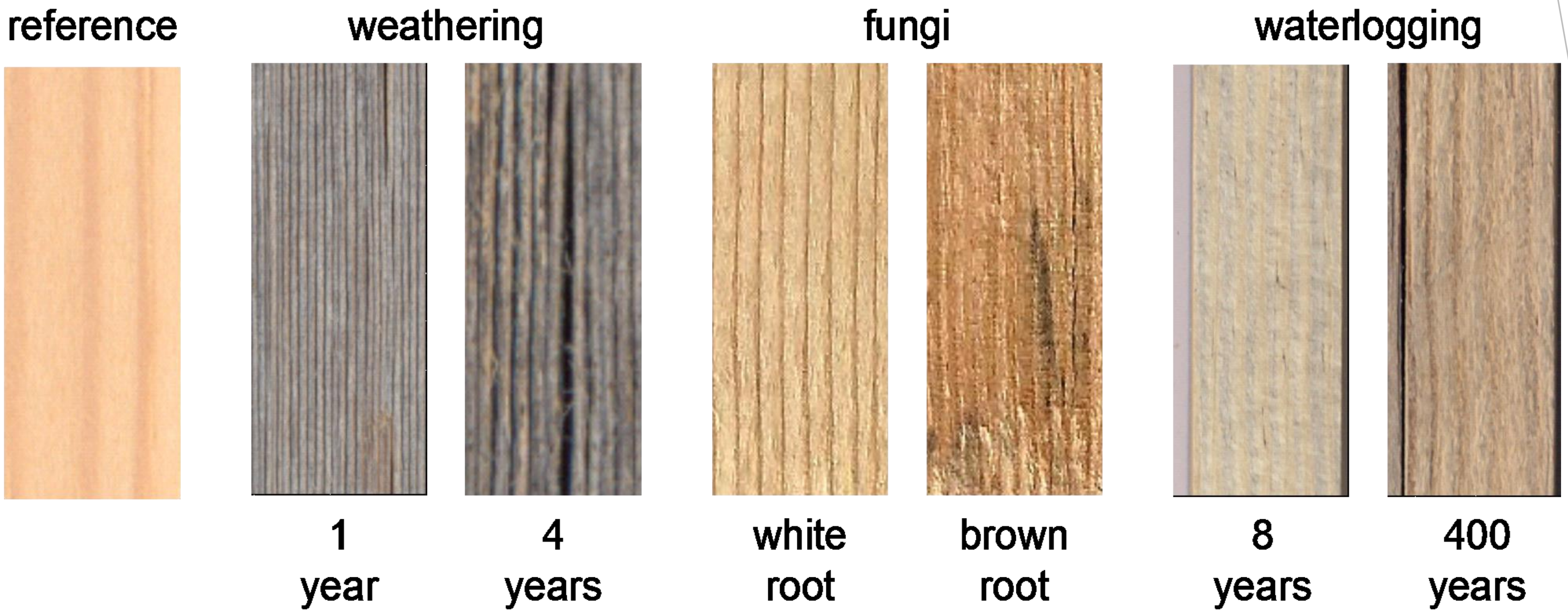
Physical service life

- The physical or technical service life is related with the **deterioration of the materials and building elements**. The deterioration of the construction elements occurs systematically, which implies that its failure rate increases over time
- The physical deterioration of buildings is **mainly due to the action of the degradation agents (whether physical, chemical or mechanical) and the natural ageing process**. In several situations, design and construction errors, or the application of inadequate materials, can contribute to the reduction of the physical service life of buildings

Degradation processes during service life

degradation type	weathering	decay	waterlogging	insects activity	vandalism	fire	flood	earthquake
process	oxidation hydrolysis erosion cracks abrasion fracture	depolymerization oxidation hydrolysis reduction	oxidation hydrolysis swelling shrinkage	depolymerization chewing	abrasion, cracking fracture	dehydration oxidation hydrolysis	swelling shrinkage freezing cracking	fracture cracking
causes								
properties	color gloss roughness cracks mold	color gloss density mech. properties	color gloss density mech. properties	color density mech. properties	color cracks	color gloss density mech. properties	color gloss density mech. properties	mech. properties
aesthetic	✓	✓	✓	✓	✓	✓	✓	✓
functionality		✓	✓	✓		✓	✓	✓
safety		✓	✓	✓		✓		✓

Material apperance



Weathering

- Used to define the slow degradation of materials exposed to weather (e.g. solar radiation, cyclic wetting, atmospheric temperature and relative humidity changes, environmental pollutants and certain microorganisms).
- The rate of weathering depends on timber species, function of product, technical/design solution, finishing technology applied but most of all on the specific local conditions.
- The degradation rate is generally slow; about 4 mm per century in case of typical softwood species (pine) and 6 mm for some hardwood species (alder).
- The process leads to a slow breaking down of surface fibres, their removal and, as a consequence, a roughening of the surface and reduction of the glossiness. Under extreme conditions, timber may deform, check, split and/or pull away from fasteners.
- The formation of discontinuities on the wooden surface can cause penetration of the wood-decaying biological agents and influence mechanical performances of the load-bearing members.
- The other significantly changing parameter, very important in terms of aesthetic considerations, is color. It is mostly caused by photodegradation of lignin and wood extractives in middle lamella.

