Biodegradation of Cultural Heritage

State of the Art, Finland

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1. Introduction

The objective in construction of buildings has always been to make sound and well functional buildings. A building, however, is a long-lasting product compared with many other utility goods, and different kinds of ageing and damage caused by several reasons may occur. There is different types of buildings and structures, and the performance of the whole buildings depends on many factors: materials, structures, coatings, environment, climate, type of use, service etc. The biodegradation of building and materials is caused by moisture exceeding the moisture capacity of materials and structures.

The service life of a building varies, and in the long history of buildings, different technology has been introduced and the problems in the function of these technologies have been seen, unfortunately, during the use of the buildings. The causes of damage may be construction errors, errors made during repair, or incorrect use, which usually is the result of missing or poor operating and service instructions. Examples from past years include defaults in repair and restoration of floors of old log houses, formaldehyde and radon problems in indoor air. Rot damage, which may cause structural problems, has traditionally been recognised as a problem in a building. In general, mould has not been considered to be very hazardous, although experts in the field have known about its adverse effects for a long time. On the other hand, good, fresh indoor air has always been a goal. The technique to attain good indoor air varies, but surely mould or microbe growth have not belonged inside a building in the previous decades. Even very old guides in the field of construction have dealt with these basic questions. Mould growth, however, has been a natural process in outside structures.

2. Natural aging of the buildings and moisture, mould and decay problems in buildings

During the service life of buildings, natural aging of materials due to different chemical, physical, and biological processes can take place. In damage cases, more severe changes of material are associated. Wood is a traditional building material in Finland and biodeterioration is important critical factor for durability of wood and wood based products. The service life of timber in a structure depends primarily upon the humidity and moisture conditions during the use of wood materials. The humidity and temperature conditions regulate the presence of wood attacking organisms. Also natural durability of wood, the properties of other materials, preservatives, surface treatments, structures and maintenance have a significant role in the activity of organisms and the durability of wooden structures.

Mould and decay problems in buildings are caused by moisture damage: water leakage, convection of damp air and moisture condensation, rising damp from the ground and moisture accumulation in the structure. During recent years moisture problems in houses seem to have been increased in Finland. This can be partly caused by the added knowledge and users are afraid of the problems. Moisture, mould and decay problems, however, can be very complicated in buildings. In buildings, mould fungi cause problems in different structures and materials: roofs, attics, basements, floors and walls. Apart from wooden material, surfaces of many other materials support growth of microbes and mould problems are more common than decay damage.

