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A risk-based approach for timber building decay prediction

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Abstract

The durability of timber structures subjected to biotic attacks is becoming of increasing concern due to several recent examples of failures caused by early degradation. Therefore, the design process of a timber building cannot prescind from accounting for the possible degradation due to biotic attack, especially in light of the recent spread of high-rise timber buildings. Furthermore, it is of extreme importance that reliable models to foresee possible sources of degradation in existing buildings are made available so that retrofit interventions can be programmed before it is too late. In the work presented herein, the decay due to fungal attack was predicted through a risk-based approach where decision trees were created to address all the possible scenarios where water or moisture can intrude within the construction details that most affect the durability. These decision trees allow to assign a risk class, defined based on a thorough review of the major European standards addressing timber "use-classes". The trees also lead to the selection of a proper prediction function for estimating the decay depth, chosen among suitable functions available in the literature. The proposed methodology was applied to selected case studies where a good correlation was found between the decay level detected onsite and the results from the prediction model. To facilitate the application of the methodology to both the design of new durable timber buildings and the assessment of existing timber structures, an ad hoc software tool named TSafe was developed. In the present paper, due to the length limit, the focus is on the decision trees and the risk classes, while just a brief description of the case study used for the procedure validation is given.

Keywords: Timber structures; Decay prediction; TSafe project

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1. Introduction

Timber as a sustainable material is increasingly being used in buildings, but as a natural material, timber can experience problems related to early degradation, for example decay due to fungal attack. Concern about the reduction of life expectancy is growing, especially regarding high-rise timber buildings (Strang et al., 2021) and a proper durability design process is of great importance to ensure the expected life of a building. The possible hazards that affect timber in the building envelope (Tengberg and Hagentoft, 2020) and the protection measures recommended by the most relevant European standards, constituted the basis for the definition of a methodology that predicts the decay due to fungal attack in a structural element of wood.

In the present paper, this methodology is introduced through the definition of five risk classes and of decision trees that enable the assignment of a risk class to the detail under analysis. Assigning the risk class permits the evaluation the parameters governing the decay prediction function used in this methodology. Towards the end of the paper, selected case studies are introduced to compare experimental evidence with the results obtained by applying the methodology proposed.

Nomenclature

t_{rain}	duration of rainfall (in *hours per month*)
t_{cond}	time of wetness of timber due to condensation (in *hours per month*)
$t_{leakage}$	time of leakage (in *hours per month*)
t_{drying}	duration in which timber can dry (in *hours per month*)

2. Critical details

The hazards that can cause the decay due to fungal attack in timber building can be identified (e.g.: Wang et al., 2018; Tengberg and Hagentoft, 2020) as follows:

- Outdoor weather during construction or operational phases
- Rising damp
- Interstitial condensation
- Water plumbing (e.g.: tap water, drainage venting)

These hazards can act on a timber building in the details exemplified in Fig. 1 where the structural elements of a typical CLT house are shown. However, these details can also be found in a light frame timber house or a log-house.

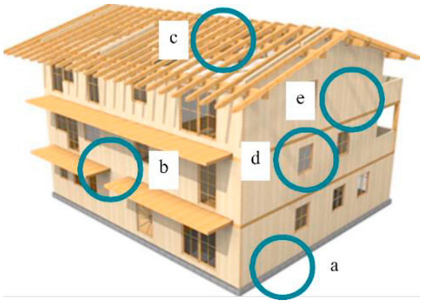


Fig. 1. (a) wall-foundation connection; (b) balcony; (c) roof; (d) window/door detail; (e) wall and floor.

The details shown in Fig. 1 can be exposed to different hazards, as reported in Table 1. Therefore, a specific procedure to predict the decay by accounting for the relevant hazards and the possible protections acting on each specific detail is necessary.

Table 1. Critical details and hazards.

