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Use of image analysis for determination of morphological parameters of thatching reed

Durability of reed thatches are partly affected by morphological properties of used reed, but until now these properties can only be determined manually with a high time and experimental effort. Thus image analysis algorithms were developed and morphological parameters as mean culm diameter, mean wall thickness and number of culms of a sample can be determined reliably. With little more effort also bulk density can be detected.

Keywords
Reed, reed thatch, image analysis, morphology

Abstract

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Common reed (*Phragmites australis* (CAV.) TRIN. EX STEUD.) has been used as thatching material for thousands of years beneath other culm biomass. Coastal areas of different countries bordering the Baltic and North Sea are still characterised by the presence of reed thatched farmhouses and residential buildings. Not only structural-physical properties such as roof pitch or ventilation influence the life expectancy of thatched roofs, but also reed quality [1; 2]. Essential information about preconditions and processing regarding reed as building material are described in the rules for thatching and product data sheet published by the association of the German roofing industry [3; 4]. According to these specifications also morphological properties have to be considered. For example, reed with high culm diameter is assumed to show higher durability due to faster desiccation and also high bulk density is supposed to influence roof durability positively [1; 5; 6].

Until now determination of morphological properties is only possible by hand. In particular, mean culm diameter of stored reed bunches is sometimes measured by calipers since it is very easy to determine. However, this manual determination is time-consuming and therefore restricted to few bunches. Other morphological parameters such as bulk density can only be measured with high experimental effort. Consequently, the development of a simple and timesaving determination method using image analysis is in the interest of all reed producing and processing participants.

Materials and Methods

Reed cutters, traders and thatchers from Germany and Netherlands provided 215 customary reed bunches. Bunches were harvested in different established source countries – mainly Germany, Netherlands, Turkey, Romania and China. Harvest of most bunches was performed in winter months of 2009, 2010 and 2011. Few of provided bunches were declared for discharge, but nevertheless these were also treated as follows to assure a large spectrum of properties. Closely above the bunch bottom a section of 55 mm height was cut off and held together by a cable tie. Circumference, weight and thereby storage density of this section was determined. Additionally, section was scanned without any editing using a conventional flatbed scanner (CanoScan LiDE 110). Scans (**Figure 1**) were used to create and optimise an algorithm for detection of culm diameter, wall thickness and culm cutting surface by image analysis in the program Halcon (version 7.1.2, MVTec Software GmbH, Munich). For calibration and optimisation of algorithm scans of 34 different bunches with apparently very different culm diameters were chosen and in total more than 7000 culms of these bunches were measured manually using ImageJ (version 1.44p, Wayne Rasband, USA).

As a first step in the developed algorithm process, circles with local maximum of brightness are searched within a specified range of radius (Houghner transformation). Contacting circles are unified and eroded. If resulting objects are similar to circles and if also at least 9 % of culm cutting area is represented by the lacuna, these objects are declared valid. Thus only culms of internode sections are used to calculate culm diameter and wall thickness. Diameter of valid culms (**Figure 2**, a) is calculated using its circular area and thereafter diameters of all valid culms are averaged (**Figure 2**, b). Additionally, increase and decrease of brightness around the realised circle is used to