Decay

- White-rot and brown-rot fungi are the most destructive microorganisms of wood.
- They are active only in the presence of oxygen and when wood possesses specific moisture content (20% ÷ 80%) for a sufficiently long period.
- Fungi degrade wood according to their specific enzymatic system.
- Brown-rot fungi have limited impact to lignin structure; however, they easily degrade polysaccharides. The wood becomes darker as results of brown-rot attack and cracks along and across the grain frequently appear. The strength loss occurs faster than weight loss in wood infested with brown-rot, thus being particularly insidious for the safety of timber structures.
- White-rot fungi have capability to degrade primarily lignin but also other wood cell components (cellulose and hemicellulose). According to Winandy and Morrell (1993), white-rot fungi had no measurable effects on specific gravity or equilibrium moisture content and had only minor effects on bending properties. The visible sign of their presence is a spongy texture of wood without cross cracks.
- Soft-rot fungi are the main wood degraders when wood is saturated with water, but oxygen is still available. They possess cellulase as main enzyme; therefore, they easily degrade cellulose. They weaken the structure of secondary wall, but the middle lamella between cells is not affected. Soft-rot degradation can result in extremely poor strength characteristics

Waterlogging

- Waterlogged timber elements are wooden items buried in the ground or submerged in water such as foundation pillars and poles.
- Wood exposed to waterlogging conditions slowly decomposes as a result of a complex interaction between the environment and the wood itself.
- Bacteria, fungi, temperature, pH, oxygen and water are the main factors influencing the presence and speed of biological, physical and/or chemical deterioration.
- Degradation slows (or stops) while organic materials are still saturated with water and when the oxygen level is reduced. However, some stages of decomposition occur even in anoxic environments, where bacteria are the main wood degraders.
- Bacteria first penetrate rays and degrade pit membranes in the outer layers of tracheids. Degradation effects become already evident after several months of bacterial activity.
- The appearance of wood varies as a consequence of waterlogging. Wood may become soft and crumbly, and cracks and splitting may appear, especially between growth rings, in a longitudinal direction.

Material apperance

Insects

- Wood destroying insects lay their eggs in cracks in the wood. Their larvae feed on wood, altering its appearance and mechanical properties. They develop their life partly or fully in the natural biological environment of wood, seriously affecting its basic qualities and characteristics.
- Some borers can cause considerable destruction to timber especially when the sapwood with lots of moisture contents is used. These borers are generally beetles which destroy the wood during larval stage by burrowing and producing a network of galleries which may considerably weaken the timber.
- Termites are more hazardous to wooden building structures and contents. They eat anything with cellulose; hence thrive on anything with cellulose including live and dead wood. They live in colony hence destroy everything by attacking in swarms. Termites feed wood generally from the inside out, so damage wood is hard to find before severe damage occurs. Wood eating termites are classified according to their living and feeding habits: dampwood, subterranean and drywood termites.

Fire

- As wood reaches elevated temperatures, the different chemical components undergo thermal degradation that affect the performance of wood.
- The extent of these changes depends on the temperature level and length of time under exposure conditions.
- Permanent reductions in strength and modulus of elasticity can occur at temperatures >65 °C, with the amount depending on the temperature, pH of wood, moisture content, heating medium, exposure period, chemical treatment, and species
- When wood is exposed to high temperatures it develops an insulating layer of char that retards further degradation of the wood.
- The load-carrying capacity of a structural wood member depends upon its cross-sectional dimensions. Because of the low thermal conductivity of wood, the temperature 6 mm inward from the base of the char layer is about 180°C. This steep temperature gradient means the remaining uncharred cross-sectional area of a large wood member remains at a low temperature and can continue to carry a load

M.A .Dietenberger and L.E. Hasburgh (2016) Wood Products: Thermal Degradation and Fire

Flood

- Timber and wood based products that have been totally immersed in water for prolonged periods will not decay or be subject to fungal deterioration due to lack of available oxygen.
- When the water has receded, it is important to clean the timber as soon as possible of all silt and mud etc. and then allow the timber and wood based products to thoroughly dry out as quickly as possible with good ventilation.
- If timber or wood based products remain damp or wet for prolonged periods and air (oxygen) is available, mould (dark staining) and eventually decay can occur, particularly in low durability timber such as untreated pine.
- Timber and wood based products that have been saturated will swell. When these products dry out they will shrink.
- The amount of swelling or shrinkage will be dependent upon the type and species of timber or type of wood product and time exposed to water

