Laboratory experiments with earth bricks

Strength of handmade earth specimens

AR3B011 EARTHY (2019/20 Q1)
Dr. Ir. F.A. Veer

Group 2: Bazaar
Angela Smit 4463021
Kees Leemeijer 4385896
Deirdre van Gameren 4372867
David den Ouden 4469712
Reji Benoy 4800559
Giancarlo Manzanares 4916352

Summary

For the course ‘AR3B011-Earthy’, group 2 is designing a method to apply a bazaar in every refugee camp in the Middle East. For thousands of years earth materials like adobe are used as building materials in hot or dry climates. As the properties of earth bricks are changing depending on the ingredients, an experiment is executed to understand the strength and production method of earth bricks. With this method, the properties which are conducted from a true experiment will be used as input for structural calculations. The following main research question will be investigated in this study: “What are the differences between an earth brick and bricks which contain reinforcement materials?”

For this study, literature research is studied, and a true experiment is executed. Literature is used to understand earth bricks and what the expected outcome of the test will be. The results of the experiment will be used for the structural analysis.

In this study, five different types of earth bricks are tested: adobe only, adobe with straw, adobe with wood chip, adobe with sorghum and adobe with feathers. When looking at the test results, stray and feather reinforced adobe are the most shape remaining. The compressive stress of an adobe with straw ranges between 2.02 MPa - 2.99 MPa and for adobe with feathers 0.83 MPa -2.92 MPa. Therefore, these two types of earth bricks will be used for structural analysis as material availability is limited.

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List of symbols

Symbol	**Definition**
б	Imprecision correction
σ	Compressive stress (N/mm^2)
ε	Strain (mm)
E	Elasticity Modulus (N/mm^2)
Mpa	Mega Pascal or (N/mm^2)

1 Introduction

For thousands of years earth materials like adobe are used as building materials in hot/dry climates. As the properties of earth bricks are changing depending on the ingredients, an experiment is executed to understand the strength and production method of earth bricks. The results of the measurements that were conducted on October 2nd, 2019 in the material test laboratory at the Faculty of Mechanical, Maritime and Material Engineering (3ME) of the Delft University of Technology. These measurements were conducted in the framework of the master Building Technology in the course 'AR3B011-Earthy'. In this course, group 2 is designing a method to apply a bazaar in every refugee camp. Therefore, the properties which are calculated will be used as input for structural calculations. The following main research question will be investigated in this study:

What are the differences between an earth brick and bricks which contain reinforcement materials?

The main aim of this paper is to find out what the influence is of the composition of clay, fine sand and coarse sand and the added reinforcement materials sorghum, wood chip, straw and pigeon feathers on self-made adobe bricks by finding out their properties. This study contributes to a wider research into self-made adobe bricks. To achieve this, 5 types of adobe bricks with different compositions were tested. The results of the series of measurements are reported in this document.

The approach of this study is based on literature and a true experiment which is executed to generate data. In this report, the methodology chapter will discuss the problem statement, research objective, method and design, research instruments and data collection techniques, execution plan, validity and reliability of the experiment and measures which are taken to ensure the scientific rigor. The results of the measurements will discuss the properties of the tested specimens, execution of the experiment and results. Finally, the results of the test and this paper will be concluded in the conclusion.

2 Methodology

In this chapter, the problem statement, research objective, general research design and execution plan will be discussed.

2.1 Problem statement

A steadily growing number of people are moving into refugee camps. Now, almost 80.000 Syrian refugees live in camp Zaatari, North Jordan. The emphasis of refugee camps is on establishing temporary solutions. These camps exist for many years. In the area of Zaatari, the original main building material is earth. To understand the strength of self-made earth bricks, this experiment is performed. In the course ‘AR3B011-Earthy’, group 2 is designing a method to apply to build a bazaar in every refugee camp. This includes roof structures with large spans. Therefore, the strength has to be known to understand the limitations of the span construction.

2.2 Research objective

The main objective of this experiment is to define the influence of the composition on the strength of the self-made adobe bricks. Not only the results of group 2 will be used for understanding the properties, but also the results of other groups which are part of the course ‘AR3B011-Earthy’. These results can be compared afterwards to determine which composition had the best properties. The chosen brick composition will be used as input for the structural design.
Based on the research objectives, the following main research question is formulated: *What are the differences between an earth brick and bricks which contain reinforcement materials?*

2.3 Research method

A laboratory experiment was conducted to find an answer to the research question. A laboratory experiment is an experimental method where the effects of independent variables on dependent variables are tested in a controlled environment, ensuring that relationships between certain factors and characteristics can be determined (Thompson, 2017). Also, literature is included in this study to select other ingredients in the brick mixed to increase the strength.

For this experiment, five types of specimens are tested:

- 1) Standard earth bricks (fine sand(30%), coarse sand (40%) and clay(30%));
- 2) Standard earth brick with wood chip (1% of the standard earth brick weight);
- 3) Standard earth brick with straw (1% of the standard earth brick weight);
- 4) Standard earth brick with Sorghum powder (400 grams added to the standard earth brick composition) and;
- 5) Standard earth brick with pigeon feathers (100 grams added to the standard earth brick composition).

2.4 General research design

This study is a quantitative research including true experiment with independent samples and repeated lab measurements. Data of the deformation and force applied on different specimens is collected and used for this research. The research was conducted at the material test laboratory at the Faculty of Mechanical, Maritime and Material Engineering (3ME) of the Delft University of Technology. Before performing the test, the specimens were closely investigated to identify the deformations and defects. The measurements were documented along with the defects and deformities. The dimensions of the samples were measured with a RVS ruler (brand AMI) and collected in Microsoft Excel.

The specimens were tested on strength, only compression force was applied to the bricks, see figure 1 for the set-up of the test. First, the bottom plate is a regular pine wood plate of 18mm. The specimen is placed on the plate below the steel plate which will compress the specimen. The compression plate had a diameter of 100mm.

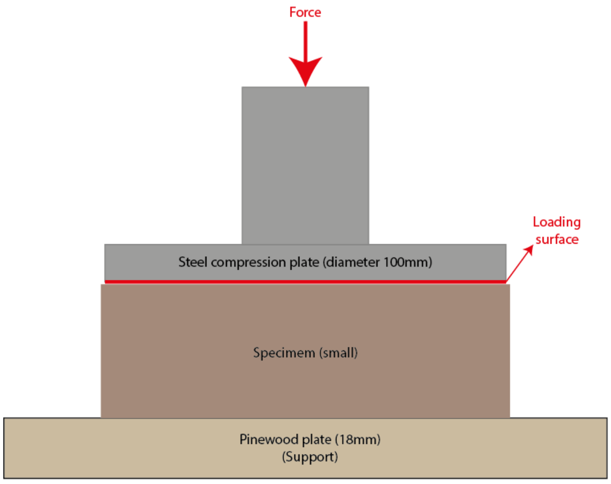

Figure 1: Schematic visualisation of the compression test.

2.5 Research instruments and data collection techniques

The specimens are measured one day before testing. The measurements are dimensions and weight of each specimen, see appendix A. Defects of the specimens were written down at the 3ME test location as the specimens are transported from the faculty of Architecture in Delft to 3ME in Delft. The following equipment is used for the laboratory experiment (compression test):

- RVS ruler (brand AMI);
- Zwick z100 compression testing machine;
- Microsoft Excel for collecting data;
- A small scale (brand Soehnle).

For making the bricks:

- a large scale (unknown brand);
- Concrete mixer (brand Festool);
- Buckets and shovels;
- Plastic containers as moulds (120x120x50 and 120x170x130).

2.6 Execution plan

The execution of this experiment is divided in two parts: 1) making the specimens and 2) testing the specimens.
For making the specimens, the following steps were followed:

1. Perform literature research to figure out which two additional raw materials can be added to find out the properties of the specimen.
2. Receiving all raw materials for making the bricks.
3. Weighing the raw materials (with a scale) and mix these in a bucket.
    a. The basic mixture is made of 3kg of clay, 3kg of fine sand, 4 kg of coarse sand and 1 liter of water.
4. Adding water to it and mix the mixture with the electrical Festool mixer for five minutes.
5. Additional:
    a. When wood chip or straw is added to the process, first the mixture is weighted and 1% of the total weight is the amount of the additional material which is added. This is mixed by hand for 5 minutes.
    b. Sorghum powder (400 grams) or pigeon feathers (100 grams) are added to a batch which had the weight of 11kg. This is mixed by hand for 5 minutes.
6. Add minimum water to the edges of the plastic containers to reduce issues while removing the specimen from the container.
7. Mixture is divided in the plastic containers (figure 2).
8. Mixture is compressed and equally divided with a wooden plate for 5 minutes (figure 3).
9. Mixture is removed from the mould and placed on a plastic sheet.
10. Place a sticky note next to the specimen to know which specimens contains which mixture.
11. The wet specimens have to dry for 1 week near the South windows at the “Maquette hal” at the Faculty of Architecture in Delft.
12. On day 6, the dimensions (RVS ruler) and weight (small scale) of the specimens were written down.
13. On day 7, the specimens were transported from the Faculty of Architecture in Delft to 3ME in Delft.

Figure 2: Big (left) and small (right) plastic moulds.

Figure 3: Equally divide mixture in container

For testing the specimens, the following steps were followed:

1. Specimens are unloaded and placed on the table in the order of testing.
2. Specimens were checked for defects or remarks. This is noted down in Excel.
3. Place the specimen on the wooden plate directly and centralized under the compression mechanism.
4. Photograph every specimen before the test.
5. Perform the test with the Zwick z100 machine.
6. Film 1 specimen type during the test.
7. Photograph every specimen after the test.
8. Note down the first findings during testing the samples.
9. Note down the maximum force per specimen.
10. Clean the wooden plate.
11. Start from point 3 for the new specimen.
12. Collect and analyze all results for finding the compression strength.
13. Discuss the results in the report.

2.7 Validity, reliability and limitations of the experiment

The internal validity of this study is based on the definition of the research and the steps per process which are executed. The results are combined with the results of the other groups which are part of the course 'AR3B011-Earthy'.

The errors in the process from making the specimens, measuring the specimens, testing the specimens, reporting and analyzing the specimens can impact the reliability of this study. The conditions which can impact the reliability of this study are:

- Instrument error; use different equipment devices, deviations.
- Quantitation error; the number of digits of the equipment devices is different.
- Method error; measuring other length, height or wall thickness of the specimen, variable placing specimen below the compression plate.
- Read-out error; read different numbers from the ruler, scale or test machine.
- Adjustment error; variable temperature in the experimental room during the drying process. Also, three different base mixtures had to be made as the buckets were too small for one big batch.

