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ADOPTION OF GRADING PRACTICES ACCORDING TO ISO 16624:2018 FOR BAMBUSA BLUMEANA IN THE PHILIPPINES: A CASE STUDY

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ABSTRACT
ISO 19624:2018 is the world's first international bamboo grading standard. It contains few prescriptive clauses and is mostly written as a recipe for a national grading standard. This paper reports the initial phases of the implementation of this standard in the context of a production plant (Kawayan Collective) exploiting *Bambusa blumeana* harvested in The Philippines. The team undertook the initial evaluation (i.e. characterization) of *B. blumeana* harvested from six sites. 123 culms were geometrically and mechanically characterised, as required by ISO 19624. Current visual grading rules used at Kawayan Collective have been recorded as well as their associated rejection rates and resulting associated cost of this rejection. Early findings from the initial evaluation are discussed.

KEYWORDS
Bamboo; grading; ISO 19624; standards; *Bambusa blumeana*

INTRODUCTION
Grading may be defined as "*the process of sorting every piece of bamboo in a sample into grades according to defined selection criteria*" (ISO, 2018). Grading constitutes a fundamental process for the adoption of any natural material in construction as an effective way to address naturally occurring variability. The timber industry has a long history of using visual or machine strength grading. Some form of grading of bamboo is practiced by most users, but the process rarely follows a standard, which hinders the reliability and perception of the end-product. *ISO 19624:2018 Bamboo structures — Grading of bamboo culms — Basic principles and procedures* is the world's first international grading standard for bamboo and resulted from the joint efforts of the INBAR Bamboo Construction Task Force and ISO Technical Committee 165 Working Group 12. The standard was adopted as a national standard in the Philippines in 2020. ISO 19624:2018 contains few prescriptive clauses and is fundamentally written as a recipe for the development of a bamboo grading process. This paper reports on the work undertaken by an international team of researchers aiming to develop a specific grading process for *Bambusa blumeana*.

PROJECT DESIGN
The project has resulted from a collaboration between Coventry University, Foundation University, Base-Bahay Foundation (a bamboo housing charity and research center) and Kawayan Collective (a bamboo treatment facility). Its aim was to follow the requirements outlined in ISO 19624:2018 in the specific context of *Bambusa blumeana* harvested in the Negros Oriental province of the Philippines in order to develop a fully compliant grading process. It should be noted that Kawayan Collective already uses a grading procedure developed in conjunction with Base-Bahay, their main client. The grading procedure is binary: accept/reject. Culms that are compliant are deemed Construction Grade Poles (CGP). The process is a form of visual grading, however, it is not compliant with ISO 19624:2018.

To reach that status, the team agreed the following phases for the project. 1A: characterisation of source-region, 1B: Geometric Characterisation, 2A: Study of current aforementioned grading practice at Kawayan Collective, 2B: Development of grading rules, 3: Initial Evaluation, 4: Pilot machine grading (if findings in phase 3 are meaningful), and 5: Dissemination. At the time of writing phases 1A, 1B and 2A have been fully completed, and the team has initiated phases 2B and 3. Subsequent will be framed within these phases.