Guide to Assessment and Repair of Flood Damaged Timber and Timber Framed Houses (2015)

Earthquake

- Earthquakes generate complex, time-varying ground motions in three dimensions
- Vertical ground motions generate forces that add or subtract to gravity, and safety margins inherent in the gravity load-carrying system helps prevent damage.
- When the ground moves horizontally, it accelerates the building, generating forces in each element of the building in proportion to its mass. The lateral force induced by earthquake ground motions is termed “shear.”
- The roof and floors act as deep beams (“diaphragms”) to collect these forces and deliver them to the wood-framed walls, where the wall sheathing – typically gypsum board, stucco or plywood – acts in shear to transfer the forces to the foundation.
- Overall, the building acts as a stiff box-like structure. The strength of the building depends upon the strength of the sheathing and connections, acting in a continuous load path. Roof and floor diaphragms must connect properly to walls, and the base of the walls need a strong positive connection to the foundation.
- The strength of wood depends on the direction of its grain, defects in wood members such as splits and knots, and moisture content. Modes of failure in wood structures include nail bending and slip, sliding and overturning of wall piers, shear failures in wall sheathing, various connection failures, and crushing of boundary members

Graf W. Woodframe Buildings (2008)

Vandalism

- Vandalism is "action involving deliberate destruction of or damage to public or private property“
- There is always the challenge of balancing visual aesthetic and robust performance while selecting of building materials.
- Coatings, treatments and preventative measures can protect a material from vandalism. Examples:
  - sacrificial polymer coatings are applied to cast stone to allow for chemical cleaners to be used to remove graffiti, without dulling the surface.
  - Anti-skate deterrents can be fitted to benches and furniture with a linear profile that is ‘grindable’, although these aren’t always popular because they can detract from the desired visual impact of the installation.
  - Timber is often varnished and thus protected from graffiti and, at worst, knife damage can be filled and sanded.
  - Steel can be polished and aluminium anodised to provide greater damage resistance in particularly challenging areas.

http://www.marshalls.co.uk/commercial/blog/article-vandalism-8211-choosing-the-most-resistant-materials-2370