The big scale which was used for weighing the raw materials has the purpose to indicate human' weight. Therefore, the weighting procedure can contain a instrument, quantitation and read-out error. Next to this, test results of other groups are included in the result calculation. This brings inconsistencies in making batches procedures as this was not monitored. Also, the test method might deviate from this test set-up. As described, this test included a compression plate with a diameter of 100mm. Other groups might have used other surfaces and shapes to test the compression. This also refers back to a method error.

When producing the specimens, it was challenging to remove the specimen from the moulds. Therefore, the strength of the specimens can be influenced by this process.

Due to time limitations, the specimens only had one week to dry. Therefore, a difference between the big and small specimens can appear as the smaller bricks might be drier than the bigger specimens. This can influence the strength. Also, the Dutch climate (even indoor climate) is different than were the earth bricks will be produced e.g. Middle East.

2.8 Materials tested

Six different variants in mixture and sizes are made. The average data is shown in table 1.

Specimen	Average size (mm)			Average volume (mm^3)	Average weight (grams)	Density (kg/m3)
	length	Width	Height			
1) Adobe only (big)	159	122	67	1.295.652	1.944	1500,1
2) Adobe only (small)	112	109	40	487.214	837	1717,5
3) Adobe + straw	114	112	41	517.687	755	1459,1
4) Adobe + Wood chip	124	117	51	733.775	1.016	1384,6
5) Adobe + Sorghum	122	117	44	634.233	923	1454,9
6) Adobe + Feathers	117	112	41	542.151	827	1524,7

Table 1: Own specimens data

Standard specimen

The standard earth specimens contain:

- Fine sand (30%);
- Coarse sand (40%) and;
- Clay(30%).

Five specimens were made with the big container mould (specimen 1A-1E) and five specimens were made with the small container mould (Specimen 2A-2E). In figure 4, two specimens are shown. The basic mixture is made of 3kg of clay, 3kg of fine sand, 4 kg of coarse sand and 1 liter of water. The raw materials were supplied by TU Delft. In total we mixed two of these mixtures together to make one consistent mix. The specimens were made from the first out of three batches which are made to make all specimens for this study. No reinforcements were added to this mixture to understand the basics of the earth bricks. Some specimens were compressed very well and had no visible cracks. Some of the specimens were more brittle in appearance.

According to Sasui (2017), the compressive strength of earth bricks is between 0,45 MPa and 1,21 MPa. However, Illampas, Ioannou and Charmpis (2014) state that the compressive strength is between 0,6 and 8,3 MPa.

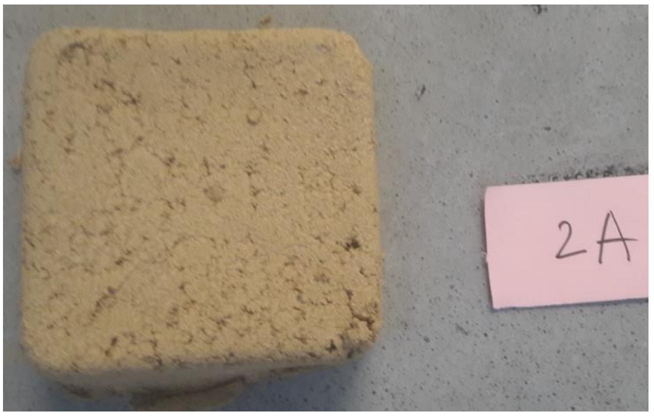

Figure 4: Big standard earth specimen 1A (left) and small standard earth specimen 2A (right).

Straw specimen

The straw specimens contain:

- Standard earth brick mixture (batch 1);
- 1% straw based on the standard earth mixture weight.

The standard earth mixture was part of the first batch which was produced. The straw is supplied by TU Delft. Only three specimens (specimen 3A-3C, figure 5) were made with the small container and left over was used for a very small specimen (specimen 3D). However, the exceptional small specimen was not tested due to time limitation. These specimens seem to be less brittle and appear to be more compressed because these specimens are the least heavy of all specimen types.

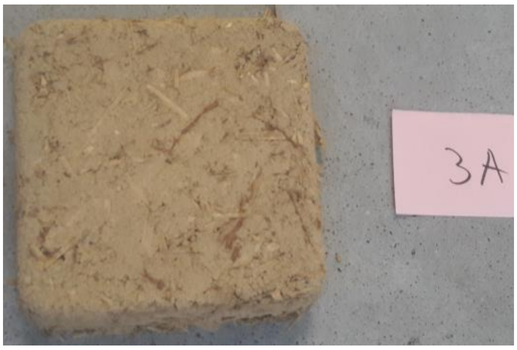

Figure 5: Small straw specimen 3A.

Wood chip specimen

The wood chip specimens contain:

- Standard earth brick mixture (batch 2);
- 1% wood chip based on the standard earth mixture weight.

Only two small specimens are made with wood chip, see figure 6. The wood chip is supplied by TU Delft. The standard earth mixture is from batch 2 out of 3. Therefore, the composition of the specimens can deviate from the standard and straw specimens. As with the straw specimens, these specimens appear to be less brittle and more compressed but is heavier than the straw specimens. This might be caused by the density of the wood chips itself.

Figure 6: Small wood chip specimen 4A.

Sorghum specimen

The Sorghum specimens contain:

- Standard earth brick mixture (batch 2);
- 400 grams of white sorghum powder (brand Holland & Barrett).

According to Salih, Imbabi and Osofero (2018) sugarcane improves the strength of an earth brick. Sugar is an ingredient which can be used for food purposes. Therefore, an ingredient which is important for feeding the camp is excluded. Therefore, an alternative is sorghum. Sorghum is a sticky ingredient which can also be used for food purposes, but also for waterproof houses. It grows quickly in dry climates(sorghumcheckoff, n.d.) and is therefore suitable for Jordan.

Seven small specimens are made with the sorghum specimen, see figure 7. The sorghum powder is supplied by group 2 and is bought at the Holland & Barrett shop. The mixture is mixed with the sorghum powder. No visual difference between the standard mixture specimens and the sorghum specimens except it looks more compressed and less brittle. This can be caused by the sorghum powder, a mixture of the standard earth and/ or mixing time.

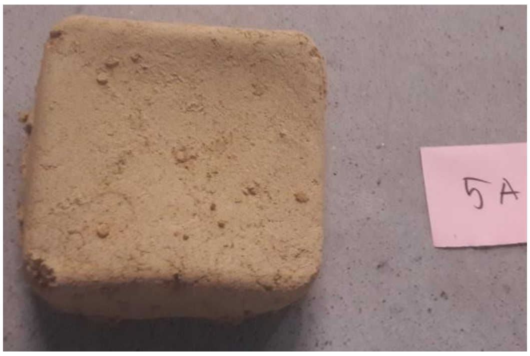

Figure 7: Small sorghum specimen 5A.

Feather specimen
The feather specimens contain:

- Standard earth brick mixture (batch 3);
- 100 grams of pigeon feathers.

According to Salih, Imbabi and Osofero (2018) chicken feather improves the strength of an earth brick. Therefore, feathers are chosen to be tested in this study.

Eight small specimens are made and one big specimen as this was a left over, see figure 8. The pigeon feathers were collected from a local pigeon keeper who keeps the birds for food purpose. The feathers were cut in pieces of approximately 30mm as the complete feather did not fit in the plastic container. Also, for mixing the feather with the earth mixture, it made it more difficult. In appearance, the specimens were the same as the standard earth mixture, but the feathers were visible on the surface. Also, it seems to be less brittle than the small standard earth specimens.

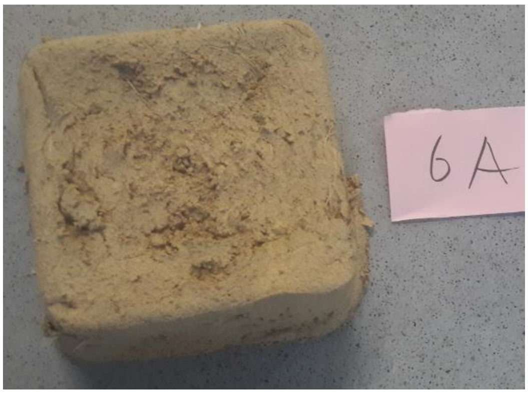

Figure 8: Small feather specimen 6A.

2.9 Measures taken to ensure scientific rigor

The process of this study is written down in detail including pictures. In appendix A, all the pictures of the tests can be found which includes showing the visible defects of the specimens. However, all specimens are made by hand. When repeating this process for validation, the end results might be different.

3 Results of the measurements

In this chapter, the properties of the tested specimens, execution of the experiment and results including calculations will be discussed. Also, the imprecision and reliability of the research will be discussed.

3.1 Properties of the tested specimens

All details of our and other groups specimens can be found in appendix B. In this overview, the dimensions, weight and ingredients are shown.

3.2 Execution of the experiment

The compression test of the specimens was performed by using the Zwick z10 machine at the Faculty of Mechanical, Maritime and Material Engineering (3ME) of the Delft University of Technology. This machine was limited till 100.000 N and will stop automatically.

First, all specimens were unloaded and ranked when every specimen should be tested, see figure 10. Also, the specimens were checked for visible defects as big cracks or missing parts. In this case, two specimens (3D & 5G) were not considered for this test.

A specimen was placed below the compression plate and visually centralized as much as possible, see figure 9. The test was executed, and the results was noted down in Excel and the specimen was photographed. Per specimen type, the test was filmed to understand the behavior of the material when it is under compression.

Figure 9: Compression test

Figure 10: Specimens at 3ME testing lab.

3.3 Results

In this paragraph, the physical fail results and the calculations of the compressive stress and elasticity modulus will be discussed. Where possible, this will be cross checked with literature.

Physical fail results

In figures 11 - 15, the physical results of each specimen type are shown. In appendix A, all the results of the specimens of group 2 are shown. Other specimens' pictures were not available as these were made by other groups. The physical results show that specimens with adobe only, wood chip and sorghum complete fail as these specimens completely lost their original shape. Specimens with straw and feathers only lost their original shape around the edges, the rest of the specimens remains as original.


Figure 11: Result adobe only (2D).


Figure 12: Result straw (3A).


Figure 13: Results wood chip (4B).


Figure 14: Result sorghum (5A).


Figure 15: Result Feathers (6C).

Accuracy

The more specimens are used for calculating the compressive stress and elasticity modulus, the more accurate the results will be. Therefore, not only the results of group 2 are used, but also the results of comparable specimens of the other groups are used. With these results, a normal distribution and statistical estimation of the imprecision with 95% are made. When the number of specimens is below 20, the factor that expresses the confidence which we state that the imprecision is correct (t) is used. See formula 1 which is used for all imprecision calculations and see formula 2-3 for the input formulas.