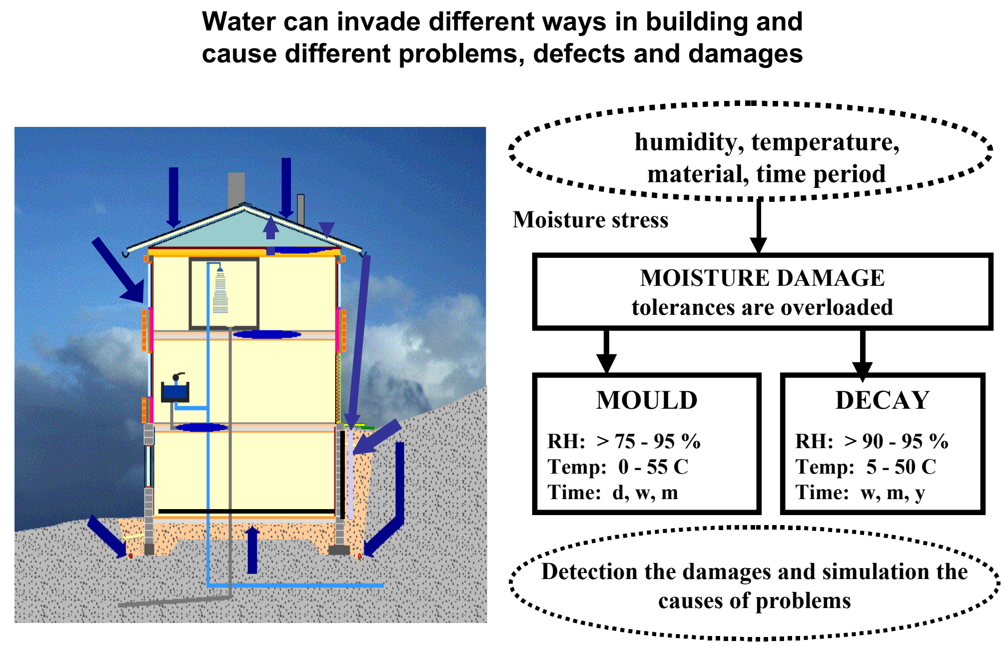

Figure 1. Moisture damages are causes to mould problems and decay damages.

The typical organisms found in old buildings or damage cases in Finland are:

- fungi: mold, bluestain and rot fungi
- bacteria: actinobacteria and streptomycetes
- insects: beetles and ants

2.1 Mould fungi

The growth of mould fungi on materials in buildings is often an early indication of increased humidity or moisture levels, but the problems caused by fungi in buildings vary depending on the type of fungal attack. Problems caused by mould fungi are mainly discolouration, odour and health disadvantages. The typical mould fungi in water damaged Finnish building are *Ascomycetes* fungi. *Alternaria*, *Acremonium*, *Aspergillus*, *Aureobasidium*, *Fusarium*, *Oidiodendron*, *Penicillium*, *Stachybotrus*, *Trichoderma* species. Mould fungi do not significantly affect the strength of materials. The surface of materials can be damaged caused by the cellulolytic activity of some discolouring fungi, e.g. *Trichoderma* spp., *Aureobasidium pullulans* and *Ghaetomium globosum*. Mould fungi cause several problems in the buildings: stains, smell, health problems. Also in the sound buildings, however, mould growth can be found on facades, attics and crawlspaces, which are typical structures exposed to high humidity conditions and attack by mould fungi.

2.2 Decay fungi

Different classifications are used for the decay fungi in practice. Often, three different decay types are classified and found also in buildings brown rot, soft rot and white rot. Most of the brown rot and white rot fungi belong to *Basidiomycetes*, but some belong to *Ascomyctes*. Most of the soft rot fungi belong to *Ascomycetes* and *Fungi Imperfecti* e.g. *Chaetomium globosum* and *Phialophora hoffmannii*. In buildings suffering from excessive moisture loading, brown rot is the most common decay type. Among the typical brown rot fungi which cause the most serious damage in buildings in temperate climates are *Serpula lacrymans* (dry rot fungus), other *Serpula* and *Leucogyrophana* spp., *Coniophora puteana* (cellar fungus), different *Antrodia or Poria* species, *Gloeophyllum sepiarium*, *Gloeophyllum trabeum*, *Paxillus panuoides* and *Lentinus lepideus*. Especially the dry rot fungus *S. lacrymans*, which is able to transport water through mycelial strands from the source of moisture into dry wood, has been reported to cause large and destructive damage in buildings and in different materials in temperate climate regions, also in Finland.

According to the studies perfomed at VTT Building technology, the brown rot fungi, e.g. the dry rot fungus *Serpula lacrymans* and the cellar fungus *Coniophora puteana*, cause damage especially in floor constructions. In roofs the damage is more often caused by mould fungi or other brown rot fungi such as *Gloeophyllum trabeum*, *G. sepiarium* and *Fibroporia* spp. However, in decay damage, several organisms are often involved: bacteria, mould fungi and decay fungi. Bacteria and algae are usually first colonizers of materials in wet conditions.