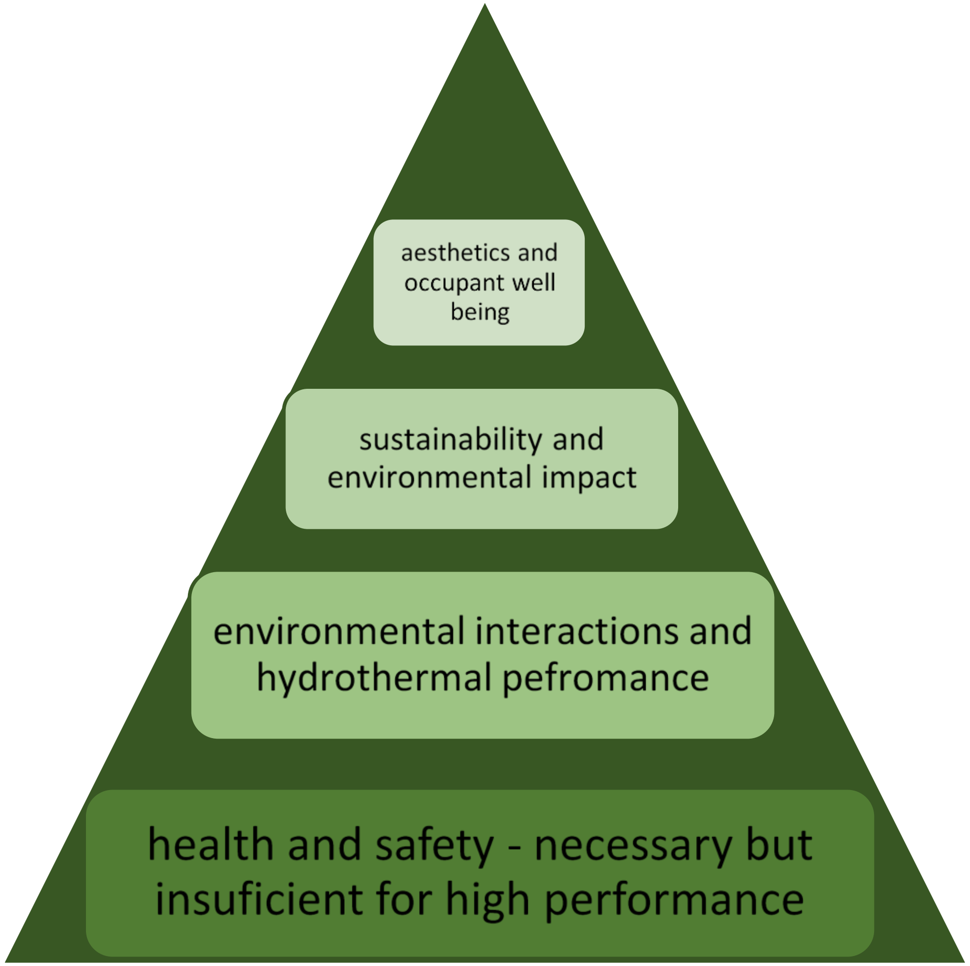
Functional service life

- Related to the expectations and demands of users.
- The factor that should be considered while designing of building are trends or fashions to use certain type of materials (Ebbert and Knaack 2007).
- In this case motivation for façade (or other elements) replacements will not be dependent on their in-service performance but will be rather stimulated by personal motivation to follow certain tendencies.

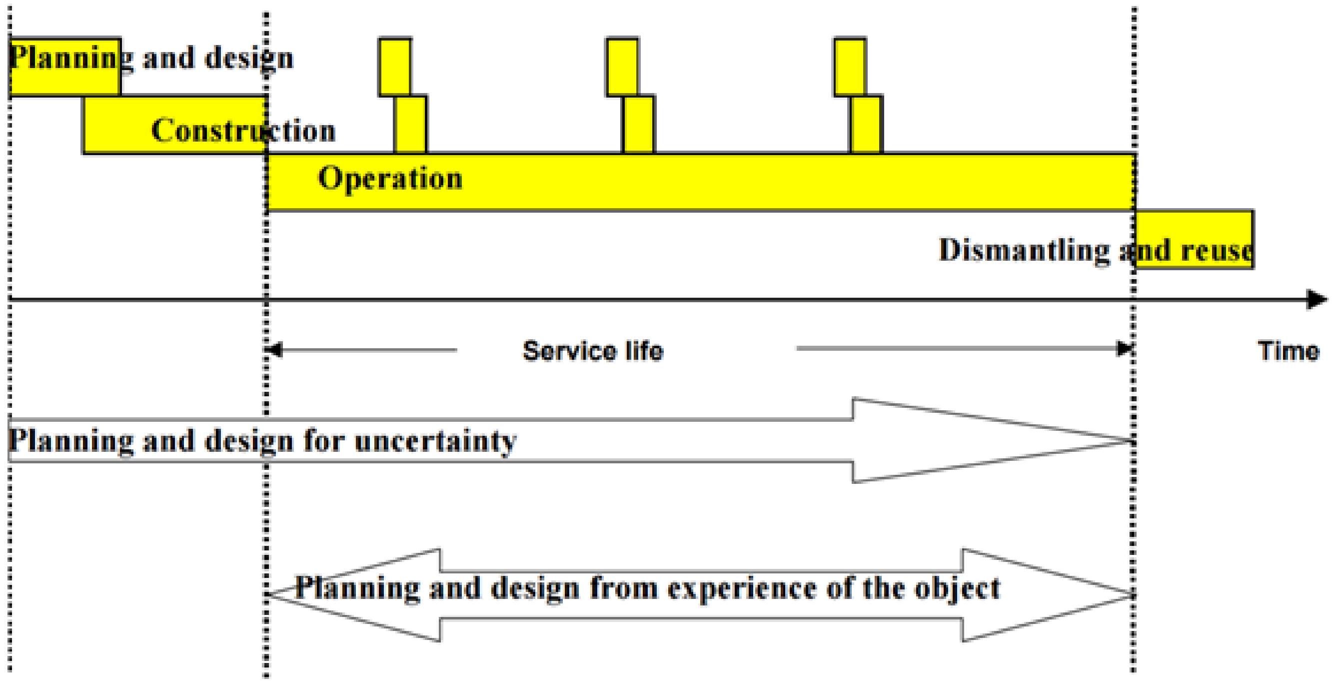
Economic service life

- defined as the **time elapsing since the construction is placed into use until the instant that it is replaced by a more profitable solution**.
- buildings do not reach the end of their economic service life while the cost/benefits ratio is more attractive than the alternatives.
- in this case, the end of the **economic service life is reached when the cost of replacing an element by another is lower than that of maintaining the existing one**.
- over time, and with the emergence of new constructive solutions (more economical, more durable and requiring less maintenance), buildings became economically obsolete.

How about aesthetics?