PHASE 1A CHARACTERISTICS OF SOURCE-REGION

Sampling

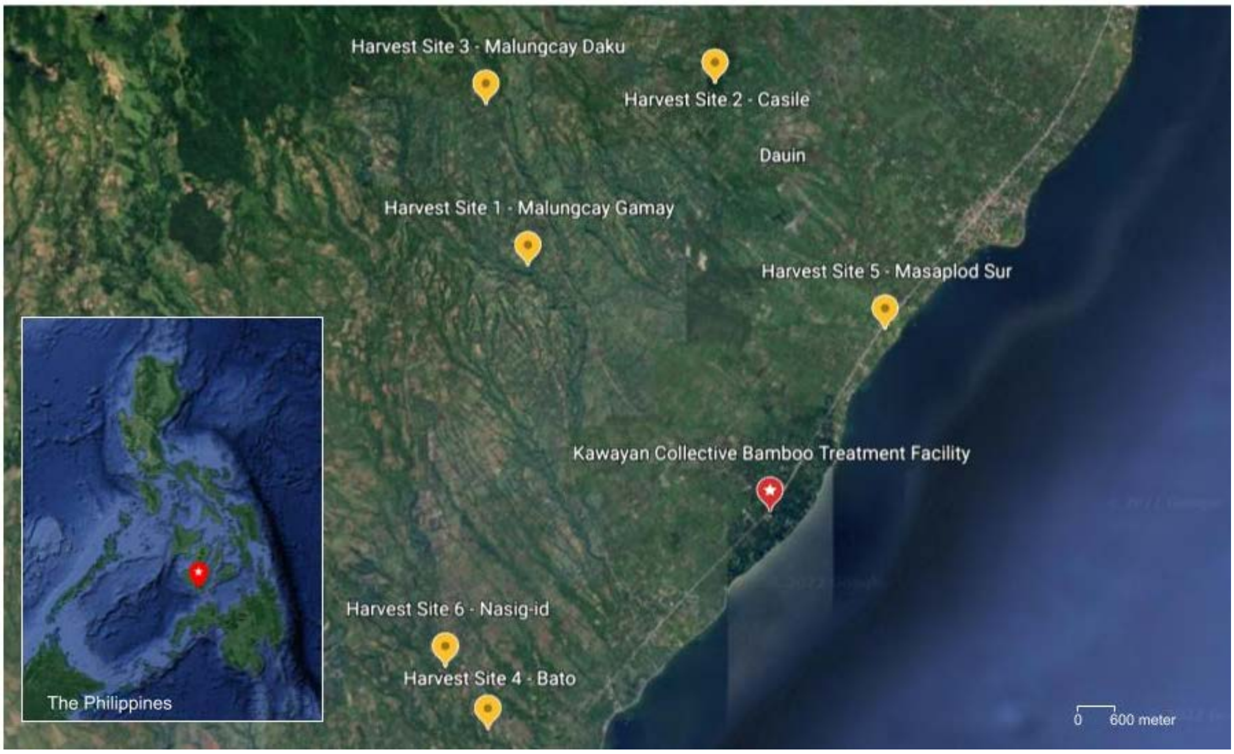
One of the first steps in the development of a grading process is to subject a sample of bamboo to a process referred to as Initial Evaluation, defined as the "*process prior to grading during which the geometric, physical and mechanical properties for bamboo originating from a source region will be assessed with the aim of developing reliable selection criteria"* (ISO, 2018). In turn a source region is defined as "*geographical location from which the bamboo resource originates*" (ISO, 2018). The sample must originate from the source region that will be used during production. The sample should also reflect the variability contained within the source region, i.e. it is undesirable to introduce a quality bias during this stage.

Kawayan Collective's source region

Kawayan Collective primarily sources its bamboo from the municipalities of Dauin and Zamboanguita in the province of Negros Oriental. Located within fifteen to twenty kilometres from Kawayan Collective Bamboo Treatment Facility, the majority of bamboo in the catchment area is wild stock planted through the efforts of the Department of Environment and Natural Resources (DENR). *B. blumeana* has been planted since the 1990s along waterways to stabilise soil and prevent landslides. As a result, *b. blumeana* bamboo clumps can be found adjacent to dry creeks, small streams, and flowing rivers that start in the mountainous areas of 1,900 meters above sea level and find their way to the Tanon Strait.

A small percentage of bamboo has been planted in plantation style forms by private individuals. However, no commercial production of bamboo exists in the province. Due to these conditions, wild bamboo is the primary source processed by Kawayan Collective and the basis for this study. Wild bamboo is not formally managed or monitored and exists on private property throughout the catchment area. Permits issued by DENR are required prior to harvest.

Six sites deemed to be representative of the source region that supplies Kawayan Collective (Figure 1) were selected. Site conditions at each harvest location were recorded as shown in Table 1. Soil saturation, topography, and elevation above sea level were the primary variables considered. Each site selected for study possessed a unique combination of conditions that represent the range of typical conditions present in the source region.



	Red Mark	Kawayan Collective Bamboo Treatment Facility
	Yellow Mark	Harvest Site

Figure 1: Harvest site map - hyperlink

Table 1: Harvest site characteristics

Harvest Site	Location (Barangay, Muncipality)	Elevation Above Sea Level (meters)	Topography and Major Landforms	Soil Saturated at Time of Harvest	Number of Clumps	Date of Visit
1	Malungcay Gamay, Dauin	293	Steep slope	yes	4	8 Jan 21
2	Casile, Dauin	313	Gentle slope	yes	4	20 Jan 21
3	Malungcay Daku, Dauin	558	Gentle slope	yes	4	27 Jan 21
4	Bato, Zamboanguita	49	Gentle slope	no	4	4 Feb 21
5	Masaplod Sur, Dauin	10	Gentle slope, near sea	no	4	21 Feb 21
6	Nasig-id, Zamboanguita	78	Steep slope	no	5	10 Feb 21

Notes: **Soil saturation** observations indicate whether the soil directly adjacent to bamboo clumps was wet or not. Harvesting was done during the northeast monsoon season of the Philippines.
Topography indicates the general slope of grade where a clump is located and any major landforms and waterways. A steep slope indicates that the angle of grade is more than thirty degrees. Gentle slope indicates the angle of grade is less than thirty degrees.
Elevation above sea level was noted by taking the geolocation of a site. The coordinates of the geolocation were used to determine elevation above sea level.

Sample collection procedure
Activities during harvest-site visits involved geotagging the location, interviewing harvesters, and marking clumps and corresponding harvested culms. Refer to the field visit checklist in Figure 2.