2.3 Insects

Wood destroying insects usually utilize wood as a foodstuff, either directly or indirectly. Many insects are dependant on partially decayed wood, live in symbiosis with wood destroying fungi. Some insects are only boring wood to make nests without feeding on it, e.g. carpenter ants. In Finland, the *Anobidae* are the most serious wood boring beetles. *Hadrobregmus confusus* and *Hadrobregmus pertinax* are typical beetles in old wooden houses which are attacked by rot fungi. *Anobium punctatum* has become more uncommon when the relative humidity of inside air is lowered due to better heating and ventilation systems in buildings. This beetle can not tolerate the cold winter in Finland. *Hylotrubes bajulus* exist only on some islands of the Turku and Ahvenanmaa archipelago. In Finland the jewel beetle *Buprestis haemorhoidalis* and carpenter ants cause local damages in wooden constructions.

3. Management of building damages

3.1 Humidity and moisture control

In buildings the performance of wood and other materials is greatly dependant on structural provisions. The main principal of structural protection is to eliminate or diminish the risk of fungal decay by designing and maintaining the constructions so that they remain constantly dry or are allowed to dry rapidly after wetting. The moisture content of wood should remain under 20 - 25 %. In the cold climate of Finland, biological deterioration can then be almost totally prevented, because the risk of insect attack is small. RH of 80 – 90 % is a critical humidity level for growth of mould fungi, but also temperature, exposure time and surface of materials are important factors. RH 90 - 95 % is often critical level for the development of decay at 10 – 40 °C.

Water supports germination, hyphal growth and sporulation of fungi. Air humidity and microclimate is critical for sporulation, spore release and survival of spores. The major factors affecting the microclimate are moisture migration and accumulation in materials, composition, texture and surface quality of the material, temperature, humidity, water condensation and air circulation. In buildings the dry rot fungus, however, can transport water and cause more serious damage due to the extensive mycelial spread from a moisture source to dry wood. However, dry rot fungus is quite sensitive to extreme conditions and the use of high temperature for the eradication of the viable dry rot from houses can be sufficient.

For understanding the processes of mould and decay in wooden material, mathematical models are derived at VTT. The models describe the risk of mould and decay development in relation to humidity, temperature and duration of exposure (Figure 2).

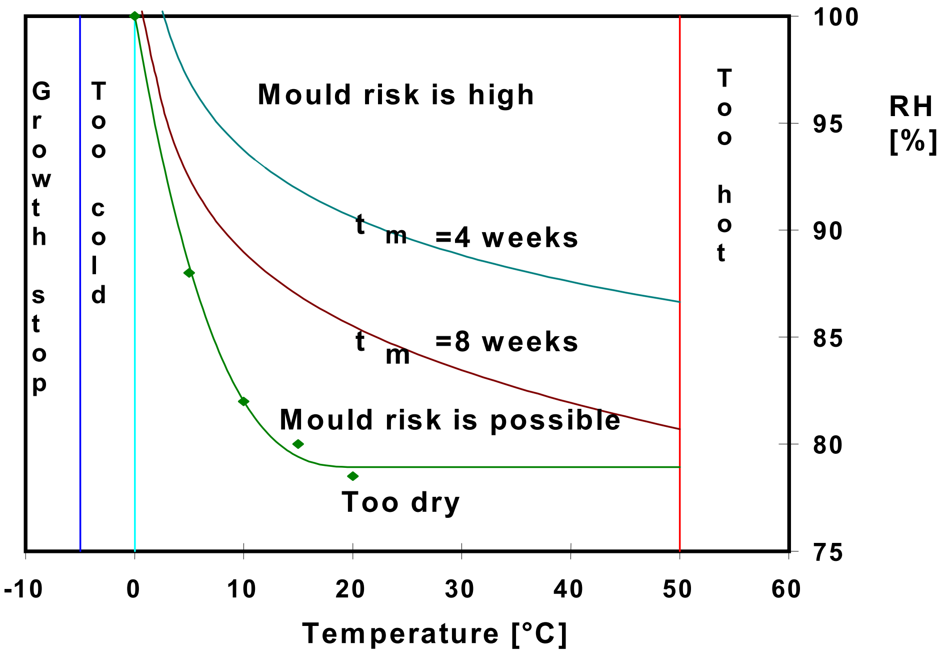

Figure 2. Conditions favourable for initiation of mould growth on wooden material as a mathematical model. RH, temperature and exposure time have to be optimal for development of problems. Decay can be developed, if RH is above 90 % or wood moisture content is above 25 - 30 % for longer time.