Methodologies for Estimated Service Life calculation



B. Marteinsson (2005) SERVICE LIFE ESTIMATION IN THE DESIGN OF BUILDINGS A DEVELOPMENT OF THE FACTOR METHOD (KTH PhD thesis)

Theory and practice

Theory is when you know everything but nothing works.

Practice is when everything works but no one knows why.

In our lab, theory and practice are combined:

nothing works and no one knows why…

Factor method

Addresses the methodology proposed in the international standard for durability (ISO 15686: 2011) for service life prediction of buildings and components

Estimated service life (ESL) can be calculated the by multiplying of Reference Service Life (RSL) by number of factors

$$ESL = RSL \times Factor\ A \times Factor\ B \times Factor\ C \times Factor\ D \times Factor\ E \times Factor\ F \times Factor\ G$$

A – quality component, B – design level, C – work execution level, D – indoor environment, E – outdoor environment, F – usage conditions, G – maintenance level.

Factor method examples

- Classic approach: estimates the service life of claddings in a purely deterministic way. In this approach, the durability sub-factors are quantified as absolute values;
- Stochastic approach: proposes a probabilistic approach to the factor method, assigning a probability distribution to each of the durability factors. In this method, the estimated service life of each case study is given by a probability distribution function.

A. Silva et al., (2016) Methodologies for Service Life Prediction of Buildings, Springer

Advantages / constrains

- simple
- neglects the fact that the degradation phenomenon is variable over time;
- calculate the service life by considering characteristics of the construction element;
- ignore the degradation condition of the single element;
- small variations in the quantification of the durability factors can lead to a very large range of estimated service lives;
- leads to an absolute value and does not provide information concerning the dispersion of the results (Silva *et al*. 2016).

Deterministic methods

- mathematical and/or statistical formulations are used to describe the relationship between the degradation factors and the building condition.
- This method intends to obtain the function that best fits a set of random data.
- Such approach is efficient when used in large and representative samples.