ISO 19624 - FIELD VISIT CHECKLIST:

1. **Before you go:** Pack paint (spray paint and canned paint), brushes, log book, phone for camera and tagging site
2. **Geo-tag site:** As soon as you arrive on site, drop a pin on google maps and save location. Share the location when you have service and add hyperlink to shared data google sheet.
3. **Take photos** of harvest site, harvesters, etc. Save in shared google photos album.
4. **Interview harvesters** and record answers in site visit summary.
    a. How do harvesters know how old a culm is?
    b. How long have harvesters been harvesting bamboo?
    c. What is the harvesters biggest challenge?
    d. What would make harvesting easier for the harvester?
    e. What does the harvester believe is good and poor quality bamboo?
5. **Check to make sure at least one full culm (including gu-od and tumoy) is harvested from every clump where sample culms are taken.**
6. **Tag culms and associated clumps - Take photos**
    a. Tagging system:
        i. Culms get painted with brush with the following code:
            1. Harvest site (#) clump (color letter) culm number (#)
        ii. Clumps are painted with spray paint at a location that will not be harvested. Spray a piece of guod.
        iii. Spray end of culm so you can identify culm when in a pile.

Figure 2: Field Visit Checklist

A supply lead from Kawayan Collective coordinates with harvesters to minimise waste at the harvest site. The supply lead orients harvesters to ensure compliance with Kawayan Collective’s current visual grading specifications including maturity, diameter, visual defects, curvature, cracks, skin damage and infestation**.** After harvest, the supply lead performs a quality control check for culms in the field to ensure only culms that Kawayan Collective will purchase are transported to the treatment facility.

Maturity of bamboo culms is inferred by harvesters from experience using as reference the color change of the *B. blumeana* culm from green to reddish-yellow – Figure 3. The majority of bamboo purchased by Kawayan Collective is wild, therefore systematic determination of bamboo age at time of harvest was not possible.

A characteristic o*f B. blumeana* is a dense thicket of branches and thorns at the base of the clump. Refer to Figures 4 and 5. This makes this species difficult to manage and harvest. The common practice is to climb two to three meters from the base, above the thorns to harvest. This is so widely practiced that the two to three meter base of the culm is known locally by another name: *guod*. This portion of the culm is has the thickest walls, but is also the most curved. Kawayan Collective's primary source of bamboo typically does not include the *guod*. However, some specimens were included in the sample to develop a full understanding of the variations of the culm.

Figure 3: The change in color of *B. blumeana* that indicates maturity

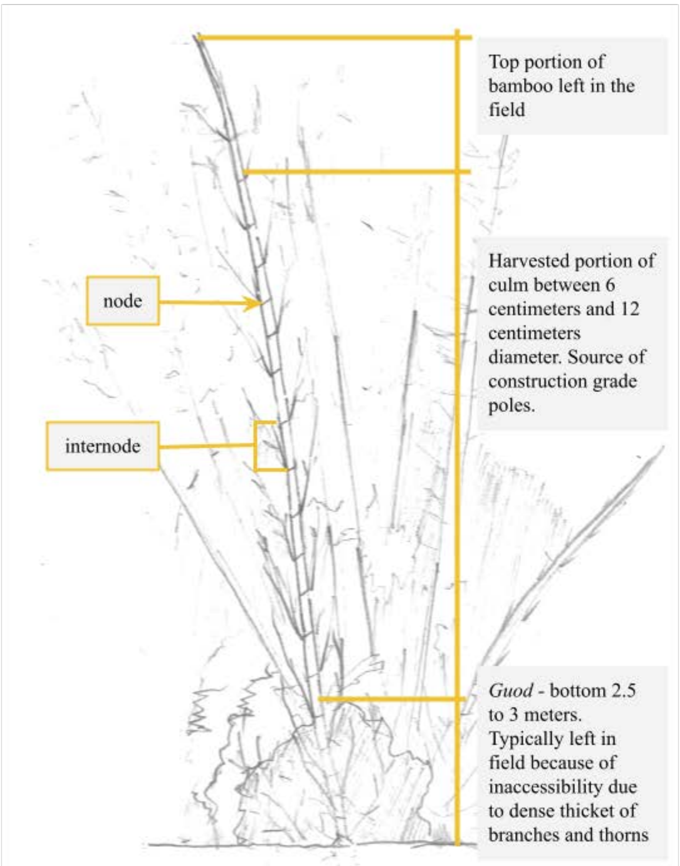


Figure 4: Schematic representation of a whole *B. blumeana* culm in the field (by authors)

Figure 6: Marking a *b. blumeana* clump in the field

As poles arrived at Kawayan Collective Bamboo Treatment Facility, culm specimens were measured for internodal distance, diameter, and full length.

Full-culm measurement and analysis: Nineteen (19) full culm specimens inclusive of the *guod* and up to 60 mm diameter were harvested as part of the geometric characterisation required for the Initial Evaluation. Wall thicknesses and diameters at the center of every internode were measured – Figure 7.

