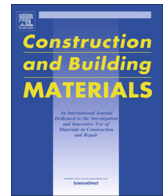




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Review

Mould growth criteria and design avoidance approaches in wood-based materials – A systematic review



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HIGHLIGHTS

- Approaches to indicate and represent mould growth are reviewed.
- Experimental results show discrepancies about mould governing factors and growth criteria.
- Mould models account for and represent differently the mould growth.
- Current standards and approaches provide unreliable representation of mould growth.

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ABSTRACT

This paper presents a systematic literature review about the development of criteria and models representing mould growth in wood-based materials. First, results from experimental research regarding factors governing mould growth are discussed; afterwards, they are used to analyse the comprehensiveness of current mould models. The review shows substantial discrepancies between criteria reported for mould growth. Moreover, mould models differ with respect to governing factors and their interrelations, applied methodology, experimental set-ups and nutrients, and how they express mould. Lastly, this paper proposes solutions that account for or reduce uncertainties related to the representation and design against mould occurrence.

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Contents

1. Introduction	78
2. Systematic literature review methodology	78
3. Literature review results: mould governing factors	78
3.1. The influence of humidity and temperature	78
3.2. The influence of the time-factor	79
3.3. The influence of type of material, surface and mould fungi	80
4. Literature review results – mould models	80
4.1. Summary of comparative studies investigating mould models	81
4.2. Comparison of minimum requirement for mould growth	81
5. Design avoidance of mould growth and conventional approaches	81
6. Summary and discussion	84
6.1. Disagreements regarding mould governing factors	84
6.2. Mould models – validity and comprehensiveness	85
6.2.1. The consideration of relative humidity, temperature and substrate	85
6.2.2. The consideration of the time-factor	85
6.2.3. The effect of the chosen methodology and experimental set-ups to establish mould models	85

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6.3. Research gaps in the literature.....	85
6.4. Limitations of current models and conventional approaches. Opportunities associated to probabilistic approach.....	86
Acknowledgements.....	86
References.....	86

1. Introduction

Mould is one of the problems associated with excessive humidity in wooden constructions, which can result in financial loss and unfavourable social problems such as discomfort and health risks [1–4]. Mould prevention is a conventional part of the timber constructions design; however, the repeated mould growth problems in buildings industry [5–8] suggest that the representation and prediction of this biological phenomenon are associated with large uncertainties. Additionally, the criteria used during the design stage need improvements.

Extensive research has been carried out during the last decades to understand and represent mould growth. Many studies have developed mould models opting for the mathematical representation of the mould growth and corresponding mould performance criteria. These performance criteria have improved by setting a threshold value to one governing factor [9–15], up to mathematical models dependent on several governing factors [16–19]. Despite a general agreement on the factors influencing mould activity, less consensus is found on their significance and how they are incorporated into the models. In order to evaluate the extensiveness and comprehensiveness of these models accurately, the mould phenomenon requires a thorough analysis, especially concerning what factors influence the growth and how. Therefore, in order to provide more clarity in this field and its application in building engineering, this paper proposes to:

- A) Conduct a systematic literature review to thoroughly:
 - Identify the mould governing factors and their influence in wood-based materials.
 - Provide a state-of-the-art of current mould models applicable to wood-based materials.
 - Analyse how the models incorporate governing factors in relation to the results as drawn from experimental and field studies.
 - Discuss the research gaps where advancement or development may improve the representation of mould.
- B) Discuss current design approaches in order to give an overview of how mould is considered in building engineering field.

2. Systematic literature review methodology

The literature review presented in this study is built upon an established research methodology [20] that ensures a comprehensive search process and systematic review of the relevant literature. This methodology originates from health and social sciences; however, its principles are applicable to other fields of study. This approach provides the tool for a transparent and reproducible research synthesis, thus offering greater clarity, internal validity and audibility [20].

The first step in the literature review process is to define the scope of the research, which allows focusing the research question [20]. In the present study, the research question opts to identify the criteria and representation for mould growth in wood-based materials as derived from the experimental analysis. The PICOC framework [21] is used to define the key concepts of the research (see

Table 1). Three electronic databases of peer-reviewed literature are used. Scopus, Web of Science and Engineering Village are relevant sources of information in this research area [22–24]. The keywords, operators and nesting combinations are presented in Table 2. The last search was performed in March 2016. The keyword “mould” is related to other fields, and it is necessary to insert several exclusion key terms. The searching scheme and exclusion criteria are shown in Fig. 1 and Table 3.

While screening the literature based on full content, cross-referencing methodology and author searching are used to check for additional literature. The final number of selected publications is 101. Subsequently, a data extraction process [20] is developed to identify common elements among individual publications. Table 4 shows the subgroups of the data extraction that structure the literature review results of the following two sections.

3. Literature review results: mould governing factors

The knowledge of the environmental requirements for mould growth is focused on its governing factors: humidity and temperature conditions at the material surface, exposure time and substrate [16,25–30]. Mould growth also depends both on pH-level of the material surface, which is directly related to the material, and the oxygen, which is always available [31–34].

3.1. The influence of humidity and temperature

Relative humidity (RH) is the most investigated criterion, considered the most decisive for mould growth and research mostly investigates the critical range 75–95% RH [31,35–38]. Table 5 chronologically presents the summarized results of minimum relative humidity at which mould can grow. The reader is referred to the respective literature for further understanding of the experimental set-ups. It goes beyond the scope of this paper to compare how these results are obtained from different experiments since to achieve the latter many factors should be controlled and the same test method should have been used [39].

Several experimental set-ups, opting to identify the critical relative humidity, are conducted at optimal constant temperature. However, a dependence on temperature should be expected since biochemical processes affect the metabolic activity of mould growth [16,30,44,51]. These values shall be further used to evaluate the models' comprehensiveness. Table 6 presents a summary of the experimental results regarding the outermost values of temperature affecting mould growth, including low and high temperatures. The results show that low (up to – 20 °C) and high (up to 60 °C) may influence mould growth.

Table 1
The PICOC framework.

Population	Mould
Intervention or Exposure	Experimental, laboratory, field studies, theoretical studies
Comparison	Comparison between different results, analyses and models
Outcome(s)	Mould growth criteria, Mould models
Context	Wood-based materials

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