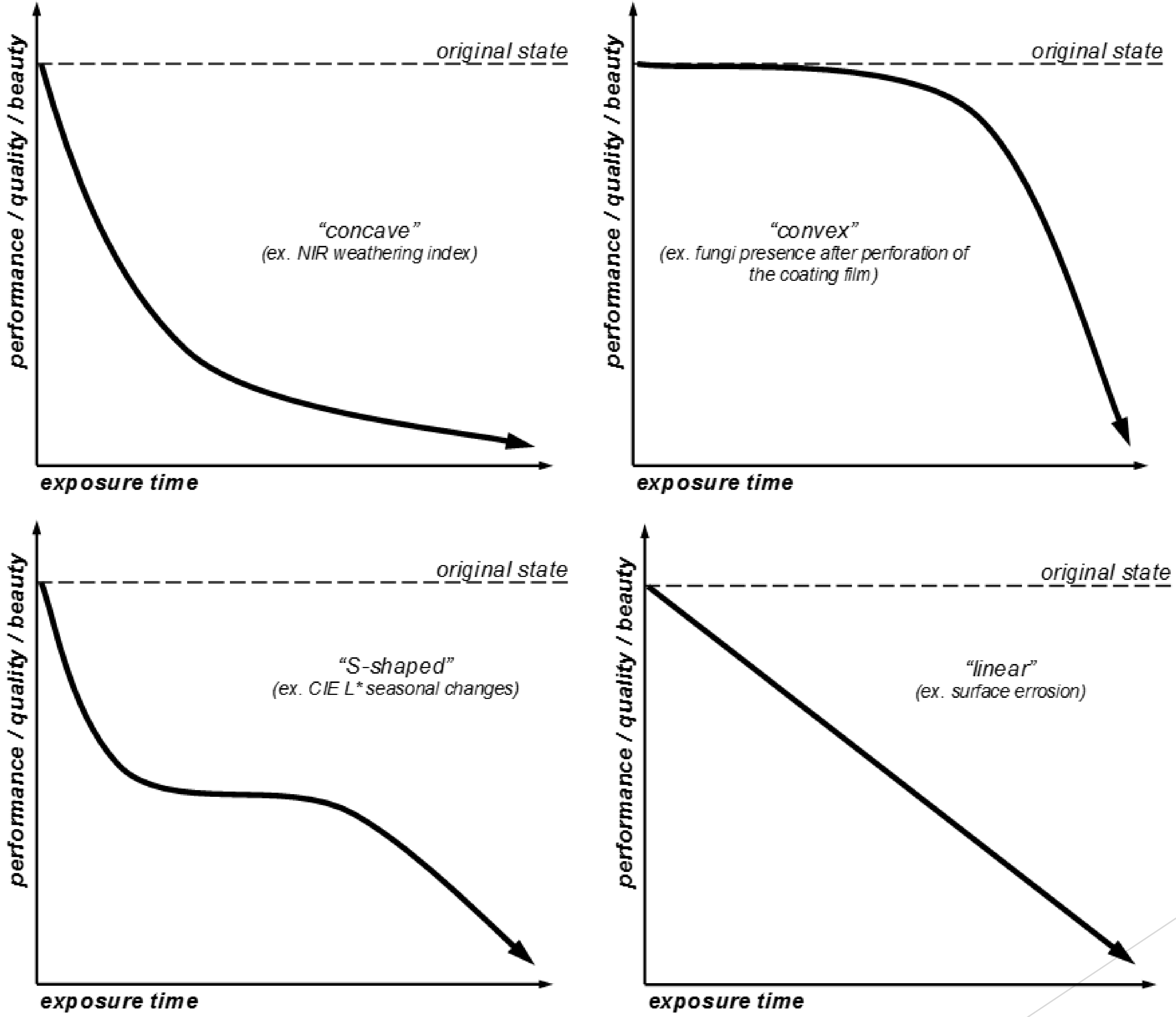
Deterministic methods examples

- Simple regression analysis (linear and non-linear): these models are based on degradation curves, which express the loss of performance of the constructive elements over time.
- Multiple linear regression analysis: where the theoretical concepts associated with this tool are applied to the service life prediction of façade claddings, evaluating the most significant variables to the description of the degradation of the claddings analysed. Based on this methodology, the causal relationships between variables and their implication on the estimated service lives of the claddings are analysed.
- Multiple non-linear regression analysis: addresses the application of various non-linear models to the service life prediction of claddings.

A. Silva et al., (2016) Methodologies for Service Life Prediction of Buildings, Springer

Deterioration patterns (deterministic methods)

- a concave pattern associated with abiotic agents (weathering), whose deterioration develops rapidly at an early stage (first few months), but tends to slow down over time
- a convex pattern associated with the physical, chemical or biological phenomena, which act slowly initially but whose action is felt cumulatively (e.g mould presence after failure of coating)
- an “S”-shaped pattern associated with a degradation phenomenon whose intensity changes over time (e.g. ΔE parameter due to seasonal variation of weathering intensity);
- a linear pattern associated with degradation agents that act permanently (eg. surface erosion).



performance / quality / beauty
original state
"concave"
(ex. NIR weathering index)
exposure time
performance / quality / beauty
original state
"convex"
(ex. fungi presence after perforation of the coating film)
exposure time
performance / quality / beauty
original state
"S-shaped"
(ex. CIE L* seasonal changes)
exposure time
performance / quality / beauty
original state
"linear"
(ex. surface errosion)
exposure time

Scholastic methods

- allow establishing an empirical relationship between variables through the estimation of parameters whose statistical robustness can be tested.
- Those methods model uncertainty and provide information about the risk of failure and the most probable failure time of building elements based on their characteristics.
- Such information can be used in the definition of maintenance strategies for different parts and elements of the building

Scholastic methods examples:

- Logistic regression: evaluates the probabilistic transition between degradation conditions over time and according to the façades' characteristics, also providing the probability of the claddings to reach the end of their service life;
- Markov chains: is based on a principle of "memorylessness". In other words the next state of the process only depends on the previous state and not the sequence of states. The application of this model produces similar results to those obtained by logistic regression, still allowing evaluating the mean time of permanence in each degradation condition.

A. Silva et al., (2016) Methodologies for Service Life Prediction of Buildings, Spring

Computational methods

- applies computational techniques, allowing simulating automated intelligent behaviors
- allow obtaining the estimated service life of façades according to the variables considered as explanatory and statistical relevant in the degradation phenomena.

Computational methods examples

- Two approaches are used to find the nonlinear function that best fits the dataset to be modelled, using a learning process based on experiences and examples: artificial neural networks (ANNs) and fuzzy systems (fuzzy logic) (Silva et al. 2016).
- ANN applies previous knowledge related to the reality that one intends to model, transforming raw data into models easy to apply.
- Fuzzy logic based models are able to deal with the uncertainty associated with complex phenomena such as degradation of construction elements with higher precision and better performance than conventional linear models. Such methods are particularly useful while dealing with inaccurate data and with samples with outliers

Normative Framework for the Service Life Prediction of Buildings

- First normative document addressing the durability and service of life of buildings and their components: the Japanese guide developed in 1989, later translated to English under the title "(Japanese principal) guide for service life planning of buildings"
- In 1992, the British Standards Institute published standard 7543 for durability "British guide to durability of building elements, products and components" (BS 7543: 1992) that lists various methods to estimate the service life of construction products:
  - through past experience, using similar buildings, subjected to similar use and climatic conditions;
  - by evaluating the degradation level of the elements in a short period of use or exposure, estimating the value for which the durability limit is reached;
  - through accelerated ageing tests, which is a complex approach, due to the need to simulate real situations that have many variables to be considered.
- BS 7543 proposes defining the **service life of buildings as a function of the type of use; buildings are classified into five categories**: temporary buildings, with a service life of less than 10 years; short-lived buildings, such as storehouses, with a service life of at least 10 years; average buildings, such as industrial buildings, with a service life of at least 30 years; current buildings, such as new housing, hospitals and schools, with a service life of at least 60 years; long-living buildings, such as public buildings, with a service life of at least 120 years.