Critical detail	Outdoor weather	Rising damp	Interstitial condensation	Water plumbing
Wall-foundation connection	x	x	x	x
Balcony	x		x	
Roof	x		x	
Window/door detail	x		x	
Wall and floor	x		x	x

3. Risk classes

Decay prediction models depend on several parameters that are evaluated by assigning a risk class to the detail under analysis. The main European standards that deal with the durability of timber have been used to define the risk classes (i.e.: ÖNORM B 2320:2017, ÖNORM B 3802-1:2015, EN 335:2013, DIN 68800-1:2019 and DIN 68800-2:2012). The risk classes allow the association of the hazards with an expected value of the moisture content and to the parameters t_{rain}, t_{cond}, $t_{leakage}$ and t_{drying}. These parameters, related to the amount of water that timber can get in contact with, are the dominant parameters of a modified version of the decay prediction function proposed in Gaspari et al., 2021.

Risk classes have been firstly defined in Gaspari et al. (2020) specifically for the wall-foundation detail, but herein rising damp and leakage from the plumbing system are now included. Moreover, the expected Moisture Content (MC) is provided for each risk class.

- Risk class 1 (R1): Timber is protected against outdoor weather (direct rain, bounce water, wind-driven rain, and external rain accumulation) or rising damp. If water plumbing is present, timber is protected against leakage. Rapid drying is ensured. In these conditions, the Moisture Content (MC) of timber is always below 20 %.
- Risk class 2 (R2): Timber is protected against outdoor weather (direct rain, bounce water, wind-driven rain and external rain accumulation) or rising damp. Occasionally, due to extreme weather events, rainwater can reach the timber. If water plumbing is present, timber is protected against leakage. Timber, however, can dry rapidly. In these conditions, the MC of timber can be occasionally higher than 20 %.
- Risk class 3 (R3): Timber can wet due to outdoor weather (direct rain, bounce water, wind-driven rain and external rain accumulation) or rising damp. If water plumbing is present, timber is exposed to leakage. The class R3 is divided into the two subclasses R3.1 and R3.2 depending on the possibility of timber to dry or not, respectively. Water accumulation on timber is not present. In these conditions, the MC of timber is occasionally higher than 20 % for R3.1 while is frequently higher than 20% for R3.2.
- Risk class 4 (R4): Timber can get wet due to outdoor weather (direct rain, bounce water, wind-driven rain and external rain accumulation) or rising damp. If water plumbing is present, timber is exposed to leakage. Timber is in direct contact with a porous material that can absorb and accumulate water. Timber cannot dry rapidly. In these conditions, the MC of timber is usually higher than 20 %.
- Risk class 5 (R5): Timber can get wet due to outdoor weather (direct rain, bounce water, wind-driven rain and external rain accumulation) or rising damp. If water plumbing is present, timber is exposed to leakage. Drying of timber is impossible and water is always in contact with timber. In these conditions, the MC of timber is always higher than 20 %.

3.1. Parameters association

Table 2 summarizes the risk classes and their association to the evaluation parameters. In this table, t_{rain}, t_{cond}, $t_{leakage}$ and t_{drying} are expressed in hours per month.

Table 2. Parameters association for the critical details.

Risk class	t_{rain}		t_{cond}	$t_{leakage}$	t_{drying}
	Timber inside the building envelope	Timber exposed			
R1	0	0	Evaluated independently from the risk class °	0	∞
R2	$^{+}$	$^{+}$		0	$^{+}$
R3.1	*	*		*	*
R3.2	*	*		*	*
R4	720	720		*	*
R5	720	720		*	0

$^{+}$ evaluated as suggested in Wang et el., 2008, considering only the contribution of wind driven rain.

* evaluated as suggested in Wang et el., 2008.

° calculated using one of the well-established methods for the hygrothermal analysis of buildings

4. Decision trees

The decision trees provide guidance for associating a risk class to the detail under analysis. Typological, geometrical, and constructive choices were considered when creating the decision trees for each construction detail. The decision trees can be applied to new buildings during the design phase but also to existing buildings, provided that onsite inspections to collect all the information required to navigate the decision trees are performed.

In the following, the decision trees are presented together with a brief description of the principal branches. Tables summarizing the association of the outcomes of the decision trees with the risk classes are given for each detail. The documents and guidelines that were used as reference for the setting of the decision trees, are listed for each critical detail.

4.1. Wall-foundation connection

The wall-foundation detail can be first analysed with the DT1$_a$ decision tree, Fig. 2 (a), that regards the distance H between the base of the timber element and the horizontal surface where there is a possible presence of water. The other two trees, DT2$_a$ and DT3$_a$ in Fig. 2 (b) and (c) respectively, consider the protection of timber, the ventilation (i.e.: the possibility of timber to dry), the possible accumulation of water, and the contact with a porous material that can absorb and conserve water for long periods of time (DIN 68800-2:2012, ÖNORM B 2320:2017).

