Non-destructive determination of morphological properties of thatching reed by image analysis

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Abstract

Reed (Phragmites australis) is used as thatching material and like other organic building materials, its in situ durability is strongly influenced by weathering and biodegradation processes. Despite chemical, procedural or strength properties also morphological parameters are commonly assumed to be important for life expectancy of reed thatches. Especially reed culm wall diameter, culm wall thickness or density and occasionally reddish or greenish colour are supposed to enable prediction of durability in situ due to potential correlations to water absorption or desiccation ability or chemical composition of reed and thus sometimes determined with high time or experimental effort. To enable rapid, reliable and non-invasive determination of these morphological properties, a method basing on image analysis was developed. Basal sections of 34 reed bunches were scanned with a customary flatbed scanner (CanoScan LiDE 110). Scans were used to measure culm diameters and culm wall thicknesses of bunches manually by using ImageJ (version 1.44p, Wayne Rasband, USA) as a reference and automatically based on a developed and optimised Halcon algorithm (version 7.1.2, MVTec Software GmbH, Munich). In this algorithm, circles are searched with local maximum of brightness within a specified range of radius and after successful validity testing, culm diameters are determined. By using this method, mean culm diameter of a bunch can be determined with an $R^2$ of 0.971. Since diameter and wall thickness are strongly correlated, wall thicknesses can easily be estimated using diameters. Mean culm wall thickness of a bunch can be estimated with an $R^2$ of 0.865. Image analysis was also developed to characterise colouration in RGB colour space and to give additional data for estimation of reed density. The completed algorithm was subsequently applied to 214 reed bunches with known chemical properties. Determined morphological properties were significantly related to each other and to specific chemical constituents, which are assumed to influence life expectancy of a thatch. Colour levels and content of potentially degradation facilitating nitrogen showed correlation coefficients between -0.705 and -0.719, and mean culm diameter and content of easily degradable hemicellulose are correlated with an $r$ of -0.523.

The current study indicates a general suitability of the developed algorithm for rapid and non-invasive determination of mean culm diameter and mean wall thickness beneath offering additional information for density estimation or about colouration of reed bunches. Use of such methods could thus enable property characterisation of many reed bunches and to ob-
jectively exclude bunches of low-grade reed from thatching. However, morphological or other properties with major contribution to thatch durability still have to be identified and require further studies.

Keywords: image analysis, reed properties, thatch

1 Introduction

Grasses have been used for roofing since Stone Age in many parts of the world. In European and other industrialized countries, thatching experienced a decline in past centuries, and nowadays thatched houses have become rare. However, thatched farmhouses and residential buildings are still essential and tourist attracting parts of traditional cultural landscapes, especially in North and Baltic Sea regions. Thatches are subject to physical and biological weathering processes and thus offer limited durability. Life expectancy of thatches varies between one and several decades, depending on the quality of the building material, constructional or locational characteristics. For owners of thatched buildings, life expectancy is an important aspect during decision for or against the traditional way of roofing.

Durability and life expectancy are assumed to be partly affected by the quality of the thatching material. Some quality properties are believed to facilitate or prevent decay to some extent (Haslam, 1989; QSR, 2008), such as culm diameters and culm thicknesses in a bunch of culms (Haslam, 1989; Schwarz & Junge, 2004; Schwarz et al., 2008), density (Schlechte, 2012), lignin content or C/N ratio. Some important quality properties and their acceptable ranges are also listed in the German Product Data Sheet of thatching reed (Zentralverband des Deutschen Dachdeckerhandwerks, 2010). Determination of these and other quality characteristics is currently only realised with medium or high temporal and financial effort. Culm diameters and wall thicknesses can be measured manually with callipers. It is a very simple, but time consuming method and thus used for only few bunches. Even less bunches are analysed concerning their chemical composition. For other building materials like wood, non-destructive methods for determination of several properties have already been established, for example on the basis of image analysis (Gonzalez-Pena & Hale, 2009).

An applicability of image analysis for quality assessment of thatching reed thus appears obvious. For this reason, image analysis was studied for quality estimation of reed in respect to following issues:

1. Can image analysis offer an accurate estimation of the morphological properties mean culm diameter and mean culm wall thickness of a bunch?
2. Could also other material properties be estimated by image analysis?