Fig. 1

Fig. 1: Scan displays of cut surface of different reed bunches

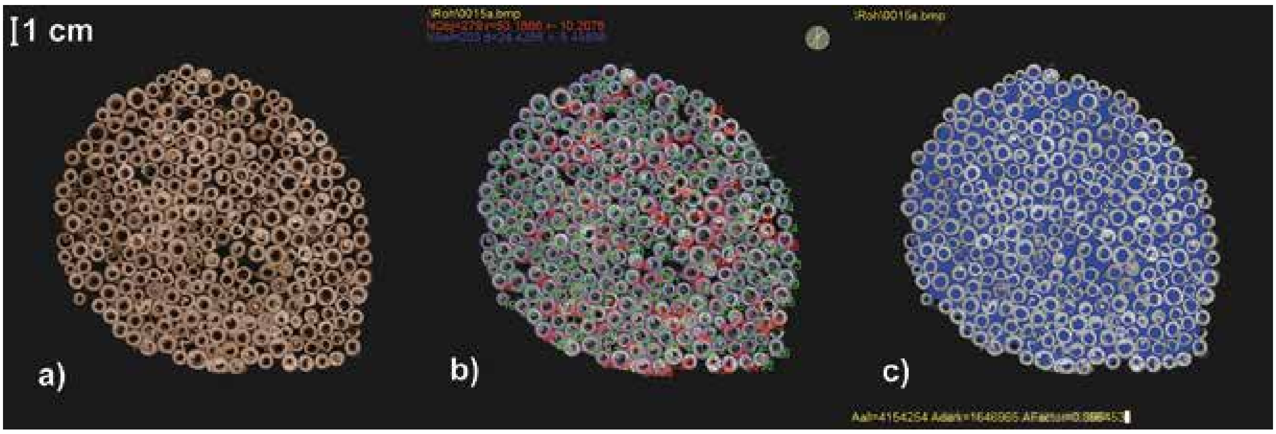
detect culm wall thickness. To optimise the present algorithm and to develop a calibration for subsequent application, analysis of correlation and regression between manually measured parameters and parameters determined by image analysis of 34 different bunches were performed.

However, conventional determination of bulk density by displacement of water or alcohol requires high experimental effort and is not an adequate option, since thatching reed shows a noticeable uplift and water-repellent character [7]. Therefore utilisation of methods basing on image analysis is recommended, in which cutting surface represents the whole bunch. On the one hand, cutting surface of culms was measured by quantifying bright areas (**Figure 2**, c). On the other hand, cutting surface was calculated including mean diameter, mean wall thickness and number of culms of a bunch, which were calculated assuming hexagonal formation of culms.

Results and Discussion

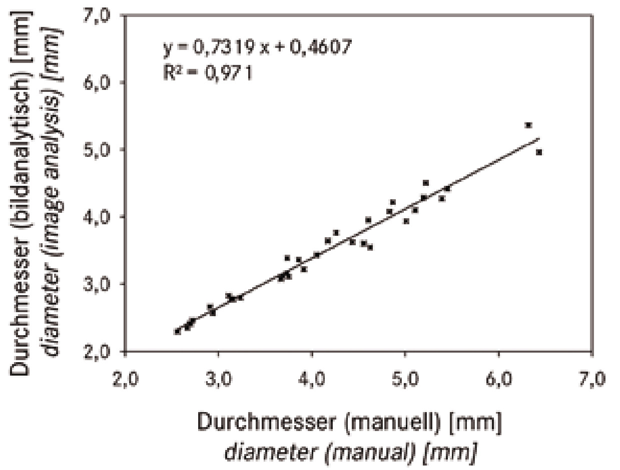
Determination of mean culm diameter of bunches is very reliable. Indeed, diameters detected manually and by image analysis do not present exactly the same values, but show high correlation with $R^2 = 0.971$ (**Figure 3**). Thus regression analysis and equation offer the opportunity to determine diameters of unknown samples, and to transfer these results as if they had been detected manually. Resulting mean diameters vary between 2.4 and 7.7 mm (**Table 1**) and are also expected in that range [8; 9; 10]. According to the product data sheet examined bunches are short (diameter ≤ 6 mm) or of mean length (mean diameter