Formula 1:

$$\delta x = \frac{ts}{\sqrt{n}}$$

Formule 2:

$$\text{Mean} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Formule 3:

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}$$

Where;
t = imprecision correction
s = sample st. dev.
n = number of specimens
x = result per specimen

Compressive Stress

Adobe constructions are mostly built on compression. Therefore, the compressive stress must be calculated to understand which specimens is best suited for the design assignment of a bazaar. Formula 4 is used to calculate the compressive stress.

Formula 4:

$$Comp.Stress = \frac{F}{A}\left[\frac{N}{mm^2}\right]$$

Where;
F = Force in Newton
A = Surface of specimen in mm2

With the results of all specimens per type, a histogram was made. For adobe only, the histogram shows two normal distributions, see figure 16. This was caused by different sizes of blocks which were made by the groups. Therefore, first a limit range was determined with a box plot, see figure 17. The box plot shows the range of the common data and exceptional data. However, there was still no normal distribution shown in the histogram. Therefore, the specimens were divided into groups based on the compression surface. A normal distribution was shown per group and this is used for determining the strength of the specimens. For the other specimens' types, this was no issue. All shows a normal distribution in the histogram. All histograms and calculation overviews can be found in appendix B.

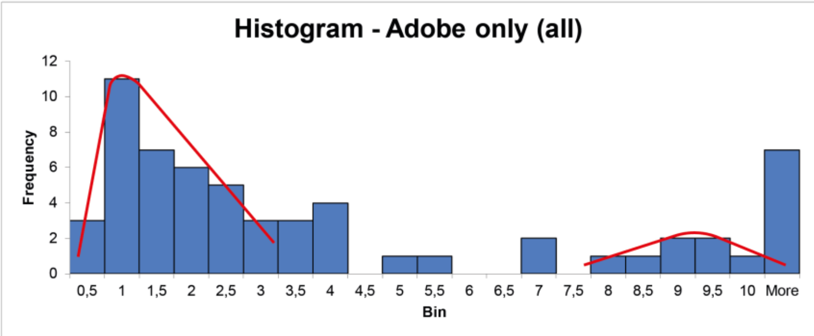

Figure 16: Histogram all adobe only.

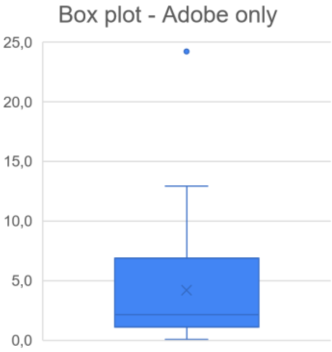

Figure 17: Box plot adobe only.

The calculated compressive stress is shown in table 2. For adobe only specimens, the results of the surface range are according to the statement of Illampas, Ioannou and Charmpis (2014) as they mentioned a compressive strength between 0,6 and 8,3 MPa for earth bricks with the same ratio of ingredients. To determine which type of material can be used as input for the design assignment, the physical outcome was selected. For the safety factor, according to Stewart and Lawrence (2007) a brick wall in compression van have a safety factor around 1.2. Due to many imprecisions of this test, a safety factor of 2 is chosen. The minimum compressive stress including safety factor will be used. Only the straw and feather specimen showed a most remaining shape. Therefore, these two types will be used as input for the structural calculation. The location of the type brick can be determined by the compressive stress as materials are limited in the camp.

Compressive stress [N/mm2]											
	Adobe only							Straw	Wood chip	Soghum	Feathers
	All	Limited range	Limited 0-5000mm²	Limited 5000-7500mm²	Limited 7.500-10.000mm²	Limited 10.000-15.000mm²	Limited 15.000+ mm²	All	All	All	All
Min	0,06	1,07	1,49	1,39	3,70	0,84	0,06	2,28	1,22	0,97	0,93
Max	24,23	6,93	24,23	12,94	11,26	8,83	3,35	10,48	7,55	1,61	7,95
Average	4,19	2,75	10,51	4,00	7,31	2,87	1,03	5,00	3,50	1,13	3,75
Median	2,13	2,13	9,01	2,62	6,79	1,47	0,76	3,81	2,84	1,04	3,25
st. dev	4,46	1,50	8,33	3,46	3,39	3,02	0,86	2,32	1,83	0,24	2,49
Correction factor	1,96	1,96	2,78	2,13	2,23	2,16	2,16	1,96	2,12	2,57	2,37
n	60,00	32,00	5,00	16,00	11,00	14,00	14,00	22,00	17,00	6,00	8,00
Correction	1,13	0,52	10,35	1,84	2,28	1,74	0,50	0,97	0,94	0,25	2,09
Min Stress	3,07	2,23	0,16	2,16	5,04	1,13	0,53	4,03	2,56	0,87	1,66
Max Stress	5,32	3,27	20,86	5,84	9,59	4,61	1,53	5,97	4,44	1,38	5,84
Safety factor	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00
Min Stress incl. factor	1,53	1,12	0,08	1,08	2,52	0,56	0,27	2,02	1,28	0,44	0,83
Max Stress incl. factor	2,66	1,63	10,43	2,92	4,80	2,30	0,77	2,99	2,22	0,69	2,92
Physical test result	Complete destroyed							Shape mostly remained	Complete destroyed	Complete destroyed	Shape mostly remained

Table 2: Results compressive stress per specimen type.

Elasticity modulus

Even when the whole design is based on compression force only, external factors can create tension in the structure e.g. wind. As the domes of the bazaar could be higher than the rest of the camp's buildings and caravans, wind has to be taken into account. According to Blondet and Vargas (1986), adobe bricks have an elasticity modulus of 170 MPa. Martins and Varum

(2006) tested adobe bricks and concluded that elasticity modulus is between 117 MPa and 273 MPa. For calculating the elasticity modulus, formula 5 is used. Less specimens were used for these calculations than with compressive stress due to software problems during testing. The deflection of the specimens was not always recorded. The strain of the specimen is not based on the total deflection, but on the linear deflection of the specimen. In figure 18 an example is shown how the strain is determined per specimen. The first part of the deflection is the adjustment of the compression plate to the specimen. The middle part is the deflection of the specimen itself. The last part is when the specimen already failed.

Formula 5:

$$E = \frac{\sigma}{\varepsilon}\left[\frac{N}{mm^2}\right]$$

Where;
ε = Strain in mm
σ = Compressive stress in N/mm2

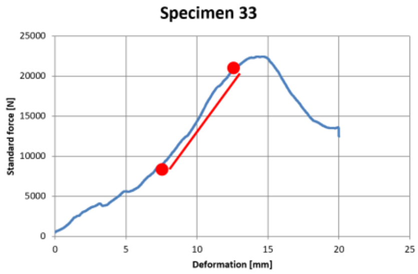

Figure 18: Determine the strain per specimen.

All histograms per type of specimens show a normal distribution. Therefore, no special ranges were made. In table 3, the results are summed. As straw and feathers are used as input for the structural design of the bazaar, the elasticity modulus will be used as an input.

Young's Modulus [N/mm2]					
	Adobe only	Straw	Wood chip	Soghum	Feathers
	All	All	All	All	All
Min	6,62	15,44	13,72	9,23	11,54
Max	647,00	174,63	141,12	16,85	55,70
Average	68,13	63,64	54,05	14,36	30,40
Median	25,22	55,94	50,74	15,99	24,37
st. dev	115,08	41,27	36,74	3,14	15,69
Correction factor	1,96	1,96	2,20	2,78	2,37
n	42,00	22,00	12,00	5,00	8,00
Correction	34,80	17,24	23,33	3,90	13,15
Min E-modulus	33,33	46,40	30,72	10,46	17,25
Max E-modulus	102,94	80,89	77,38	18,26	43,55
Physical test result	Complete destroyed	Shape mostly remained	Complete destroyed	Complete destroyed	Shape mostly remained

Table 3: Results elasticity Modulus per specimen type.

3.4 Imprecision and reliability of the research

As it is not known how the other groups selected their specimens for testing, the results can deviate. Also, The compression strength is not always the maximal strength which can be applied to the specimen. The specimen can be unequal so it breaks directly after the first moment of compression. Next to this, compression was applied on the specimen while is physically already failed(e.g. due to unequal bottom which caused major cracks. It is unknown if the other groups took this into account when they shared their results. Also, the number of specimens impact the final results of this study. For the feathers and sorghum variants, only seven specimens are tested in comparison with 22 straw specimens. The specimen sizes differ between 60 and 7 per type. Therefore, the comparison of the properties per type is less reliable. Finally, the mixture of the specimens can be made different by every group as factors like weight of the ingredients and mixture time can deviate. Also, the drying time and how the brick was positioned and treated during to process. Some groups turned the bricks during the drying process, and some did not. According to Sasui (2017), the bricks should dry for 28 days in the shadow to increase the strength of the brick, while the tested specimens only had 1 week to dry due to time limitation.

To conclude, the compressive stress and elasticity modulus for adobe is near the scientific studies, but it is made with Dutch ingredients instead of the Jordan ingredients. As we chose for adobe + straw and adobe + feathers, these types of bricks can even be stronger in Jordan. For filling up domes which has no structural purpose, adobe only bricks can be used. For now, we use the outcome of our tests.

4. Discussion, limitations and conclusion of the research

Discussion and limitations in combination with the conclusion will be discussed in this chapter.

4.1. Discussion and limitations

This study is based on literature research and a true experiment. However, limited literature is used as it was only to understand the limitations and treatment of earth bricks.

Next to this, this research contains limited specimens which were produced by different groups. This means different batches were produced and drying process deviates from each other. Also, the specimen sizes were different per group which not only impacts the compressive strength, but also the behavior of the specimen in the drying process

4.2 Conclusion

The research question of this study is as follows: What are the differences between an earth brick and bricks which contains reinforcement materials?
The strength of an adobe only specimen was between 0,16 MPa and 9,59 MPa. This deviates from other study's outcome. The tested adobe only specimens were destroyed, so the use of this type of adobe is not an option. Also, for adobe with wood chip and adobe with sorghum, the specimens lost their original shape completely. The compressive stress of adobe with straw was between 2.02 MPa and 2.99 MPa and for adobe with feathers between 0.83 MPa and 2.92 MPa. These two variants remained mostly in shape after testing.

To answer the research question: the difference of a plane earth brick and earth bricks with adhesive materials depends on the type of adhesive. Only straw and feathers made a difference in result as the shape was mostly intact after testing. Therefore, these two types of bricks will be used for further structural research for the course 'AR3B011-Earthy', designing a method of a bazaar in a refugee camp in the Middle East.