Figure 7: *B. blumeana* full culm analysis.

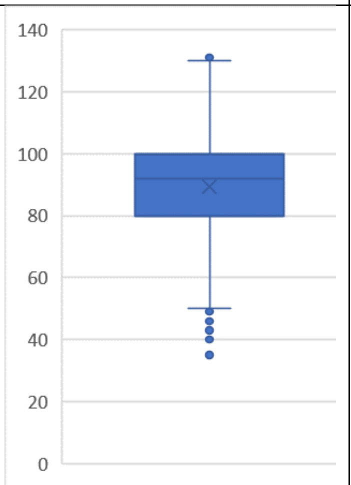
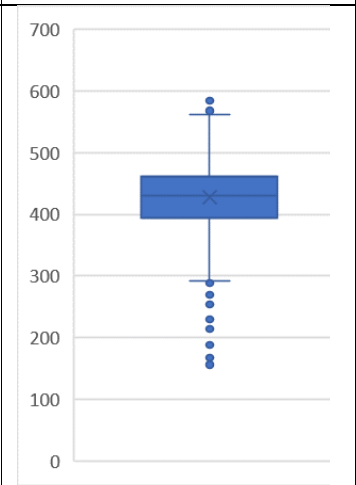
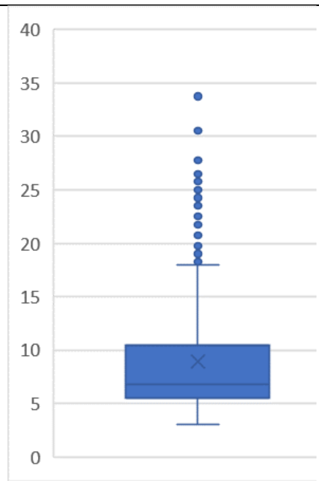
PHASE 1B - GEOMETRIC CHARACTERISATION

The geometric properties for 123 culms from across six sites were recorded as summarised in Table 2. For 104 culms, only diameter and internode lengths were recorded along the culm until its diameter was reduced to around 60 mm. These 104 culms excluded the *guod*, and readings for wall thickness values were only recorded at the top and bottom of the specimen. For 19 specimens the culm was harvested including the *guod* and every single internode was cut at mid-point to reveal the wall-thickness. The length of the specimen was dependent, as before, on reaching a diameter of around 60mm. In total over 3000 values of internode lengths were recorded, with their respective average diameters, and over 800 average values of wall-thickness were recorded. Preliminary analysis is captured in Figures 8, 9 and 10 as histograms, and in Table 3 as descriptive statistics.

Table 2: number of specimens measured per site

Harvest Site	Culms only measured externally	Culms sectioned at every internode and inclusive of *guod*
1	13	0
2	23	3
3	21	4
4	22	4
5	20	4
6	24	4
Total:	123	19

Table 3: descriptive statistics for three geometric properties

	Diameter (D)	Internode length (L_i)	Wall-thickness (t)
Mean (mm)	89.4	427.8	8.9
CoV (%)	15.6	12.5	58.4
Median (mm)	92.0	430.0	6.75
Sample size	5948	2904	665
Boxplot			