The principles of structural protection in wood building have been known and followed since old times. However, they are sometimes neglected with resulting decay hazards. Most moisture damage in a building can be avoided if a few basic issues are taken into consideration during construction. According to feedback information, wet rooms, floor structures, some roof construction and the joint between the footing and the bottom edge of exterior walls are the most difficult places in a building. Careful design, construction and maintenance of these structures will guarantee long life for a building.

3.2 Chemical treatments and modification processes to protect materials

The preservation of wood with chemicals is a conventional technique to add the durability of wood. Different type of chemicals has been used. Tar and creosote oils are very old preservatives. Tar oil is used for protection of shingle roofs, boats, fences etc. It is actually a surface treatment method. In industrial wood preservation, different impregnation technologies are used. After 1950 pressure process and water based chemicals, like CCA preservatives, came into use in Finland.

To protect wood against water penetration, different paints and water repellents has been used. Ochre paints are very permeable paints; oil paints are less permeable. Permeability of many modern acrylate paints is higher than that of oil paints or alkyd oil paints, but the permeability is lower than that of ochre paints. Water penetration through a acrylate paint layer is higher than that through an oil paint, which can introduce problems in old facades.

During recent years number of studies and method development work have been directed to apply different modification technology to solid wood in order to improve the durability and behaviour of wood in adverse environments. The modification of wood can be directed to improve the dimensional stability properties, hardness properties and/or durability properties of wood against decay. Among the chemical modification reactions acetylation is one of the most studied, as this method has shown potential with minimum adverse side effects. Also resin compounds and tar oil derivatives has been studied.

Heat treatment of wood is very popular topic in Finland and in Europe at the moment. The basic of this technology is actually very old: wood was fire treated already in ancient times. Now research is carried out in the field by several European countries, research institutes and industrial parties.

Also new biocide treatments have been studied. According to research results, targeted biocides provide an efficient tool for designing of wood preservation. Targeted wood protection is efficient, safe in use, have low environmental impact and is designed to most suitable end use.

3.3 Structures

3.3.1 Wet rooms and floors

In wet rooms water is most often penetrated through inside surface or pipe leakage into the structures. Good waterproofing is essential regardless of whether the building is made of stone or wood. The walls and floor must be waterproof, which means joints and inlets must be carefully sealed. Good ventilation during and after use of the room removes moisture that places a stress on the surfaces in the room. In old buildings, the malfunction of wet rooms has caused severe mould, decay and insect problems.

In the old wooden buildings in Finland, the floor is often based on a cold ventilated basement. The floor of living rooms should be sufficiently high above the surface of the ground around the building and the foundation and surroundings of the building should be kept as dry as possible. If water is penetrated in the crawl base, the ventilation may not keep the floor dry. If ventilation caps are closed, severe decay problems have been found, e.g. dry rot damage.

The ground base floor is used in the old buildings. This type a floor is very sensitive for water damage and microbial growth. In the newer buildings, wooden beams are often based on concrete slab on ground. As insulation materials, moss, wood chips or mineral wool is most often used. This type of structure is often sensitive for moisture stress, and mould or decay damages has often been found due to water damage. For better function, the ground slab structures should have at least 50 mm of insulation below the bottom concrete slab. Waterproofing material, such as bitumen felt, should be placed between wooden and concrete parts. In conjunction with repair, bricks or concrete blocks should be used to raise the wooden supporting rails of a wood floor above the level of the lower concrete slab. Waterproof material should also be placed between the brick or concrete block and the wood structure. The wooden parts of interior walls should always be above the finished floor and insulated from the concrete below by means of strips of bitumen.