For future research, the behavior of the two chosen earth bricks can be further explored as only compressive stress and elasticity Modulus are based on compression. Also Tension and impact testing can be performed to understand the behavior of the bricks when it is under tensile force.

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5. Appendix

Appendix A: Specimens
Appendix B: Calculations and Histogram Compressive stress
Appendix C: Calculations and Histogram elasticity Modulus

Appendix A: Specimens

Specimen	1L water	% sand (coarse)	% sand (fine)	% clay	% Straw	% Wood chip	Sorghum (grams)	Pigeon feathers (grams)	Batch	Weight (grams)	Length (mm)	Width (mm)	Height (mm)	Moulds	F_{max} (N)	dL at F_{max} (mm)	Area (mm2)	Compressive Stress (n/mm2)	Comment
1A	Yes	40	30	30	No	No	No	No	1	2.099	164	121	71	Big	8.320	11,8	19844	0,42	
1B	Yes	40	30	30	No	No	No	No	1	1.732	159	124	63	Big	15.681	11,8	19716	0,80	
1C	Yes	40	30	30	No	No	No	No	1	2.004	155	124	67	Big	10.478	11,2	19220	0,55	
1D	Yes	40	30	30	No	No	No	No	1	1.796	159	114	64	Big	12.006	13,1	18126	0,66	
1E	Yes	40	30	30	No	No	No	No	1	2.087	159	128	68	Big	8.844	12,4	20352	0,43	Unequal in bottom
2A	Yes	40	30	30	No	No	No	No	1	904	113	113	43	Small	19.500	-	12769	1,53	Unequal in bottom
2B	Yes	40	30	30	No	No	No	No	1	820	109	111	40	Small	93.036	25,0	12099	7,69	
2C	Yes	40	30	30	No	No	No	No	1	752	109	108	36	Small	101.161	24,3	11772	8,59	
2D	Yes	40	30	30	No	No	No	No	1	908	116	109	42	Small	20.700	-	12644	1,64	Unequal in bottom
2E	Yes	40	30	30	No	No	No	No	1	800	111	102	40	Small	99.968	24,1	11322	8,83	
3A	Yes	40	30	30	1	No	No	No	1	725	115	111	40	Small	100.549	15,0	12765	7,88	
3B	Yes	40	30	30	1	No	No	No	1	780	116	114	41	Small	100.385	19,8	13224	7,59	
3C	Yes	40	30	30	1	No	No	No	1	761	111	110	41	Small	100.294	20,9	12210	8,21	
3D	Yes	40	30	30	1	No	No	No	1	373	119	88	30	Except. small	-	-	10472		
4A	Yes	40	30	30	No	1	No	No	2	988	125	118	50	Small	38.374	20,0	14750	2,60	
4B	Yes	40	30	30	No	1	No	No	2	1.044	122	115	52	Small	65.934	25,0	14030	4,70	
5A	Yes	40	30	30	No	No	400	No	2	854	119	117	45	Small	22.449	14,6	13923	1,61	
5B	Yes	40	30	30	No	No	400	No	2	953	121	113	48	Small	14.198	10,4	13673	1,04	
5C	Yes	40	30	30	No	No	400	No	2	1.052	124	118	50	Small	14.135	13,0	14632	0,97	
5D	Yes	40	30	30	No	No	400	No	2	859	124	117	42	Small	15.700	-	14508	1,08	
5E	Yes	40	30	30	No	No	400	No	2	965	120	118	46	Small	14.385	17,5	14160	1,02	
5F	Yes	40	30	30	No	No	400	No	2	849	121	120	38	Small	15.158	11,3	14520	1,04	Partirly breaking
5G	Yes	40	30	30	No	No	400	No	2	927	123	118	42	Small	-	-	14514		Partirly breaking
6A	Yes	40	30	30	No	No	No	100	3	883	118	115	44	Small	22.502	15,0	13570	1,66	
6B	Yes	40	30	30	No	No	No	100	3	795	118	109	35	Small	11.900	-	12862	0,93	
6C	Yes	40	30	30	No	No	No	100	3	888	119	116	42	Small	27.988	15,0	13804	2,03	
6D	Yes	40	30	30	No	No	No	100	3	840	116	114	41	Small	28.210	15,0	13224	2,13	
6E	Yes	40	30	30	No	No	No	100	3	905	119	111	46	Small	57.591	20,0	13209	4,36	
6F	Yes	40	30	30	No	No	No	100	3	715	116	109	39	Small	100.492	18,3	12644	7,95	
6G	Yes	40	30	30	No	No	No	100	3	811	118	115	44	Small	86.520	20,0	13570	6,38	
6H	Yes	40	30	30	No	No	No	100	3	776	113	106	40	Small	54.940	20,0	11978	4,59	
6I	Yes	40	30	30	No	No	No	100	3	1.682	159	122	63	Big	19.300	-	19398	0,99	

Standard specimen (left:Dry specimens at BK, middle: before test, right: after test)

1A:

1B:

1C:

1D:

1E: 

2A: 

2B: 

2C: 

2D: 

2E: 

Straw specimen (left:Dry specimens at BK, middle: before test, right: after test)

3A: 

3B: 

3C: 

3D:  Not tested

Wood chip specimen (left:Dry specimens at BK, middle: before test, right: after test)

4A: 

4B: 

Sorghum specimen (left:Dry specimens at BK, middle: before test, right: after test)

5A:

5B:

5C

5D:

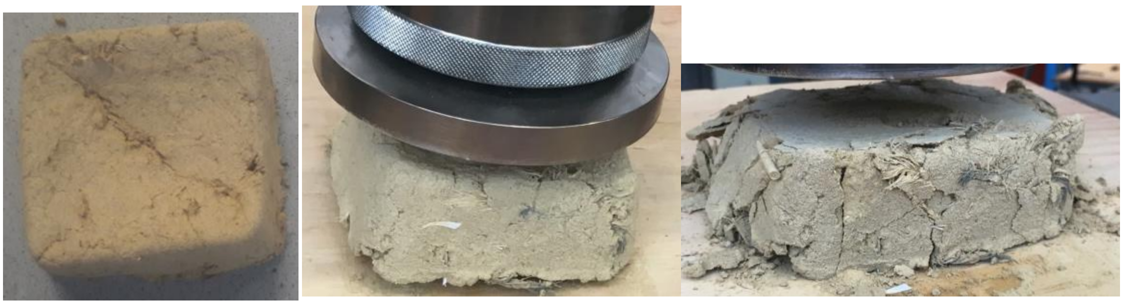
5E:

5F:

5G: Not tested

Feather specimen (left:Dry specimens at BK, middle: before test, right: after test)

6A:



6B:

6C:

6D:

6E:

6F:

6G:

6H:

6I:

Appendix B: Calculations and Histogram

Compressive stress

Data adobe only specimens:

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax (mm)	Area (mm2)	Compressive stress [N/mm2]
	L	W	H				
2	165	105	65	1.104	0,09	17325	0,1
1A	164	121	71	8.320	11,76	19844	0,4
1E	159	128	68	8.845	12,41	20352	0,4
1C	155	124	67	10.478	11,19	19220	0,5
5	165	105	65	11.457	9,67	17325	0,7
1D	159	114	64	12.006	13,09	18126	0,7
3	165	105	65	12.436	9,60	17325	0,7
1B	159	124	63	15.681	11,81	19716	0,8
A1	175	85	40	12.458	11,32	14875	0,8
A3	175	85	40	13.028	11,29	14875	0,9
4	165	105	65	15.587	8,49	17325	0,9
A2	175	85	40	13.624	9,26	14875	0,9
1	165	105	65	16.123	8,98	17325	0,9
A1	160	100	60	14.900	NA	16000	0,9
A4	175	85	40	15.951	14,95	14875	1,1
A5	175	85	40	19.770	8,56	14875	1,3
1	100	100	60	13.310	9,13	10000	1,3
S1s	95	70	30	9.216	7,91	6650	1,4
A6	175	85	40	21.832	10,02	14875	1,5
5	100	100	60	14.792	8,95	10000	1,5
7	60	60	50	5.352	12,54	3600	1,5
A3	95	70	30	10.380	4,91	6650	1,6
4	100	100	60	16.457	14,33	10000	1,6
A4	100	75	30	13.673	9,43	7500	1,8
3	100	100	60	19.247	12,70	10000	1,9
A9	170	90	40	29.867	9,68	15300	2,0
A6	100	75	30	14.996	11,96	7500	2,0
A8	170	90	40	31.979	7,55	15300	2,1
A3	100	75	30	15.700	NA	7500	2,1
A4	95	70	30	14.003	5,90	6650	2,1
2	100	100	60	21.595	9,90	10000	2,2
A2	95	70	30	16.087	NA	6650	2,4
S5s	95	70	30	16.900	NA	6650	2,5
S3s	95	70	30	17.900	NA	6650	2,7
A5	95	70	30	18.571	NA	6650	2,8
S4s	95	70	30	20.200	NA	6650	3,0
S2s	95	70	30	21.900	NA	6650	3,3
A7	170	90	40	51.283	19,53	15300	3,4
A9	105	75	30	29.158	NA	7875	3,7
A11	105	75	30	30.335	NA	7875	3,9
7	110	80	30	35.100	NA	8800	4,0
10	110	80	30	35.139	NA	8800	4,0
9	110	80	30	39.892	NA	8800	4,5
A1	100	75	30	38.700	NA	7500	5,2
8	110	80	30	59.763	NA	8800	6,8
A5	100	75	30	52.000	NA	7500	6,9
2B	109	111	40	93.036	24,98	12099	7,7
9	60	60	50	30.596	3,82	3600	8,5
2C	109	108	36	101.161	24,30	11772	8,6
2E	111	102	40	99.968	24,05	11322	8,8
10	60	60	50	32.418	6,39	3600	9,0
6	60	60	50	33.602	2,73	3600	9,3
A7	105	75	30	78.228	14,97	7875	9,9
A12	105	75	30	79.126	14,98	7875	10,0
A10	105	75	30	87.904	14,99	7875	11,2
6	110	80	30	98.454	14,98	8800	11,2
A2	100	75	30	83.998	11,97	7500	11,2
A8	105	75	30	88.700	NA	7875	11,3
A6	95	70	30	86.044	NA	6650	12,9
8	60	60	50	87.217	3,74	3600	24,2

Data straw specimens:

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax (mm)	Area (mm2)	Compressive stress [N/mm2]
	L	W	H				
S2	175	85	40	33.958	14,79	14875	2,3
12	135	90	40	29.811	8,86	12150	2,5
S1	175	85	40	36.593	14,94	14875	2,5
16	135	90	40	38.757	14,94	12150	3,2
S4	175	85	40	51.785	14,93	14875	3,5
S6	105	75	30	27.459	9,97	7875	3,5
S1	170	90	40	53.933	24,96	15300	3,5
15	135	90	40	43.370	13,16	12150	3,6
S3	175	85	40	56.106	14,94	14875	3,8
S5	175	85	40	56.502	14,94	14875	3,8
14	135	90	40	46.270	14,94	12150	3,8
11	135	90	40	46.286	14,94	12150	3,8
S2	170	90	40	69.109	18,18	15300	4,5
S4	170	90	40	72.196	23,67	15300	4,7
13	135	90	40	63.062	14,95	12150	5,2
S2	100	75	30	47.607	11,97	7500	6,3
S3	170	90	40	100.499	16,27	15300	6,6
3B	116	114	41	100.385	19,83	13224	7,6
3A	115	111	40	100.550	14,95	12765	7,9
3C	111	110	41	100.294	20,94	12210	8,2
S3	100	75	30	66.656	11,96	7500	8,9
S1	100	75	30	78.582	11,98	7500	10,5

Data wood chip specimens:

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax (mm)	Area (mm2)	Compressive stress [N/mm2]
	L	W	H				
WD3	90	90	40	9843	7,28	8100	1,22
WD1	170	90	40	24253	6,72	15300	1,59
20	135	90	40	26409	9,44	12150	2,17
19	135	90	40	27851	14,94	12150	2,29
SW1s	95	70	30	15900		6650	2,39
Sw3s	95	70	30	16700		6650	2,51
4A	125	118	50	38374	19,96	14750	2,60
17	135	90	40	32480	9,24	12150	2,67
WD2	170	90	40	43393	16,73	15300	2,84
18	135	90	40	35831	9,97	12150	2,95
21	135	90	40	35841	14,69	12150	2,95
Sw2s	95	70	30	22700		6650	3,41
4B	122	115	52	65934	24,97	14030	4,70
WD2	100	75	30	38300	-	7500	5,11
W1	105	75	30	43293	11,96	7875	5,50
WD3	100	75	30	52496	11,98	7500	7,00
WD1	100	75	30	56650	11,97	7500	7,55

Data sorghum specimens:

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax (mm)	Area (mm2)	Compressive stress [N/mm2]
	L	W	H				
5A	119	117	45	22.449	14,6	13923	1,61
5B	121	113	48	14.198	10,4	13673	1,04
5C	124	118	50	14.135	13,0	14632	0,97
5D	124	117	42	15.700	-	14508	1,08
5E	120	118	46	14.385	17,5	14160	1,02
5F	121	120	38	15.158	11,3	14520	1,04

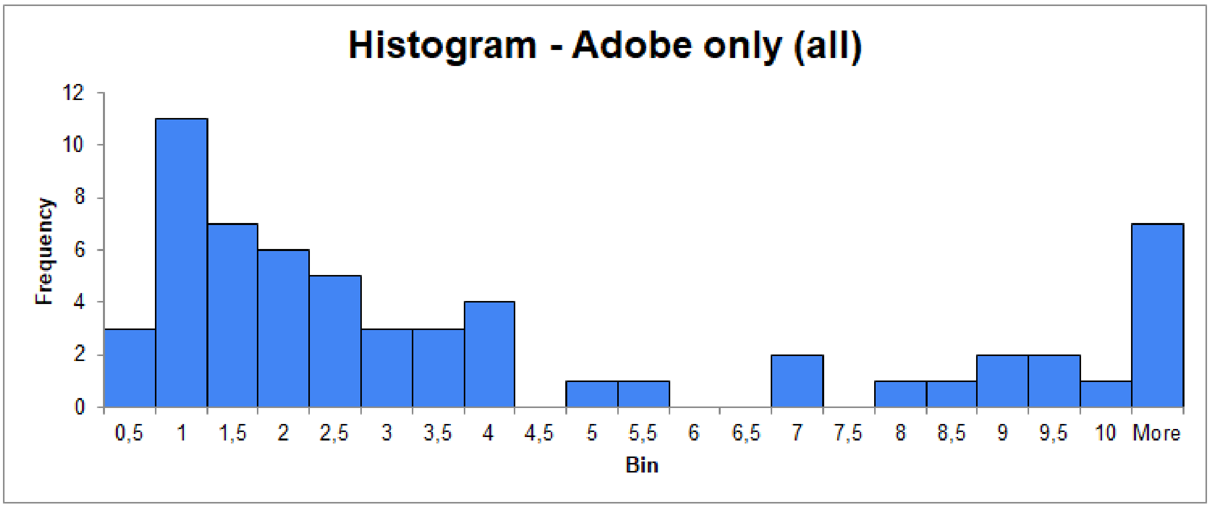
Data feathers specimens:

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax (mm)	Area (mm2)	Compressive stress [N/mm2]
	L	W	H				
6A	118	115	44	22.502	15,0	13570	1,66
6B	118	109	35	11.900	15,0	12862	0,93
6C	119	116	42	27.988	15,0	13804	2,03
6D	116	114	41	28.210	15,0	13224	2,13
6E	119	111	46	57.591	20,0	13209	4,36
6F	116	109	39	100.492	18,3	12644	7,95
6G	118	115	44	86.520	20,0	13570	6,38
6H	113	106	40	54.940	20,0	11978	4,59
6I	159	122	63	19.300		19398	0,99

Accuracy calculation - Statistical estimation of the imprecision:

Compressive stress [N/mm2]											
	Adobe only							Straw	Wood chip	Soghum	Feathers
	All	Limited range	Limited 0-5000mm²	Limited 5000-7500mm²	Limited 7.500-10.000mm²	Limited 10.000-15.000mm²	Limited 15.000+ mm²	All	All	All	All
Min	0,06	1,07	1,49	1,39	3,70	0,84	0,06	2,28	1,22	0,97	0,93
Max	24,23	6,93	24,23	12,94	11,26	8,83	3,35	10,48	7,55	1,61	7,95
Average	4,19	2,75	10,51	4,00	7,31	2,87	1,03	5,00	3,50	1,13	3,75
Median	2,13	2,13	9,01	2,62	6,79	1,47	0,76	3,81	2,84	1,04	3,25
st. dev	4,46	1,50	8,33	3,46	3,39	3,02	0,86	2,32	1,83	0,24	2,49
Correction factor	1,96	1,96	2,78	2,13	2,23	2,16	2,16	1,96	2,12	2,57	2,37
n	60,00	32,00	5,00	16,00	11,00	14,00	14,00	22,00	17,00	6,00	8,00
Correction	1,13	0,52	10,35	1,84	2,28	1,74	0,50	0,97	0,94	0,25	2,09
Min Stress	3,07	2,23	0,16	2,16	5,04	1,13	0,53	4,03	2,56	0,87	1,66
Max Stress	5,32	3,27	20,86	5,84	9,59	4,61	1,53	5,97	4,44	1,38	5,84
Safety factor	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,00
Min Stress incl. factor	1,53	1,12	0,08	1,08	2,52	0,56	0,27	2,02	1,28	0,44	0,83
Max Stress incl. factor	2,66	1,63	10,43	2,92	4,80	2,30	0,77	2,99	2,22	0,69	2,92
Physical test result	Complete destroyed							Shape mostly remained	Complete destroyed	Complete destroyed	Shape mostly remained

Histogram: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10
8
6
4
2
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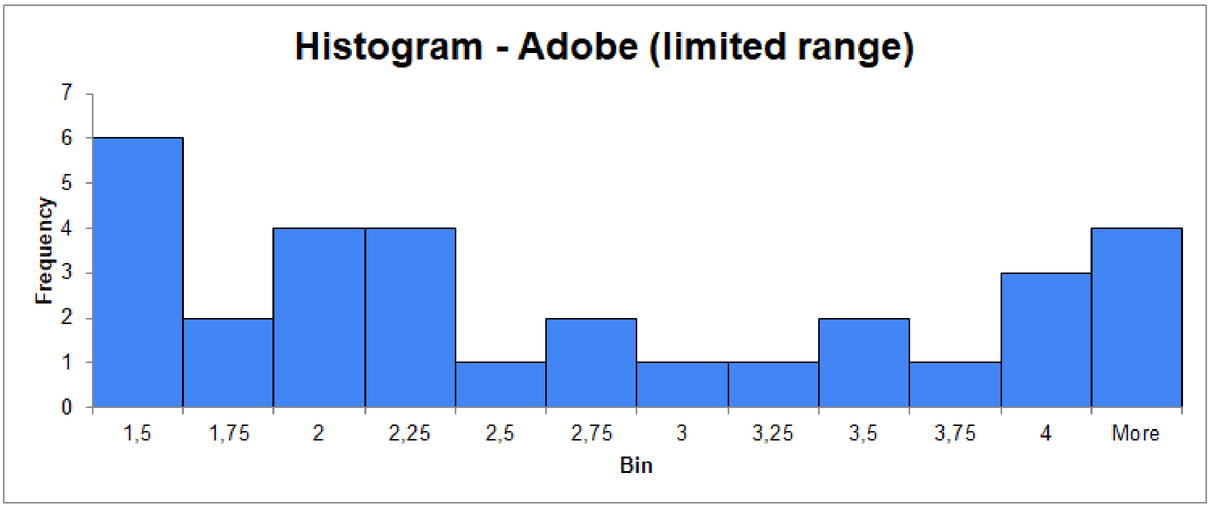
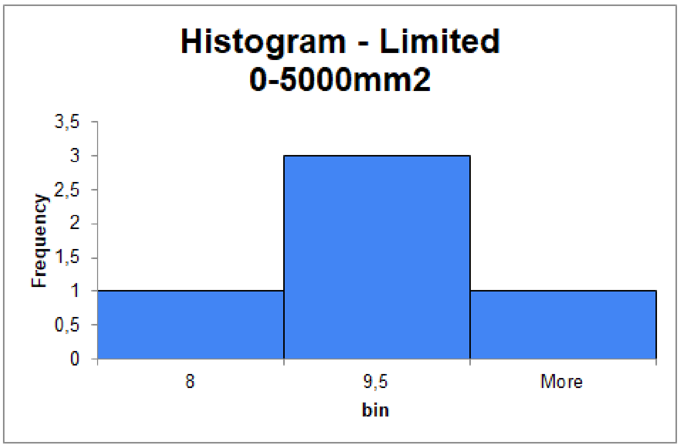
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6
6,5
7
7,5
8
8,5
9
9,5
10
More
Bin