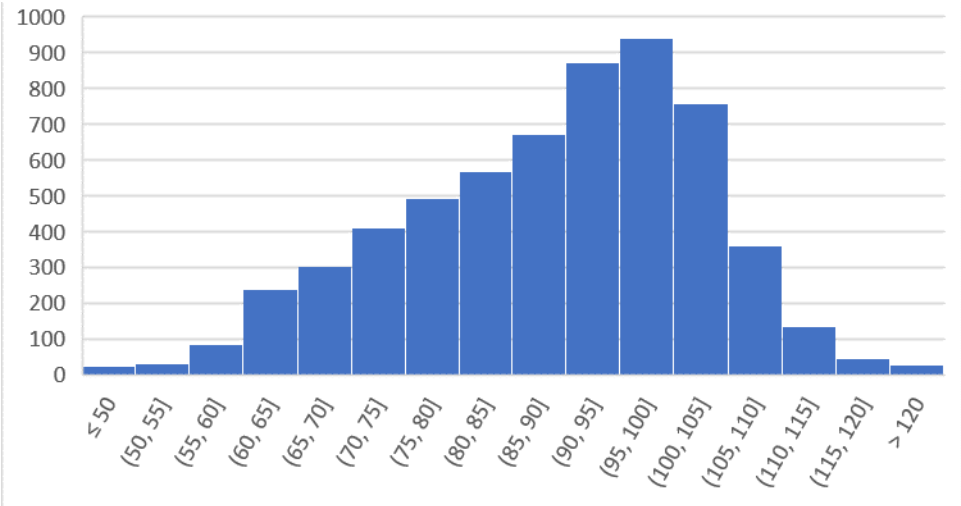


Figure 8: Histogram for external diameter values, *D*, in millimetres

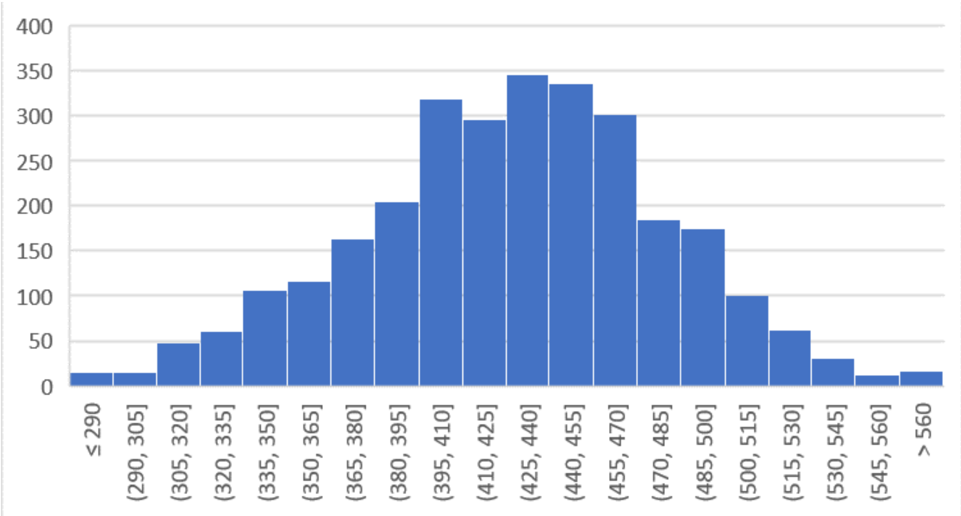


Figure 9: Histogram for internode lengths, L_i, in millimetres

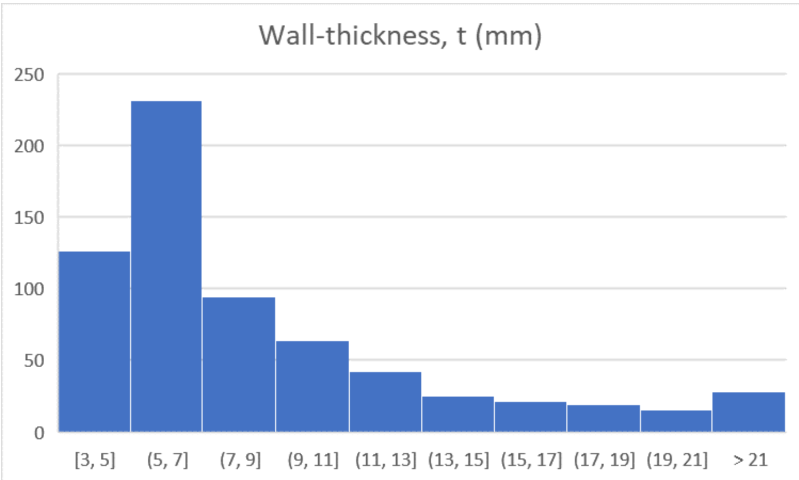


Figure 10: Histogram for wall-thickness values, t, in millimetres

These figures are not conclusive and should be treated as preliminary, as a full reconciliation of the data is yet to be undertaken. Nevertheless, this preliminary analysis indicates that the interquartile range for diameter is between 80 to 100mm, for internode length between 395 to 460mm, and for wall-thickness between 5.5 and 10.5mm. However, it is important to note that wall-thickness displays a significantly left-skewed distribution, this is reflected in the noticeable difference between the mean wall-thickness (8.9mm) and the median wall-thickness (6.75mm).

One of the aims of capturing these geometric properties at every single internode was to develop a model for the variation in geometric properties along the culm similar to those proposed by Shigematsu (1958). As argued by Trujillo and Jangra (2016) and Trujillo and López (2019), geometric characteristics have a greater effect over the load-bearing capacity of bamboo elements than mechanical or elastic properties, and unlike sawn timber products, bamboo culms cannot be dimensioned to a standard size. The aim of the geometric characterisation is to establish what are the 'typical' characteristics produced of a bamboo species from a specific source region.

Shigematsu (1958) proposed that variation along the culm could be captured in terms of equations. An example of the type of equations that could be developed are shown in Figures 11, 12 and 13. These capture geometric variation along the culm for the 19 specimens that included the *guod*. A more comprehensive analysis will include variation of diameter and wall-thickness along the length of culm from the base (the current analysis is reliant on internode number), as well as variation of internode length along the length of the culm. Another aspect to explore the relationship between diameter, wall-thickness, and internode length. Additionally, a more rigorous statistical analysis will be undertaken.