Fig. 2



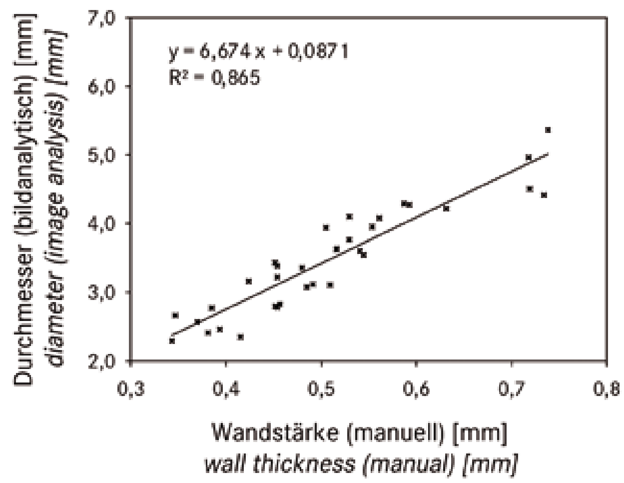
a) Scan display of a sample before image analysis, b) scan after determination of diameter and wall thickness, green numbers: valid culms, red numbers: invalid culms, c) quantification of culm cut surface

Fig. 3



Correlation between diameters determined manually and by image analysis

Fig. 4



Correlation between manually detected wall thickness and diameter determined by image analysis

3–9 mm). Such thin reed is preferred for thatching because of its good procedural properties and appearance on roofs [11; 5].

However, prediction accuracy of the algorithm for determination of wall thickness is lower. Manually detected wall thicknesses and those determined by image analysis algorithm show less strong correlation with $R^2 = 0.696$. But in contrast, manually detected wall thickness shows strong correlations to diameter ($R^2 = 0.865$), hence wall thickness of unknown samples can be determined using diameters (**Figure 4**). Resulting mean wall thicknesses vary between 0.2 and 0.8 mm (**Table 1**), a range which is also reported in literature [6] or slightly lower than those [12].

Bulk density determined mathematically is with 0.5 to 1.3 g/cm³ almost twice as high as density which is detected by image analysis accounting for 0.2 to 0.5 g/cm³ (**Table 1**). Similar contradictory results are reported in literature. For example, Wulf reports bulk densities of about 0.3 g/cm³ [13], whereas Stephan with 0.9 to 1.2 g/cm³ and Schwarz with 1.0 to 1.6 g/cm³ also measured higher densities [14; 6]. Since experimental determination is inaccurate [7], this reported discrepancy is plausible. Also it seems to be questionable if reported values actually represent the real bulk density.

However, results of both methods described in this issue correlate with each other ($R^2 = 0.643$) and also with storage density ($R^2 = 0.719$ for mathematically and 0.893 for bulk density determined by image analysis, respectively). But which of these methods is more representative for the real bulk density remains ambiguous.

Storage density varies between 0.1 and 0.3 g/cm³ (**Table 1**), a range which has been reported before [13]. Generally all detected densities correlate with mean culm diameter and mean wall thickness, but with low correlation coefficients. Therefore, it is disadvised to use only diameter or wall thickness for prediction of reed density.

Conclusions:

Image analysis is an excellent method for determining culm diameter and wall thickness of thatching reed and could thus of-

Tab. 1

Characteristic values of morphological parameters of all 215 samples.

	Mittelwert *Arithmetical mean*	Minimum *Minimum*	Maximum *Maximum*	Variationskoeffizient [%] *Variation coefficient [%]*
Halmdurchmesser [mm] *Culm diameter [mm]*	4.3	2.4	7.7	22.9
Halmwandstärke [mm] *Culm wall thickness [mm]*	0.4	0.2	0.8	24.8
Rohdichte, mathematisch ermittelt [g/cm³] *Bulk density, determined mathematically [g/cm³]*	0.9	0.5	1.3	15.9
Rohdichte, bildanalytisch ermittelt [g/cm³] *Bulk density, determined by image analysis [g/cm³]*	0.3	0.2	0.5	12.6
Lagerdichte [g/cm³] *Storage density [g/cm³]*	0.2	0.1	0.3	13.8

fer information about durability. Additionally, bulk density can be detected faster and easier this way than using conventional experimental methods. Importance of morphological properties for durability of thatching reed will be investigated in following studies.

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