Histogram - Adobe (limited range)
Frequency
7
6
5
4
3
2
1
0
1,5
1,75
2
2,25
2,5
2,75
3
3,25
3,5
3,75
4
More
Bin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0-5000mm2
Frequency
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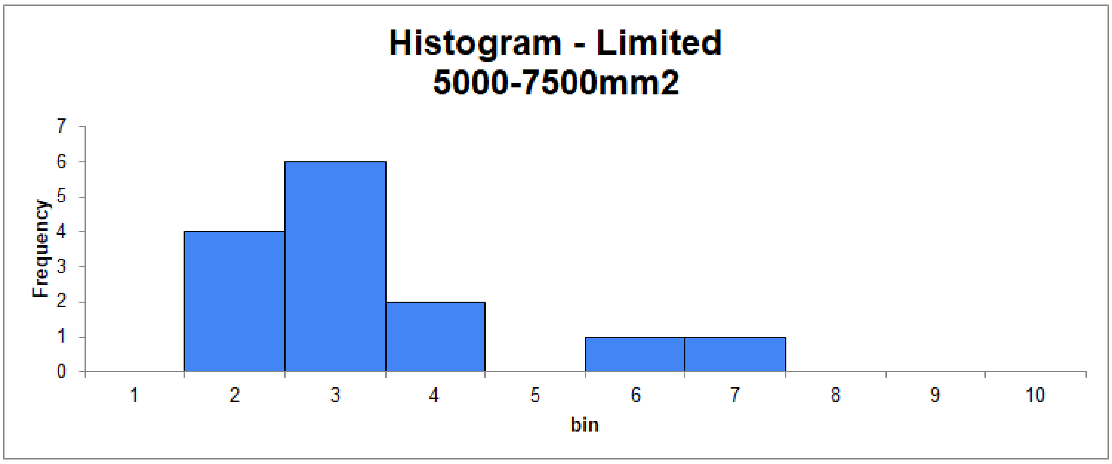
3
2,5
2
1,5
1
0,5
0
8
9,5
More
bin


Histogram - Limited
5000-7500mm2
Frequency
7
6
5
4
3
2
1
0
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2
3
4
5
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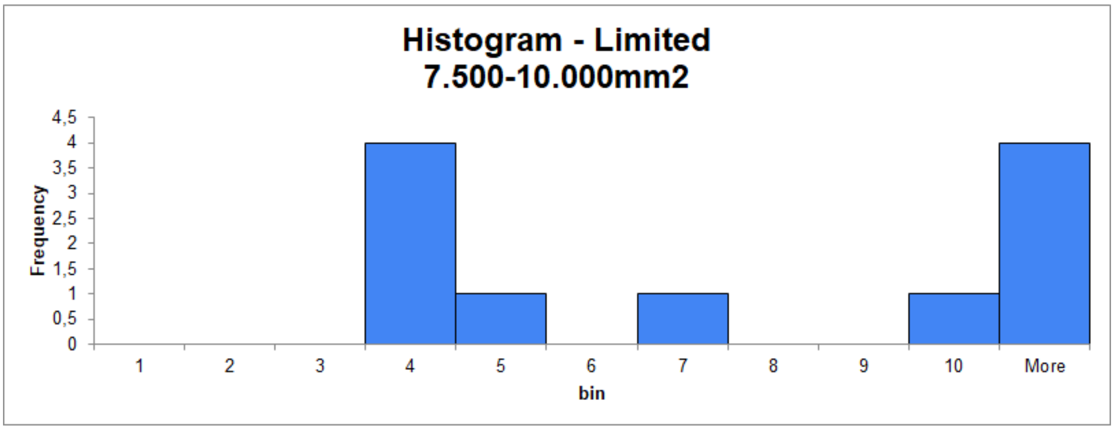
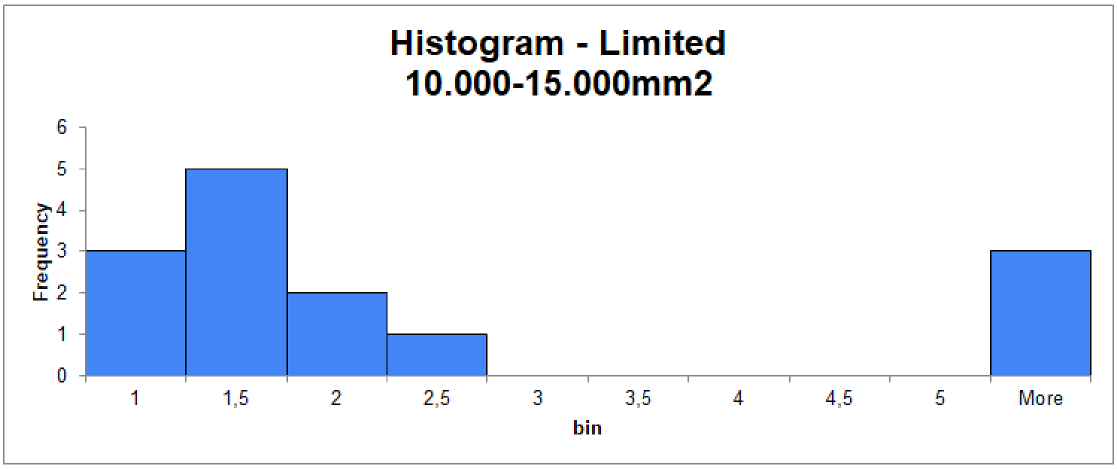
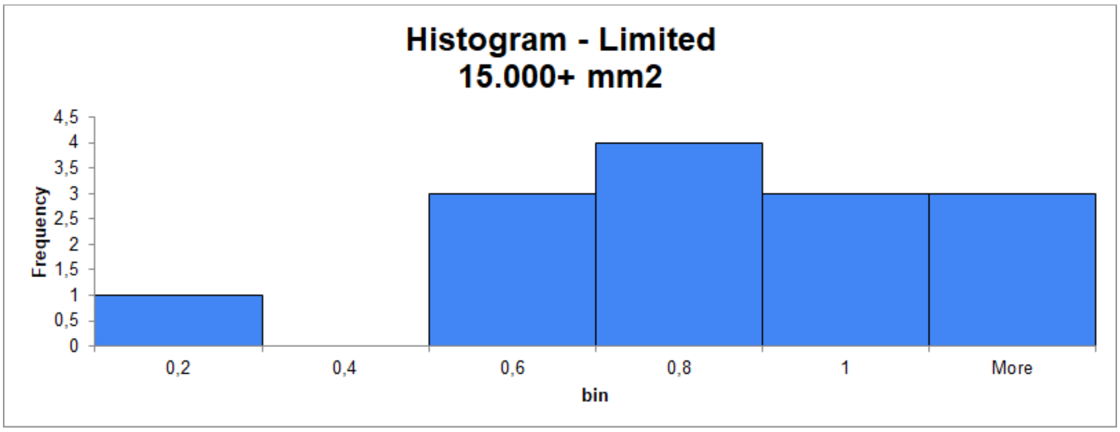
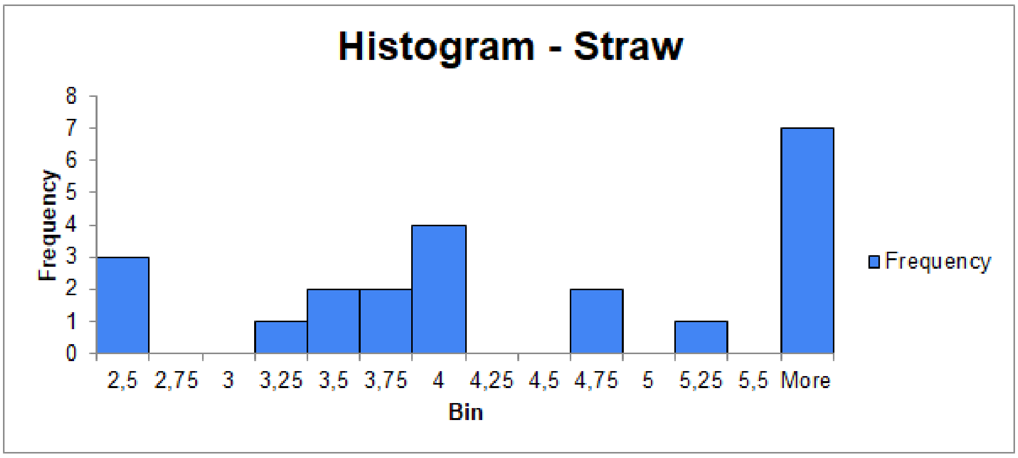
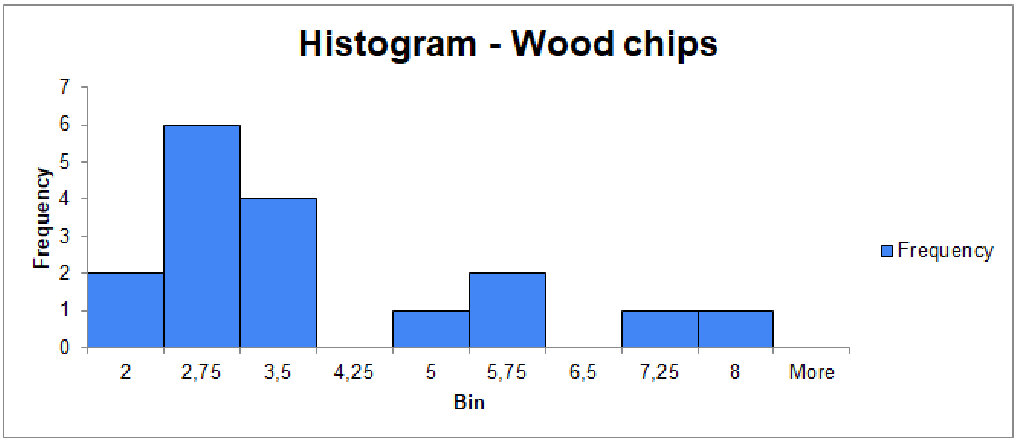
7
8
9
10
bin