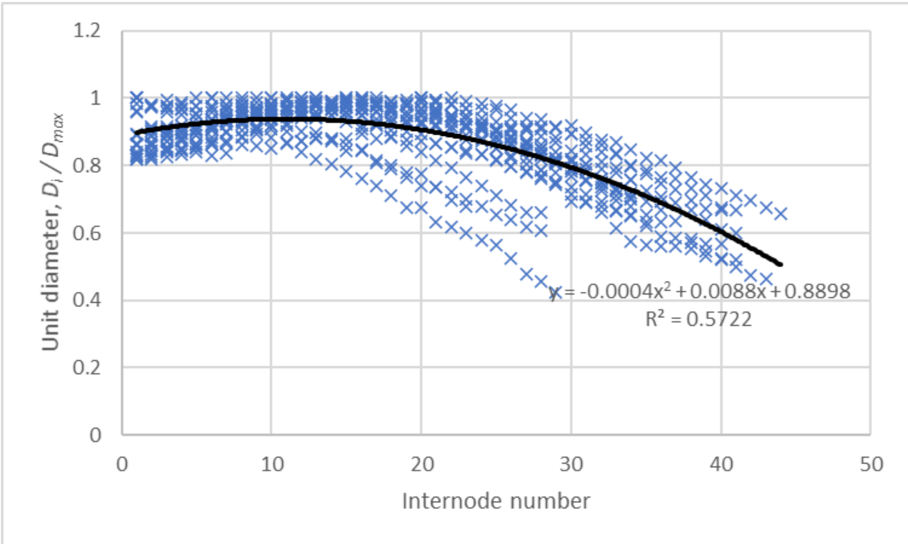


Figure 11: unit diameter (D at internode / maximum D) versus internode number

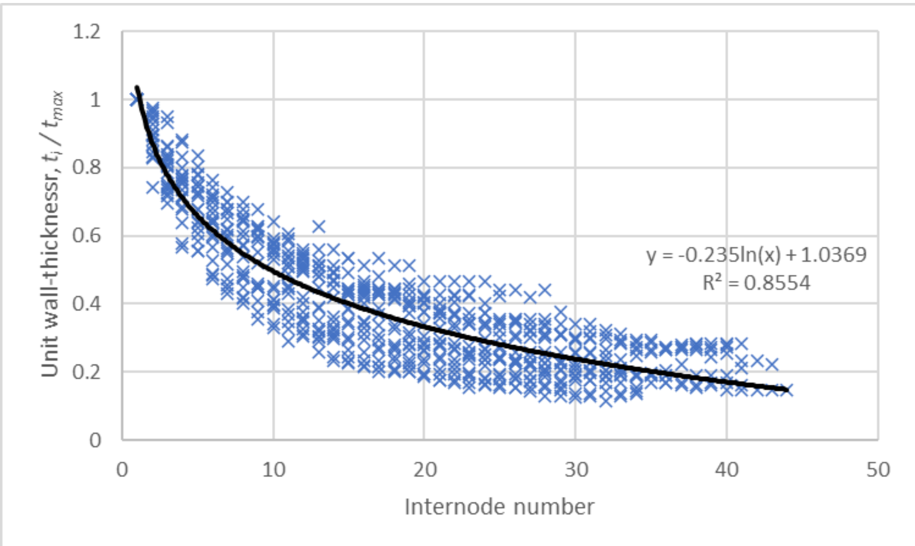


Figure 12: unit wall-thickness (t at internode / maximum t) versus internode number

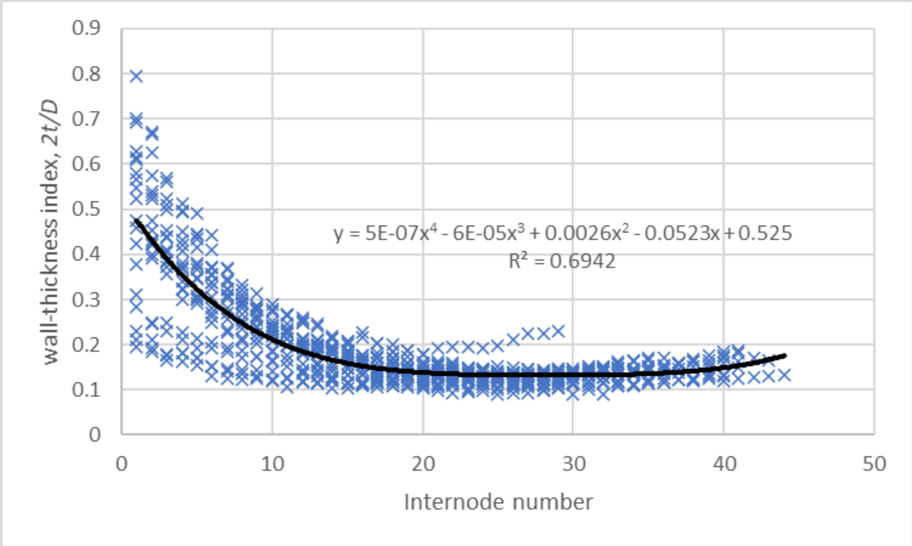


Figure 13: wall-thickness index (2 * t / D) versus internode number

Initial inferences from geometric characterisation

From observing Figure 11, it is interesting to note that *B. blumeana* culms increase in diameter with respect to the base, then sustain a fairly constant diameter to then undergo a reduction in diameter, reflected well as parabola. This characteristic has not been reported for *Phyllostachys edulis* (Amada et al. 1996), *Guadua angustifolia* or *Bambusa stenostachya* (Harries et al 2016), and not significantly visible in the species studied by Shigematsu (1958). However, Salzer et al. (2018) does report larger diameters in the middle of the culm, than at the base, which suggests this may be a peculiarity of the species.