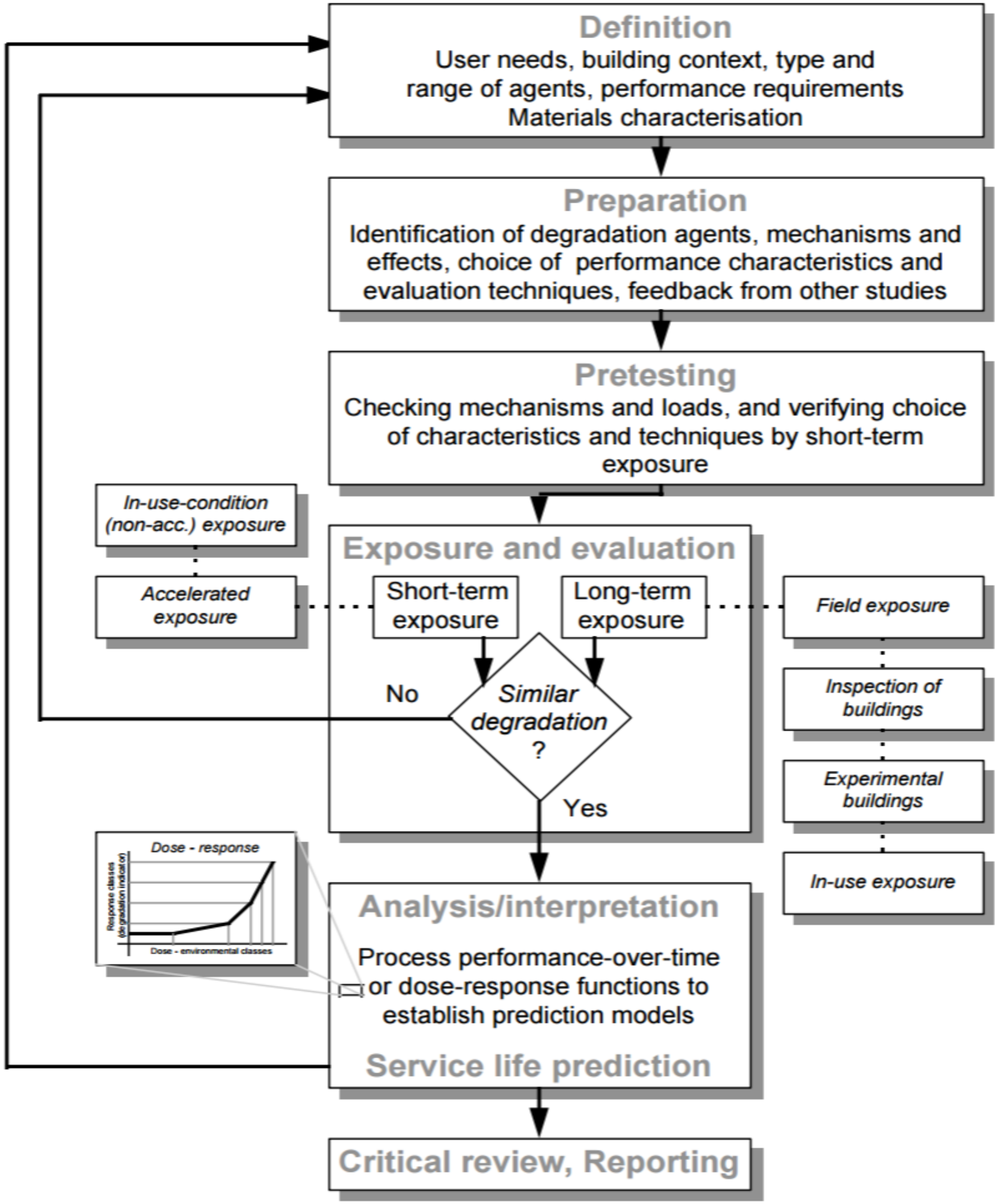
ISO

- proposed an international standard for the service life prediction of buildings, based on a recommendation of RILEM (International Union of Testing and Research Laboratories for Materials and Structures).
- Currently, the ISO 15686 "Building Service Life Planning" standard has eleven parts that define the general principles, framework and procedures of the proposed service life prediction methodology.
- Moreover, this standard defines the functional performance criteria to be fulfilled in the design phase and throughout the buildings' life cycle, which ultimately contribute to the definition of the end of the service life of the elements under analysis