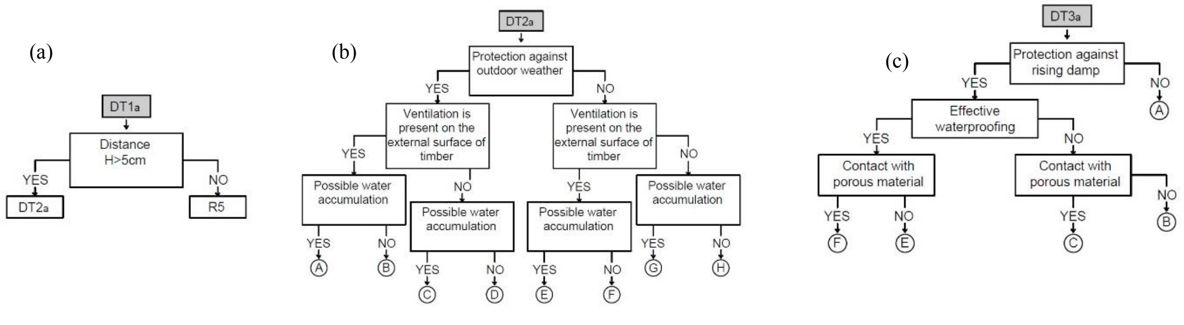


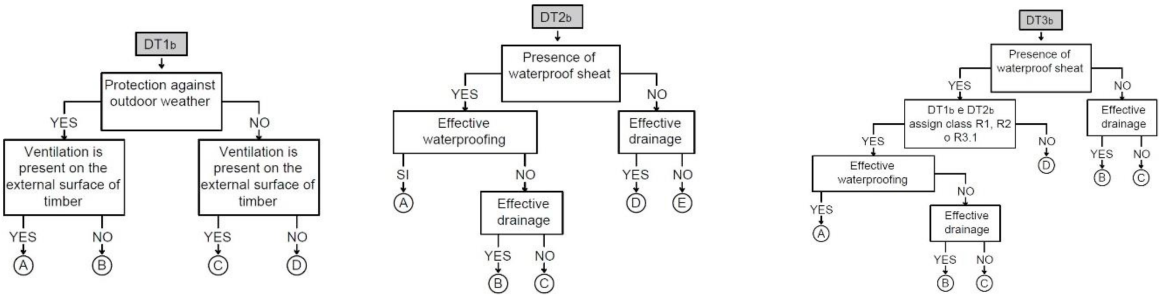
Fig. 2. Wall-foundation connection Decision Tree (a) DT1$_a$, (b) DT2$_a$ and (c) DT3$_a$.

Table 3. Risk classes assignment for the wall-foundation connection.

$DT3_a$	$DT2_a$							
	A	B	C	D	E	F	G	H
A	R5	R4	R5	R4	R5	R4	R5	R5
B	R4	R3.1	R4	R3.2	R4	R3.1	R5	R5
C	R5	R4	R5	R4	R5	R4	R5	R5
D	R2	R1	R5	R4	R4	R3.1	R5	R5
E	R3	R2	R3	R2	R4	R3.1	R5	R5
F	R5	R4	R5	R4	R5	R4	R5	R5

4.2. Balcony

Considering that the balcony has a tridimensional shape, $DT2_b$ shall be applied to the upper and lateral surfaces of the balcony, while $DT3_b$ shall be applied to the lower surface. $DT1_b$ is instead a common decision tree that applies to all of the tree surfaces of the balcony (Gaspari et al., 2021 and DIN 68800-2:2012, ÖNORM B 2320:2017). $DT1_b$, $DT2_b$ and $DT3_b$ are represented respectively in Fig. 3 (a), (b) and (c).



(a) (b) (c)

Fig. 3. Balcony Decision Trees (a) $DT1_b$, (b) $DT2_b$ for the upper and lateral surfaces and (c) $DT3_b$ for the lower surface.