It should be noted tapering of the diameter is not linear, and therefore there is an abundance of certain diameters and a dearth of others, which is reflected in the histogram in Figure 8. Instead, Figure 12 indicates that wall thickness rapidly decreases and then tapers in a fairly linear manner. This results in a very large variability of wall-thicknesses. This phenomenon accompanied by the unknowability of wall-thicknesses at intermediate locations of a bamboo pole (i.e. not at the ends) shows the value of Figure 13. As can be noticed the wall-thickness index decreases rapidly within the first ten internodes and then becomes fairly constant at around 0.15. This knowledge about a resource gives the supply-chain and designers confidence of what a realistic wall-thickness for a culm is likely to be.

ISO 19624:2018 states that "*a grade can be set to correspond to a particular bamboo resource in order to make optimum use of the resource*". An additional value of the geometric characterisation is that it provides a clear picture of how to arrive at an optimal use of the resource.

PHASE 2A – STUDY OF GRADING PRACTICE AT KAWAYAN COLLECTIVE

Cost of grading

Grading comes at a cost. This cost includes labour costs, capital costs and costs associated with rejection of unsuitable pieces. These costs should be captured in the end-price of the graded product and passed onto the consumer. Grading criteria do not solely relate to structural performance and natural characteristics of the material, they also need to be financially viable. In other words, criteria should not be so strict to make the process uncompetitive, or so lax to render the process pointless. As mentioned, Kawayan Collective already uses a binary visual grading process, but the rate of rejection, and hence the cost of grading had not been evaluated. With the aim of understanding the costs of grading, the team investigated the current rate of rejection.

Visual Grading at Harvest Site

As discussed in the sampling process, Kawayan Collective personnel inspect material prior to purchase and transportation. The costs of rejection at this stage are not included in this analysis, because they are assumed by the cutter. Rejection rates range between 2 – 10%. Experienced cutters have fewer pieces rejected.

Current visual grading rules for Construction Grade Poles

Kawayan Collective's current visual grading rules for a Construction Grade Pole (CGP) are noted below.

> **Maturity:** As described in the sampling section of this paper.
> **Fissures:** Fissures are inspected upon delivery to processing plant and prior to dispatch to buyers. A fissure in the internode is deemed acceptable but rejected if it penetrates the node.
> **Insect infestation:** If there is more than two holes caused by boring beetles the piece is rejected. Inspection for holes takes place at all stages (from cutting to dispatch).
> **Bow:** limited to 2%.
> **Diameter:** must less than 120mm at the base of the piece and at least 70mm at the top.
> **Length:** specimens less than 1000mm long are not useful to construction, hence rejected.

Waste generated from off-cuts

To compute the rejection rate at Kawayan Collective associated with grading to CGP, the team recorded the rate of rejection and causes for three 500 metre batches. Table 4 records the percentage of rejects for each batch.

Table 4: Average rejection percentage for three batches of 500 metres

Group	Rejection criteria	Percentage of rejects			Average
		Batch 1	Batch 2	Batch 3	
D > 120 mm	Reject because piece is <1000mm long or diameter is >120mm; or does not meet other CGP criteria.	7.20%	10.00%	6.00%	7.73%
70mm ≤ D ≤ 120 mm	Reject because piece is < 1000mm long; or does not meet other CGP criteria.	7.40%	2.00%	4.80%	4.73%
D < 70 mm	Reject because diameter is too small	14.60%	6.00%	16.40%	12.33%
TOTAL		29.20%	18.00%	27.20%	24.80%
Average Rejection Rate		= 24.8%			

Rejects after seasoning

After seasoning, the culms are then transferred to their respective storage facilities awaiting pick up for delivery and this can take up to a couple of months and may take a toll through the manifestation of new fissures. Rejections at this late stage are more costly, because these are treated, graded and seasoned (MC<10%) specimens.

Two batches were inspected prior to dispatch. The rejection criteria was the manifestation of more than one fissure between nodes or one fissure that enters through a node. The first batch contained 1000 poles, 26 were rejected, resulting a 2.6% rejection rate. The second batch contained 950 poles, 17 were rejected, resulting in a 1.7% rejection rate. Resulting in an overall 2.2% rejection rate at delivery / after seasoning.