ISO 15686

- The ISO 15686 standard is one of the most relevant information sources regarding service life prediction and is composed of the following parts:
- ISO 15686-1: 2011 (General principles);
- ISO 15686-2: 2012 (Service life prediction procedures);
- ISO 15686-3: 2002 (Performance audits and reviews);
- ISO 15686-4 (Data requirements/data formats);
- ISO 15686-5: 2008 (Life cycle costing);
- ISO 15686-6: 2004 (Procedure for considering environmental impacts);
- ISO 15686-7:2006 (Performance evaluation for feedback of service life data from practice);
- ISO 15686-8: 2008 (Reference service life and service life estimation);
- ISO 15686-9: 2008 (Service life declarations);
- ISO 15686-10: 2010 (Using requirements for functionality and ratings of serviceability during the service life);
- ISO 15686-11 (Terminology).

Systematic methodology for service life prediction of building components. (From ISO 15686 Part 2)



Data Acquisition Methods to Establish Service Life Prediction Models

Methodologies for the service life prediction of structures can be based on:

- previous experience;
- the performance of the materials analyzed under similar conditions;
- laboratory tests, e.g. accelerate ageing tests;
- mathematical models to describe the physical and mechanical degradation processes;
- through the application of reliable stochastic models.

Sustainability aspects

- **Form and function of buildings are being changed constantly due to the development of technology, economy and new styles in architecture**
- The cost of modifications made in buildings during their 50-year operation are twice as high as the cost of the original construction
- Premature dismantling of structures is detrimental to the environment, due to the discharge of used materials to landfills and the need for the manufacture of new ones.
- The anticipation of future adaptations of buildings at the design stage would certainly result in financial savings

Adaptability of buildings

- susceptibility of buildings to changes
- It allows buildings to be effectively used far beyond the planned life span of the original structure

Adaptability in architecture means:

- accessibility (design of spaces accessible for all stages of use and different physical conditions),
- open plan (enables variable interior plans – mainly in offices),
- expansiveness (interactivity, reactivity to environmental changes through diversified mobility, location and geometry),
- effectiveness (relating to function and susceptibility to maintenance works).

How to improve durability in sustainable architecture

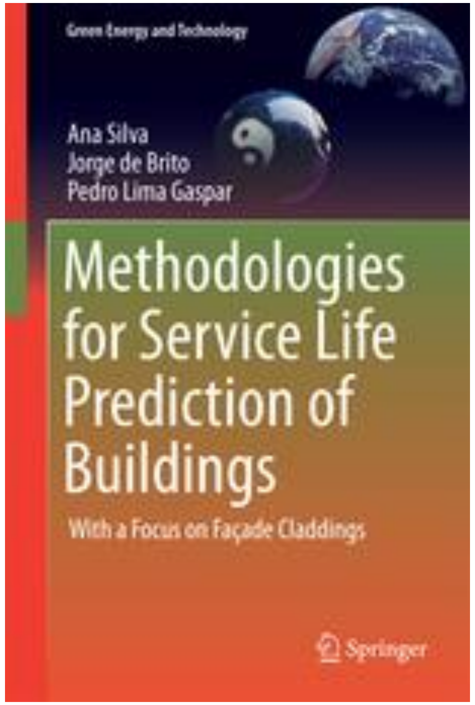
- functional effectiveness (low cost and simple technologies)
- adaptability (easy change in function and potential for relocation in the future)
- easiness of dismounting and separation of combined materials or components for reuse
- selection of materials susceptible to recycling
- ability for maintenance
- transparency (clarity of applied technical solutions and easy inspection)
- evaluative capacity (possibility of future improvements)
- dynamism of systems allowing for ecological risks instead of their stability

Technologies and materials in sustainable construction

- Preferred technologies should correspond with the idea of adaptability which is facilitated by orderly geometry of plans, modular and durable structure.
- Recommended are large-span pre-stressed, prefabricated systems.
- Priority is the application of building technologies characterized by low embodied energy and high durability
- The most advantageous materials for sustainable constructions are those considered most ecological and most durable
- The durability of buildings or their elements depends mostly on the quality of their maintenance

Future readings

- A. Silva et al. (2016) Methodologies for Service Life Prediction of Buildings, Springer
- P. J. Hovde, K. Moser (2004) Performance Based Methods for Service Life Prediction, RILEM
- ISO 15686 (2011) Buildings and constructed assets - Service life planning



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BIO4ever

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