2 Materials and methods

2.1 Sample preparation

Customary bunches of thatching reed (*Phragmites australis* (Cav.) Trin. Ex Steud.) from different countries of origin were used for the studies. Initially, the conicity was calculated as the ratio of the bunch circumference at a height of 0.8 m and the circumference at the basal
bunch part. Sections with a height of 55 mm were cut off the basal part, weight and circumference was determined and used for calculation of packing density. Sections were scanned with a customary flatbed scanner (CanoScan LiDE 110).

2.2 Development of an algorithm for estimation of morphological properties by image analysis

Of a total number of 214, 34 bunches were selected due to their apparently different culm diameters (Figure 1) for the development and optimization of the algorithm. This algorithm was created in Halcon (Version 7.1.2, MVTec Software GmbH, Munich) and operates as follows: Within a specified range, circles with a local maximum brightness are searched (Houghner transformation) and contacting circles are combined and eroded. Resulting shapes are validated as culms in case of being similar to circles and presenting a distinct cavity. This validation ensures only internode segments of culms to be included in further analyses. Area of each shape is determined and used for calculation of culm diameter. Finally, all diameters of culm of one bunch are averaged. Culm wall thicknesses are determined by an increase or decrease in brightness of detected circular shapes. Simultaneously, diameter and wall thicknesses of scanned culms were measured manually in ImageJ (Version 1.44p, Wayne Rasband, USA) as a reference. Correlation and regression analyses between manually measured parameters (reference) and those automatically detected by the created algorithm were used to optimize the algorithm and to provide a calibration for later use. Additionally, culm cutting surface was quantified and colouration in RGB colour space was determined.

Conventionally, density of culms can be estimated by displacement of water or alcohol in pycnometers and weighing. However, since thatching reed exhibits a strong hydrostatic uplift and hydrophobic character, this method is imprecisely (Greef, pers. comm.). As an alternative method, image analysis could be used to estimate culm cutting surface and thus estimate density after weighing concerning sections. On the one hand, cutting surface was estimated by quantifying bright areas. On the other hand, cutting surface was estimated mathematically including mean culm diameter and wall thickness assuming hexagonal formation of culms.

2.3 Determination of further quality properties

Cutted bunch sections were partly milled, sieved for 1 mm and analysed for chemical composition. The substances crude ash, Neutral Detergent Fibres (NDF) and Acid Detergent Fibres (ADF) and crude lignin were determined according to VDLUFA Methodenbuch III (1976). Contents of crude cellulose and crude hemicellulose were calculated from fibre substances NDF, ADF and crude lignin.

Contents of carbon and nitrogen were determined according to Dumas using a CHN analyser. Additionally, bunches were analysed for contents of mineral substances Silicium, magnesium, phosphor, calcium, potassium and sulphur by X-ray fluorescence.
3 Results and discussion

3.1 Estimation of morphological parameters and accuracy

Correlation between manually measured mean culm diameters and those estimated by the created algorithm is very high ($R^2 = 0.971$), but their values are not exactly in the same range (Figure 2A). However, regression analysis enables an estimation of mean diameter, as it would be expected by manual measurement. Further analysis showed unbiased residuals (Figure 2B) but homoscedasticity could be suggested, so estimation error could be lower for bunches with low mean diameter than for bunches with high mean diameter. Apart from that, mean diameters seem to be estimable by created algorithm and regression equation with very high accuracy.

Diameters of all 214 analysed bunches vary between 2.4 and 7.7 mm in a range, that corresponds with values reported in literature (Mochnacka-Lawacz, 1974; Van Ryckegem, 2005; Dinka et al., 2010). According to the German Product Data Sheet, bunches would be classified as short reed (diameter $\leq 6$ mm) to medium length reed (diameter $3 \sim 9$ mm). Reed of short or medium length is often preferred by German thatchers and house owners due to its good procedural properties and appearance on roofs (Schattke, 2002; Schwarz & Junge, 2004).

Besides diameter, also mean culm wall thickness was estimated by created algorithm. Correlation between manually measured and wall thickness, estimated by created algorithm, is with $R^2 = 0.696$ far lower than for estimation of diameter by the algorithm. However, manually measured wall thicknesses and diameters estimated by algorithm exhibit a higher correlation with a determination coefficient of 0.865 (Figure 3A). Residuals of regression analysis are homogeneously scattered (Figure 3B), but increase with higher diameters.

Mean culm wall thicknesses of all examined bunches vary between 0.2 and 0.8 mm, and are thus at a similar level (Schwarz et al., 2008) or slightly lower than those observed by other authors (Rodewald-Rodescu, 1974).