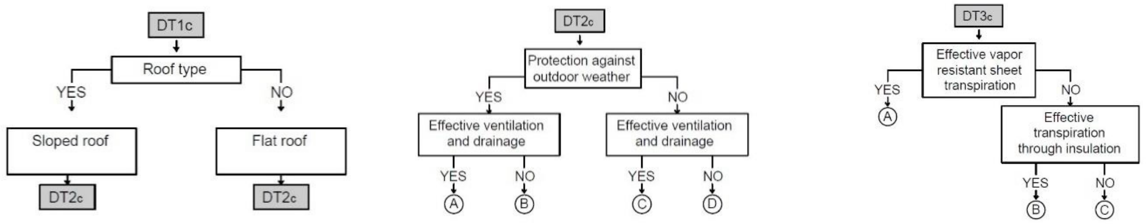
Table 4. Risk classes assignment for the balcony.

$DT2_b$	$DT1_b$			
	A	B	C	D
A	R1	R1	R3.1	R3.2
B	R1	R2	R4	R4
C	R2	R4	R4	R5
D	R2	R2	R3.1	R3.2
E	R2	R3.2	R4	R5

$DT3_b$	$DT1_b$			
	A	B	C	D
A	R1	R1	R3.1	R3.2
B	R1	R2	R4	R4
C	R2	R4	R4	R5
D	R5	R5	R5	R5
E	R2	R2	R3.1	R3.2
F	R2	R3.2	R4	R5

4.3. Roof

The typology of the roof is considered in $DT1_c$, while $DT2_c$ and $DT3_c$ take into account protection, ventilation, and vapor diffusion (DIN 68800-2:2012, ÖNORM B 2320:2017). $DT1_c$, $DT2_c$ and $DT3_c$ are represented respectively in Fig. 4 (a), (b) and (c).



(a) (b) (c)

Fig. 4. Roof Decision Trees (a) DT1$_c$, (b) DT2$_c$ and (c) DT3$_c$.

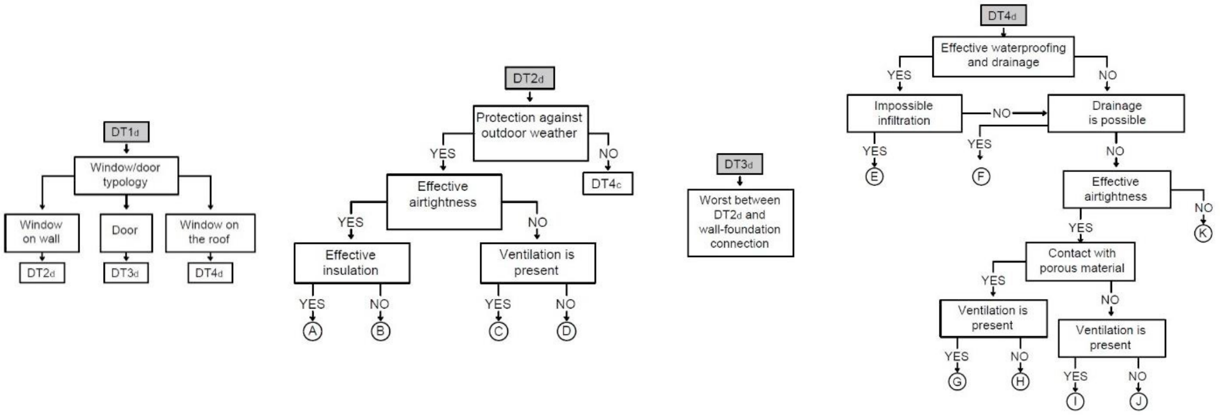
Table 5. Risk classes assignment for the roof.

DT3$_c$	DT2$_c$			
	A	B	C	D
A	R1	R3	R2	R4
B	R2	R4	R2	R5
C	R3	R4	R3	R5

DT3$_c$	DT2$_c$			
	A	B	C	D
A	R2	R4	R4	R5
B	R2	R4	R4	R5
C	R2	R4	R4	R5

4.4. Window/door detail

The connection between the window, or the door, to the wall is a critical point that shall be designed and realized considering the protection against water intrusion (DIN 68800-2:2012, ÖNORM B 2320:2017, ÖNORM B 5320:2017, UNI 11673-1:2017, UNI 11673-2:2019). DT1$_d$, DT2$_d$, DT3$_d$ and DT4$_d$ are represented respectively in Fig. 5 (a), (b), (c) and (d).