3.3.2 Exterior walls and roof

Partial decay or insect damage is often found in the lower beam of exterior wall due to water penetration from the basement. Waterproofing material should be placed between the bottom beam of the wall and the basement. The lower structures of the exterior walls should not come into contact with the concrete or sand outside. Regardless of the structure of the exterior wall, a functional ventilation space should be left at the bottom edge of the wall to allow air to pass through the ventilation space behind the facade. In old buildings, however, no ventilation space exists.

The water vapour resistance of the material layer on the warm side of an open porous thermal insulation layer should be five times higher than that on the cold side. It is necessary to have a genuine air barrier in the envelope in order to be able to control the pressure conditions in buildings and to avoid the harmful water vapour convection from indoor air to the envelope.

A building’s functional roof and roof structure protect the building against rain. Rainwater is, however, often penetrated through the exterior wall in the inside structure. Wide eaves, long gutters and rainwater drainage systems protect the walls against water damage risk. Inlets, different levels, ridges and valleys of a roof are potential places of damage. Installation of an air barrier is always recommended in a wooden roof structure. In the Finnish climate it is typical that mould growth can begin in the autumn on the wooden surfaces in contact with outdoor air, when the temperature and relative humidity are high enough. The results of VTT show that, in most buildings, minor mould growth can be found in cold parts of structures regardless of the materials used.

3.3.3 Indoor air

There has recently been discussion about air permeability of buildings. Inside air quality, however, is primarily dependent on the ventilation system of a building. Regardless of what kind of ventilation system is used, it must be capable of exchanging a sufficient amount of air to prevent hazardous substances from accumulating indoors. This is very important especially in cold climate, and controlled air ventilation is needed to save the energy consumption.

If the interior surface of a building is made of porous material, such as wood or construction sheeting, they may accumulate moisture and possibly other gaseous substances. This can have an effect on the inside air quality. A prerequisite is, that the surface should not be coated or treated with an impenetrable material, such as a paint. Wooden material in interaction with indoor air will balance the variation of indoor air humidity when moisture load is varying. According to present knowledge in Finland, however, the best situation from the standpoint of ventilation is controlled entry of fresh, clean air into the rooms of a building and controlled exhaust of used air. Control of ventilation is improved if the outer shell is airtight, which means an airtight layer inside (an air barrier) and a wind barrier on the outside.

4. A building is an individual and whole unit

From the standpoint of the functioning of a building, it is important to design, construct and repair a building with overall functionality in mind. The structures should be functional, but the ventilation system, plumbing system and automation should support overall functionality. Even though separate parts and devices of a building function well independently, this does not guarantee proper functioning of the whole product. In this sense, simple, clear operating and service instructions are not the least important matters. They should be included in all types of buildings. Maintenance and upkeep are important from the standpoint of long-term functionality of a building. Most important is preventive maintenance, which helps in eliminating undesirable factors beforehand.

Moisture and biological damages in buildings are technical problems and therefore the experts of the building field must be used in studying and repairing them. In the most difficult cases, the co-operation of different parties (experts of the building field, health and building authorities and biology experts) is required. A repair plan of moisture and decay damages in buildings should be made based on the acquired information: how the cause of the damage should be removed and how further damage should be prevented, how extensive the repair work will be, what should be repaired and how. This will require close co-operation between experts, research scientist and companies.

The design of structural solutions and proper material choice, both for new and old buildings, needs to be developed in the future. Also proper analyses and reparation technology of mould, decay and insect damages are needed. Then it would be possible to agree to use only a good and proven basic solutions. In Finland, the Ministry of the Environment’s new moisture regulations and directives (C2) and related application instructions will provide a good base for constructing buildings that withstand moisture. For prevention of mould and decay reparation, several techniques can be and have been used.

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