Density of undried bunch sections differs between the used estimation methods and accounted for 219 to 448 kg m$^{-3}$ (by quantification of bright areas) and 447 to 1225 kg m$^{-3}$ (by calculation including diameters and wall thicknesses). Similar contradictory results are reported in literature (Table 1). The diversity of used methods and also the ranges of reported values illustrate the general difficulty of determining reed density. Assuming density to be important for life expectancy of a thatch as Schlechte (2012) did, it is strongly advised to further examine these different methods concerning their accuracy and precision.

3.2 Estimation of chemical composition basing on morphological parameters

Since all colour hues are highly correlated with each other ($0.980 \leq r \leq 0.996$), resulting in correlations to other properties at very similar levels, only correlations concerning blue hue are presented. Wall thickness exhibits a very high correlation to diameter and is thus also excluded from presentation.

Only few chemical properties correlate with morphological parameters at considerable levels. Highest correlation was observed for blue hue and nitrogen ($r = -0.719$) as well as blue hue and C/N ($r = 0.595$). Nitrogen can not only be component of several substances in reed, such as chlorophyll, nucleic acids, nitrate or proteins, but also of proteins and chitin in reed colonizing fungal tissues. Raw building material with high fungal colonization is predisposed for early decay on thatch. In general, nitrogen is known to partially facilitate decomposition of
organic substrates (Güsewell and Verhoeven, 2006; Zhang et al. 2008) and thus believed to affect life expectancy of a thatch. Other considerable correlations were detected for conicity and ADF \((r = 0.581)\) or cellulose \((r = 0.516)\) and mean culm diameter and hemicellulose \((r = -0.523)\). Culms with higher diameters can have a higher conicity \((r = 0.456)\) and length \((r = 0.698)\). A correlation between diameter and length was also reported by Mochnacka-Lawacz (1974), Ksenofontova (1988) and Schieferstein (1997). Long culms require increased mechanical stability and thus exhibit higher fibre contents than short culms. Also injuries of culms and rhizomes could contribute, since these can induce formation of secondary shoots. Secondary shoots are assumed to be thinner and show different chemical profiles (Schwarz et al. 2008). They did not only report differences between secondary and primary shoots, but also considerable correlations between density and cellulose or hemicellulose. Correlations in these dimensions could not be validated in the current study.

4 Conclusions

The created algorithm offers a non-destructive, rapid and accurate method for determination of mean culm diameter and mean culm wall thickness of a reed bunch, an objective characterization of colours and data for estimation of density. These and other morphological parameters are significantly correlated to chemical composition of bunches, but correlations are not high enough to enable a reliable estimation of contents of substances with anti- or pro-degradative qualities. However, methods on the basis of image analysis could be used for objective determination of important morphological properties and possibly give a contribution to preserve this traditional way of roofing.

5 Acknowledgements

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6 References


*Figure 1: Scan details of sections of different reed bunches with apparent differences in mean culm diameter, wall thickness and colouration.*
Figure 2: Regression analysis for estimation of mean diameters of bunches. A) Regression plot, B) Residual plot.

Figure 3: Regression analysis for estimation of mean culm wall thickness of bunches. A) Regression plot, B) Residual plot.

Table 1: Reported ranges of density of common reed, estimated by different methods. Volume of culms is determined either by displacement by liquids or by calculation. ¹ Calculation of volume by use of diameters and wall thicknesses and height of examined section, ² Calculation of volume by quantification of bright areas during image analysis and height of examined section.

<table>
<thead>
<tr>
<th>Density [kg m⁻³]</th>
<th>Method for determining volume of culms</th>
<th>Material</th>
<th>Sample size</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>320-610</td>
<td>-</td>
<td>reed, not specified</td>
<td>-</td>
<td>Rodewald-Rodescu, 1974</td>
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<td>displacement by a liquid</td>
<td>dried thatching reed</td>
<td>6</td>
<td>Wulf, 2009</td>
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<tr>
<td>1000-1200</td>
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<td>dried thatching reed</td>
<td>5</td>
<td>Schwarz et al., 2008</td>
</tr>
<tr>
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<td>dried thatching reed</td>
<td>-</td>
<td>Schlechte, 2012</td>
</tr>
<tr>
<td>447-1225</td>
<td>calculated¹</td>
<td>undried thatching reed</td>
<td>214</td>
<td>own results</td>
</tr>
<tr>
<td>219-448</td>
<td>calculated²</td>
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