(a) (b) (c) (d)

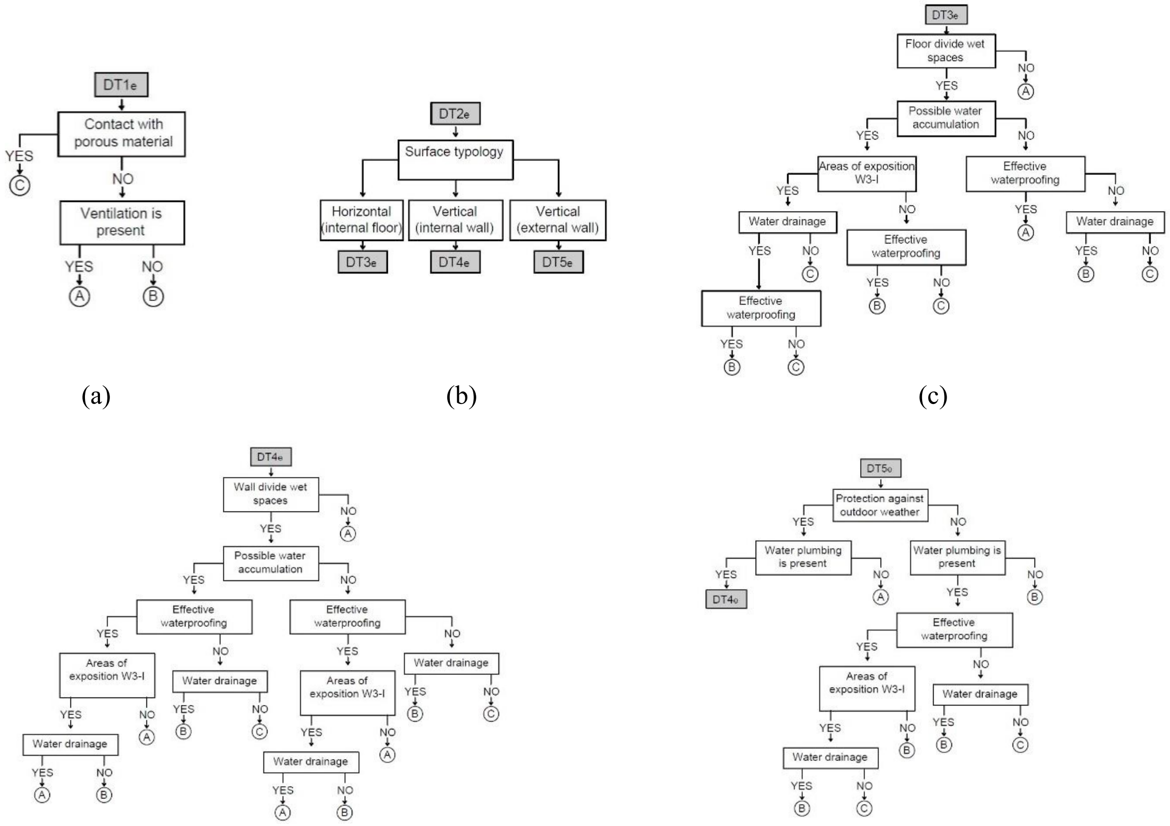
Fig. 5. Window-wall Decision Trees (a) DT1$_d$, (b) DT2$_d$ and (c) DT3$_d$.

Table 6. Risk classes assignment for the wall-foundation construction detail.

	A	B	C	D	E	F	G	H	I	J	K
DT2$_d$	R1	R2	R3.1	R3.2	R1	R2	R3.1	R4	R3.1	R3.2	R5
DT4$_d$	-	-	-	-	R2	R2	R4	R4	R3.1	R3.2	R5

4.5. Wall and floor

Internal and external walls and floors can be exposed to both water coming from wet spaces (such as bathrooms) and leakage from water plumbing. In the case of external walls, the outdoor weather shall also be considered. Therefore, the classification of the indoor surfaces exposed to water provided by DIN 18534-1:2017 was referred to in the definition of the decision trees (DIN 68800-2:2012, ÖNORM B 2320:2017, DIN 18534-1:2017). $DT1_e$, $DT2_e$, $DT3_e$, $DT4_e$ and $DT5_e$ are represented respectively in Fig. 3 (a), (b), (c), (d) and (e).