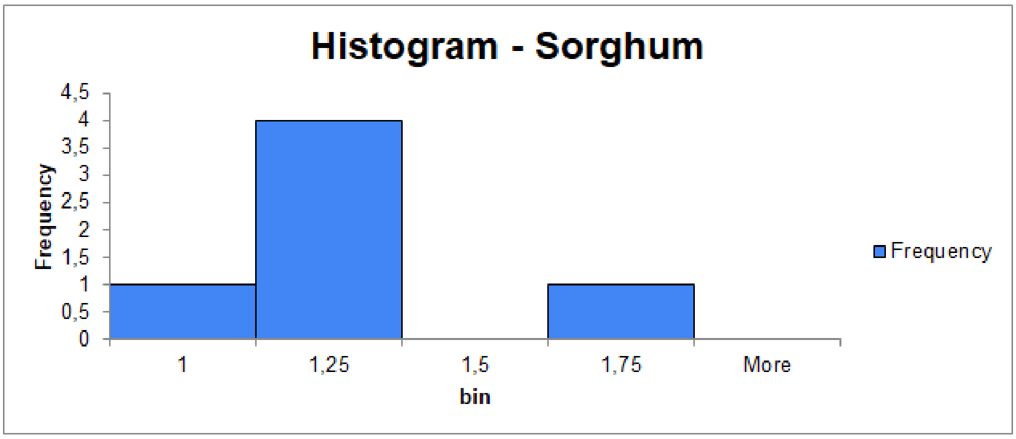

Histogram - Limited
7.500-10.000mm2
Frequency
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
1
2
3
4
5
6
7
8
9
10
More
bin

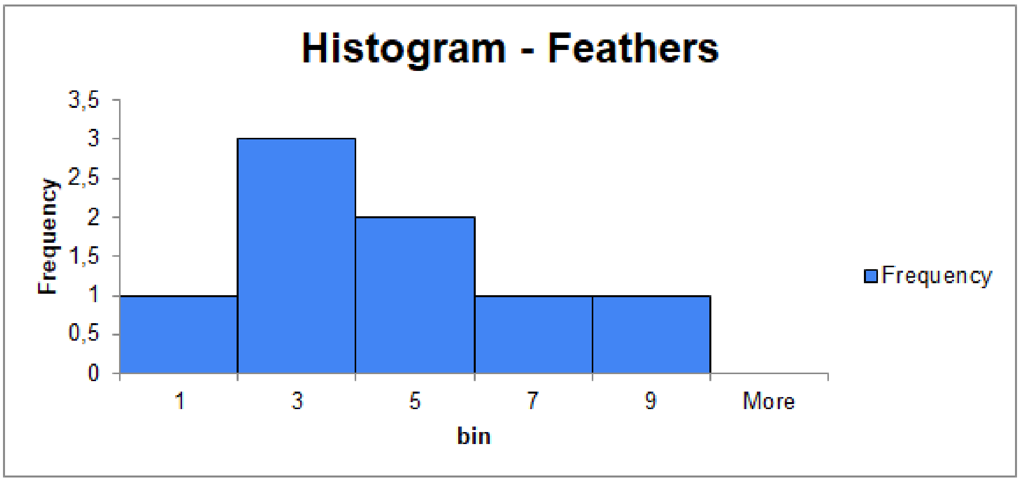

Histogram - Limited
10.000-15.000mm2
Frequency
6
5
4
3
2
1
0
1
1,5
2
2,5
3
3,5
4
4,5
5
More
bin


Histogram - Limited
15.000+ mm2
Frequency
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
0,2
0,4
0,6
0,8
1
More
bin


Histogram - Straw
Frequency
8
7
6
5
4
3
2
1
0
2,5 2,75 3 3,25 3,5 3,75 4 4,25 4,5 4,75 5 5,25 5,5 More
Bin
Frequency


Histogram - Wood chips
Frequency
7
6
5
4
3
2
1
0
2 2,75 3,5 4,25 5 5,75 6,5 7,25 8 More
Bin
Frequency


Histogram - Sorghum
Frequency
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
1 1,25 1,5 1,75 More
bin
Frequency


Histogram - Feathers
Frequency
3,5
3
2,5
2
1,5
1
0,5
0
1 3 5 7 9 More
bin
Frequency

Appendix C: Calculations and Histogram elasticity Modulus

Data adobe only specimens:

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax (mm)	Area (mm^2)	Compressive stress [N/mm^2]	Moment of Inertia (mm^4)	Strain (mm)	Young's modulus (N/mm^2)
	L	W	H							
2	165	105	65	1.104	0,09	17325	0,1	2.402.969	0,09	70,81
1A	164	121	71	8.320	11,76	19844	0,4	3.608.936	6,00	6,99
1E	159	128	68	8.845	12,41	20352	0,4	3.353.941	6,00	7,24
1C	155	124	67	10.478	11,19	19220	0,5	3.107.884	5,00	10,90
5	165	105	65	11.457	9,67	17325	0,7	2.402.969	4,00	16,53
1D	159	114	64	12.006	13,09	18126	0,7	2.490.368	10,00	6,62
3	165	105	65	12.436	9,60	17325	0,7	2.402.969	6,00	11,96
1B	159	124	63	15.681	11,81	19716	0,8	2.583.819	10,00	7,95
A1	175	85	40	12.458	11,32	14875	0,8	453.333	10,00	8,37
A3	175	85	40	13.028	11,29	14875	0,9	453.333	5,00	17,52
4	165	105	65	15.587	8,49	17325	0,9	2.402.969	5,00	17,99
A2	175	85	40	13.624	9,26	14875	0,9	453.333	9,26	9,89
1	165	105	65	16.123	8,98	17325	0,9	2.402.969	8,98	10,36
A4	175	85	40	15.951	14,95	14875	1,1	453.333	6,00	17,87
A5	175	85	40	19.770	8,56	14875	1,3	453.333	8,56	15,53
1	100	100	60	13.310	9,13	10000	1,3	1.800.000	4,10	32,46
S1s	95	70	30	9.216	7,91	6650	1,4	157.500	7,91	17,52
A6	175	85	40	21.832	10,02	14875	1,5	453.333	10,02	14,65
5	100	100	60	14.792	8,95	10000	1,5	1.800.000	6,50	22,76
7	60	60	50	5.352	12,54	3600	1,5	625.000	8,00	18,58
A3	95	70	30	10.380	4,91	6650	1,6	157.500	3,91	39,92
4	100	100	60	16.457	14,33	10000	1,6	1.800.000	9,00	18,29
A4	100	75	30	13.673	9,43	7500	1,8	168.750	6,00	30,38
3	100	100	60	19.247	12,70	10000	1,9	1.800.000	10,00	19,25
A9	170	90	40	29.867	9,68	15300	2,0	480.000	6,68	29,22
A6	100	75	30	14.996	11,96	7500	2,0	168.750	6,00	33,33
A8	170	90	40	31.979	7,55	15300	2,1	480.000	7,55	27,68
A4	95	70	30	14.003	5,90	6650	2,1	157.500	4,90	42,97
2	100	100	60	21.595	9,90	10000	2,2	1.800.000	9,90	21,82
A7	170	90	40	51.283	19,53	15300	3,4	480.000	11,00	30,47
2B	109	111	40	93.036	24,98	12099	7,7	592.000	15,00	51,26
9	60	60	50	30.596	3,82	3600	8,5	625.000	3,82	222,70
2C	109	108	36	101.161	24,30	11772	8,6	419.904	7,00	122,76
2E	111	102	40	99.968	24,05	11322	8,8	544.000	10,00	88,30
10	60	60	50	32.418	6,39	3600	9,0	625.000	6,39	141,01
6	60	60	50	33.602	2,73	3600	9,3	625.000	2,73	342,35
A7	105	75	30	78.228	14,97	7875	9,9	168.750	9,00	110,38
A12	105	75	30	79.126	14,98	7875	10,0	168.750	9,00	111,64
A10	105	75	30	87.904	14,99	7875	11,2	168.750	9,00	124,03
6	110	80	30	98.454	14,98	8800	11,2	180.000	9,00	124,31
A2	100	75	30	83.998	11,97	7500	11,2	168.750	8,00	140,00
8	60	60	50	87.217	3,74	3600	24,2	625.000	3,74	647,00

Data straw specimens:

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax (mm)	Area (mm^2)	Compressive stress [N/mm^2]	Moment of Inertia (mm^4)	Strain (mm)	Young's modulus (N/mm^2)
	L	W	H							
S2	175	85	40	33.958	14,79	14875	2,3	453.333	14,79	15,44
12	135	90	40	29.811	8,86	12150	2,5	480.000	6,86	35,77
S1	175	85	40	36.593	14,94	14875	2,5	453.333	14,94	16,47
16	135	90	40	38.757	14,94	12150	3,2	480.000	10,94	29,16
S4	175	85	40	51.785	14,93	14875	3,5	453.333	14,93	23,32
S6	105	75	30	27.459	9,97	7875	3,5	168.750	5,97	58,41
S1	170	90	40	53.933	24,96	15300	3,5	480.000	10,96	32,16
15	135	90	40	43.370	13,16	12150	3,6	480.000	6,16	57,95
S3	175	85	40	56.106	14,94	14875	3,8	453.333	10,94	34,48
S5	175	85	40	56.502	14,94	14875	3,8	453.333	14,94	25,42
14	135	90	40	46.270	14,94	12150	3,8	480.000	7,94	47,96
11	135	90	40	46.286	14,94	12150	3,8	480.000	4,94	77,12
S2	170	90	40	69.109	18,18	15300	4,5	480.000	5,50	82,13
S4	170	90	40	72.196	23,67	15300	4,7	480.000	8,75	53,93
13	135	90	40	63.062	14,95	12150	5,2	480.000	4,95	104,85
S2	100	75	30	47.607	11,97	7500	6,3	168.750	6,00	105,79
S3	170	90	40	100.499	16,27	15300	6,6	480.000	12,27	53,53
3B	116	114	41	100.385	19,83	13224	7,6	654.750	9,93	76,45
3A	115	111	40	100.550	14,95	12765	7,9	592.000	10,95	71,94
3C	111	110	41	100.294	20,94	12210	8,2	631.776	10,94	75,08
S3	100	75	30	66.656	11,96	7500	8,9	168.750	6,00	148,12
S1	100	75	30	78.582	11,98	7500	10,5	168.750	6,00	174,63

Data wood chip specimens:

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax (mm)	Area (mm^2)	Compressive stress [N/mm^2]	Moment of Inertia (mm^4)	Strain (mm)	Young's modulus (N/mm^2)
	L	W	H							
WD3	90	90	40	9843	7,28	8100	1,22	480.000	5,27	23,06
WD1	170	90	40	24253	6,72	15300	1,59	480.000	6,72	23,59
20	135	90	40	26409	9,44	12150	2,17	480.000	3,44	63,18
4A	125	118	50	38374	19,96	14750	2,60	1.229.167	18,96	13,72
17	135	90	40	32480	9,24	12150	2,67	480.000	7,24	36,92
WD2	170	90	40	43393	16,73	15300	2,84	480.000	6,73	42,14
18	135	90	40	35831	9,97	12150	2,95	480.000	4,97	59,34
21	135	90	40	35841	14,69	12150	2,95	480.000	4,69	62,90
4B	122	115	52	65934	24,97	14030	4,70	1.347.493	24,97	18,82
W1	105	75	30	43293	11,96	7875	5,50	168.750	7,96	69,06
WD3	100	75	30	52496	11,98	7500	7,00	168.750	4,96	141,12
WD1	100	75	30	56650	11,97	7500	7,55	168.750	7,97	94,77