Cost of rejection

The cost of purchase and delivery to Kawayan Collective of an untreated, unseasoned and ungraded bamboo pole has been estimated to be 12 PHP/m (0.235 USD/m at 31 December 2021 exchange rate). Therefore, the cost of grading poles upon arrival to Kawayan Collective results at:

$$\text{Cost of Rejection} = \text{Total cost of Production} \times \text{Rate of rejection}$$

12 PHP/meter × 24.8% = **2.97 PHP/meter (Untreated Pole)**

The cost of producing a CGP has been estimated to be 75PHP/m, therefore the cost of rejection after seasoning results at:

75 PHP/meter × 2.2% = **1.65 PHP/meter (Treated Pole)**

This suggests that the total cost of grading (solely from rejection rates) at Kawayan Collective is 4.62PHP/m, or 6.2% of the total production cost of a CGP (75 PHP). It should be noted that few of the 24.8% of the rejected untreated poles are waste, as they are treated as a feedstock for other by-products such as furniture, pinboo, bamboo slats, bamboo panels, and other home goods. As for 2.2% of rejected treated poles, these are also used for other applications. Therefore, it would seem grading does not come at an excessive cost, though this study does not include other costs such as labour and capital costs associated with the process. Grading may instead offer added value to the end product.

PHASE 3 - PHYSICAL AND MECHANICAL CHARACTERIZATION

Another important aspect of the initial evaluation is the determination of the physical and mechanical properties of the sample. The team aims to test at least 100 specimens in bending, shear and compression parallel to the fibres, as these were deemed to be the most useful and relevant of the six strength properties contained in ISO 22157:2019. To date only 50 bending tests and 30 shear tests have been undertaken at the Base innovation center in Manila, the Philippines – Tables 5 and 6. Later stages of the project will allow the team to assign characteristic values to each grade that is agreed. Specimens for these tests were taken from the poles collected during Phase 1A and treated using the conventional processes adopted at Kawayan Collective.

Bending Test: A total of one-hundred and ten (110) specimens were processed at Kawayan Collective and dispatched for bending tests at Base-Bahay. The specimens were four meters long and typically 100mm in diameter. One specimen from each harvested culm. In order to comply with the spirit of the Initial Evaluation, it was deemed essential that the sample was a true reflection of the bamboo that is typically sold to Kawayan Collective. No bias for “good” or “straight” poles was made during selection of this sample.

Compression and Shear parallel test: Five hundred (500) specimens were prepared for compression and shear parallel. Specimen size for this test complied with ISO 22157:2019 (SO, 2019), therefore the length of the test piece equalled to the diameter of piece. For each culm, two specimens with a node and three specimens without a node were produced and dispatched. Refer to Figure 14.

Figure 14: *B. blumeana* testing specimens being treated

Table 5: Descriptive statistics for shear tests to date

	Average external diameter, D	Average wall-thickness, t	Shear strength, f_v	Moisture content, w	Density under test conditions, ρ_{test}
	(mm)	(mm)	(N/mm^2)	(%)	(kg/m^3)
Mean	99.83	8.35	10.34	10.79	708.8
COV	6%	16%	16%	8%	18%
5th percentile	91.73	6.63	7.56	9.45	549.6
n	30				

Table 6: Descriptive statistics for bending tests to date

	Average external diameter, D	Average wall-thickness, t	Flexural strength parallel to direction of fibres, f_m	Apparent flexural modulus of elasticity parallel to direction of fibres, $E_{m,0}$	Moisture content, w	Density under test conditions, ρ_{test}
	(mm)	(mm)	(N/mm^2)	(N/mm^2)	(%)	(kg/m^3)
Mean	91.21	6.73	87.54	21476	11.01	836.3
COV	7.6%	14.6%	18.5%	29.5%	6.2%	11.1%
5th percentile	81.00	5.36	63.34	15048	10.10	685.6
n	50			47		50

SUMMARY AND FURTHER WORK

The research team has been able to follow the procedures contained in ISO 19624:2018 successfully up to Initial Evaluation. The team has yet to determine if a binary grading system (accept/reject) as currently used at Kawayan Collective is adequate, or if a more differentiated grading system is preferable and feasible. A wealth of geometrical data has been collected, yet it is felt that further work can be undertaken to better understand the characteristics of *B. blumeana* harvested in the source region. Once the experimental work has concluded, the team will cross-refence geometric and mechanical properties, in order to propose one or more structural grades. Variations in properties across the six sites will also be studied and reported. Similarly, the potential to infer mechanical properties from non-destructively measured properties will also be investigated, as this forms the basis of machine grading. Further analysis into the cost of grading will be explored, including labour costs, benefits of binary v differentiated grading, and machine v visual grading. The findings will be shared with other production plants across The Philippines with the aim of converging towards a national grading standard.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest associated with the work presented in this paper.

DATA AVAILABILITY

Data on which this paper is based is available from the authors upon reasonable request.