(a) (b) (c)

(d) (e)

Fig. 6. Wall and floor Decision Trees (a) $DT1_e$, (b) $DT2_e$ and (c) $DT3_e$.

Table 7. Risk classes assignment for walls and floors.

$DT1_e$	$DT3_e/DT4_e/DT5_e$		
	A	B	C
A	R1	R3.1	R4
B	R2	R3.2	R4
C	R4	R4	R5

Fig. 7 offers a brief insight on one of the case-studies currently being surveyed: a light-frame timber house built in 2010 in north Italy. It is presented through the photos made with an endoscope of the timber elements during the first inspection. The inspection point shown in Fig.7 is located at the wall-to-foundation joint, one of the details that the methodology quantified as most critical regarding the decay depth.

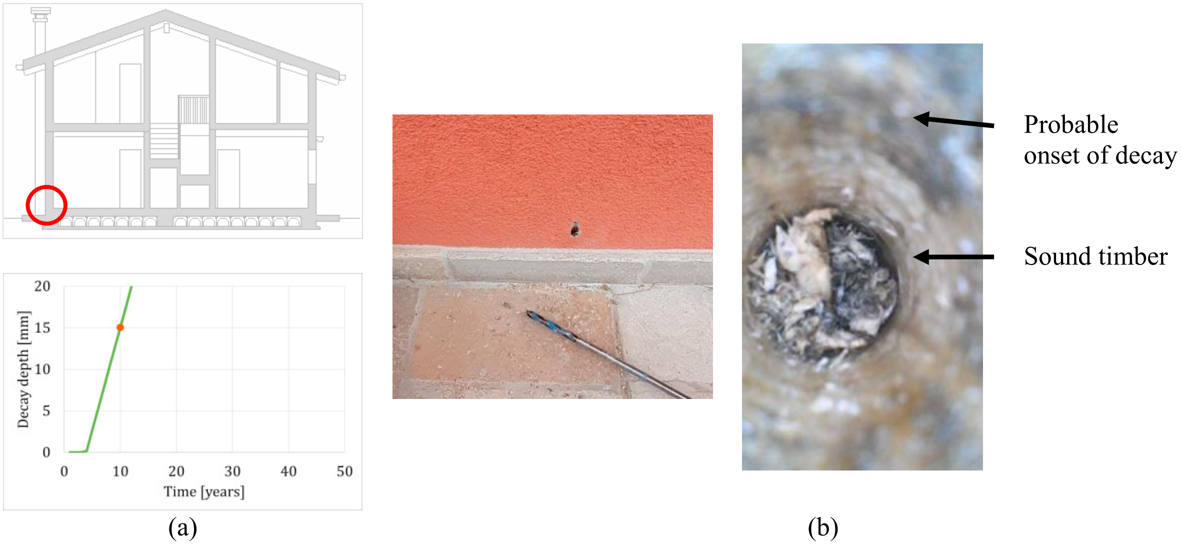


Fig. 7. (a) Inspected detail and expected decay depth in the timber panel, and (b) the drilling phase and the image of the probable onset of decay in the timber element.

The inspection was carried out in the points that the method proposed identified as potentially critical. The results of the inspection shown a good correlation with what predicted from the decay prediction function (as introduced in Gaspari et al., 2021) in terms of potential risk for timber. In fact, the methodology proposed consider the worst scenario for the timber element and the probable onset of decay was a sign of the reliability of the method proposed.

5. Conclusions

The paper defines a methodology that estimates the life-expectancy of the structural elements of a timber building. In this methodology, the decay due to fungal attack can be predicted through decay prediction functions evaluated depending on the risk class assigned to the detail under analysis. The risk classes are assigned using ad-hoc decision trees that consider the potential hazards and the adopted protections. The procedure is valid for estimating the durability of new buildings during the design phase and for assessing existing buildings. In this paper, due to length limitations, the focus has been on the risk classes and the decision trees. However, from the experimental evidence collected so far, the adequacy of the methodology presented herein for predicting decay in timber structures appears as promising. Future publications will be dedicated to the experimental validation of the procedure.

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