Data sorghum specimens:

Code	Dimensional Properties (mm)			Fmax (N)	dL at Fmax (mm)	Area (mm^2)	Compressive stress [N/mm^2]	Moment of Inertia (mm^4)	Strain (mm)	Young's modulus (N/mm^2)
	L	W	H							
5A	119	117	45	22.449	14,6	13923	1,61	888.469	9,57	16,85
5B	121	113	48	14.198	10,4	13673	1,04	1.041.408	6,40	16,22
5C	124	118	50	14.135	13,0	14632	0,97	1.229.167	6,04	15,99
5E	120	118	46	14.385	17,5	14160	1,02	957.137	7,53	13,49
5F	121	120	38	15.158	11,3	14520	1,04	548.720	11,30	9,23

Data feathers specimens:

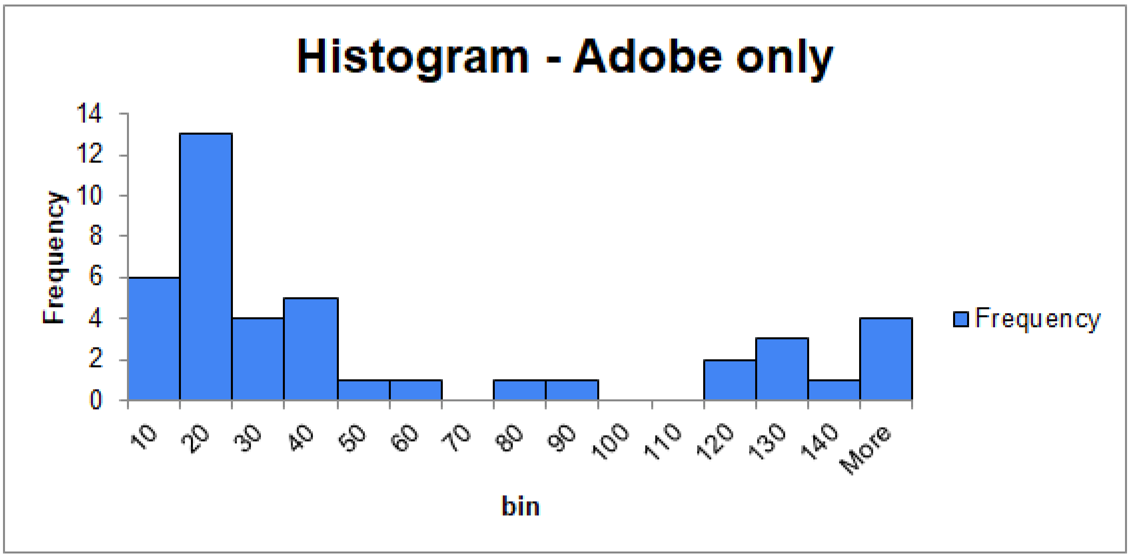
Code	Dimensional Properties (mm) L	W	H	Fmax (N)	dL at Fmax (mm)	Area (mm²)	Compressive stress [N/mm²]	Moment of Inertia (mm⁴)	Strain (mm)	Young's modulus (N/mm²)
6A	118	115	44	22.502	15,0	13570	1,66	816.347	9,06	18,30
6B	118	109	35	11.900	15,0	12862	0,93	389.448	8,02	11,54
6C	119	116	42	27.988	15,0	13804	2,03	716.184	9,96	20,36
6D	116	114	41	28.210	15,0	13224	2,13	654.750	9,95	21,44
6E	119	111	46	57.591	20,0	13209	4,36	900.358	15,97	27,30
6F	116	109	39	100.492	18,3	12644	7,95	538.814	14,27	55,70
6G	118	115	44	86.520	20,0	13570	6,38	816.347	14,97	42,59
6H	113	106	40	54.940	20,0	11978	4,59	565.333	9,98	45,96

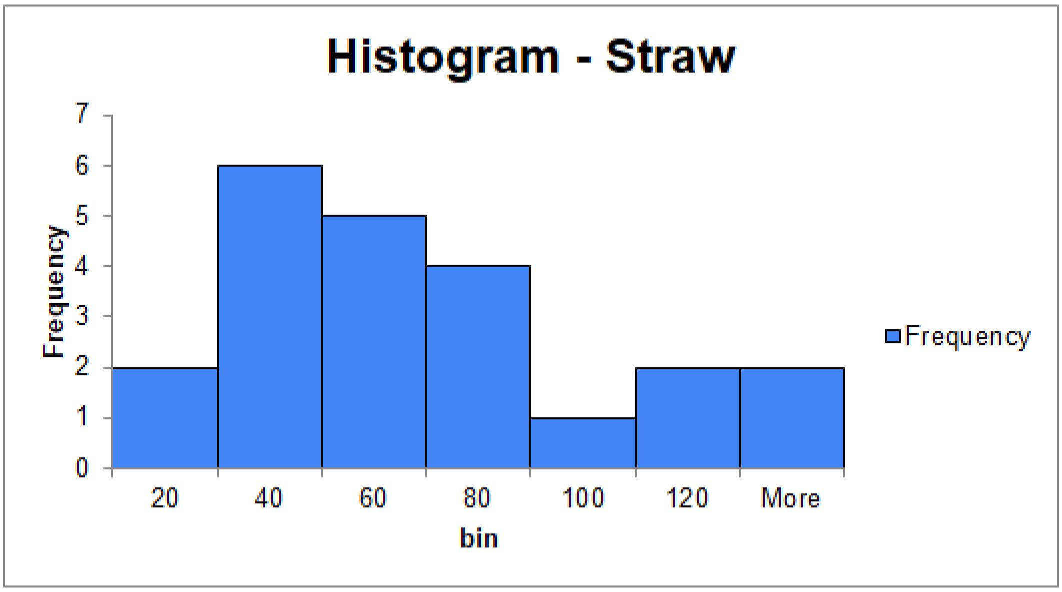
Accuracy calculation - Statistical estimation of the imprecision:

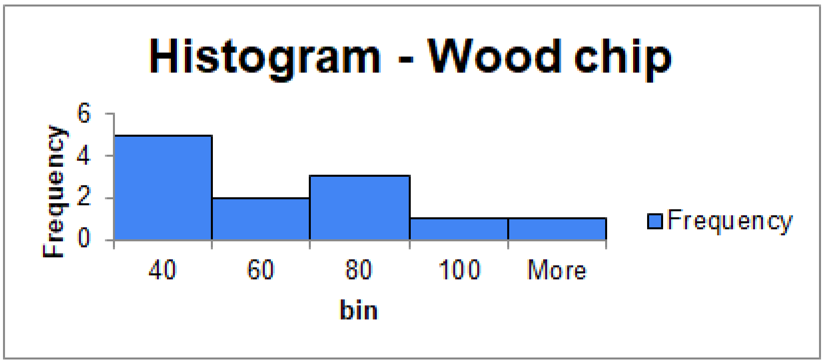
Young's Modulus [N/mm2]	Adobe only	Straw	Wood chip	Soghum	Feathers
	All	All	All	All	All
Min	6,62	15,44	13,72	9,23	11,54
Max	647,00	174,63	141,12	16,85	55,70
Average	68,13	63,64	54,05	14,36	30,40
Median	25,22	55,94	50,74	15,99	24,37
st. dev	115,08	41,27	36,74	3,14	15,69
Correction factor	1,96	1,96	2,20	2,78	2,37
n	42,00	22,00	12,00	5,00	8,00
Correction	34,80	17,24	23,33	3,90	13,15
Min E-modulus	33,33	46,40	30,72	10,46	17,25
Max E-modulus	102,94	80,89	77,38	18,26	43,55

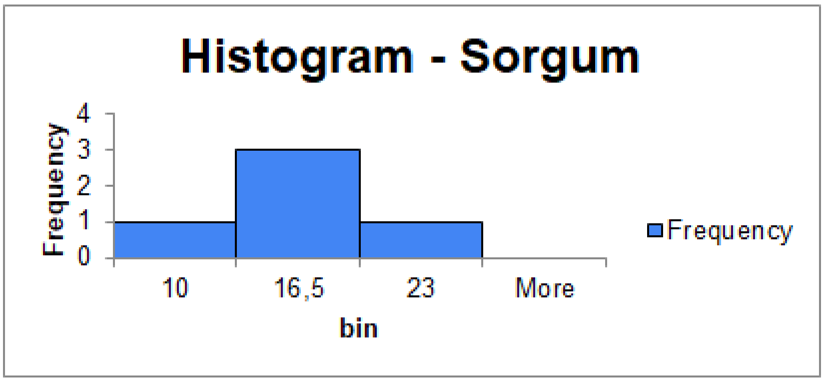
Physical test result	Complete destroyed	Shape mostly remained	Complete destroyed	Complete destroyed	Shape mostly remained

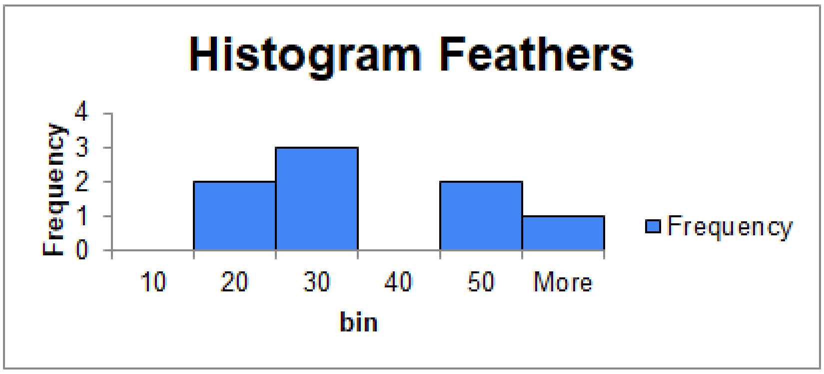
Histogram:




Histogram - Straw
Frequency
7
6
5
4
3
2
1
0
20
40
60
80
100
120
More
bin
Frequency


Histogram - Wood chip
Frequency
6
4
2
0
40
60
80
100
More
bin
Frequency


Histogram - Sorgum
Frequency
4
3
2
1
0
10
16,5
23
More
bin
Frequency


Histogram Feathers
Frequency
4
3
2
1
0
10
20
30
40
50
More
bin
Frequency