The Reeds Performance Study on Traditional Architecture as Building Material in Wae Rebo Village

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Abstract. The use of natural materials in traditional architecture has the advantage that the natural resources are owned together by the people living around the resources, the distance is not too far away from the settlement, the extraction resource's process didn't spend a lot of energy, and it's more environmental friendly because easy to decompose and return to nature. Natural material as an element in traditional architecture become important as part of architectural research, not only to preserve the form, but also to pass on local knowledge about the traditional architectural construction process. One of the dominant materials for building's roof located on small islands along the banks of the Indian Ocean is reed roof. It is derived from tall grass-shaped grasses with the latin name *Imperata cylindrica*. This study aims to explore the material's potential of reeds as a local identity by tracing local-based techniques/indigeneous utilization of reeds in traditional architecture in Indonesia. By tracing the way the reeds are utilized, we can find technical performance that makes the reeds useful as building materials that survive for hundreds of years which is also known of the life cycle process. The methods were by doing interviews and observation at traditional settlements at Wae Rebo and by measuring the reeds' performance in each cycle of life cycle so that we could identify the causes of reeds decay. From these methods it would be revealed how humidity influenced at each stage of the life cycle ranging from extraction to maintenance, and to the strength of reeds. The traditional treatment on the process of the reeds maintenance could reduce moisture and extend the life of the reed roof.

1 Introduction

The reeds roof in Indonesia spread its use in many small islands on the edge of the Indian Ocean as traditional architecture. This material derived from *Imperata cylindrica* species is also known by the names of regions such as *alalang, halalang* (Bjn, Min.), *lalang* (Mly., Md., Bl.), *eurih* (Sd.), *rih* (Bat.), *jih* (Gayo), *re* (Sas., Sumbawa), *rii*, *kii*, *ki* (Flores), *rie* (Tanimbar), *reya* (Sulsel), *eri, weri, wel*i (Ambon dan Seram), *kusu-kusu* (Menado, Ternate and Tidore), *nguusu* (Halmahera), *wusu, wutsu* (Sumba) and others [1]. In these islands are found reeds as a natural material used by traditional settlements apart from the growing land which is about a few hours on foot.

Imperata grows as a companion crop on agriculture and is often regarded as a pest. In an extensive farming group, *Imperata* is regarded as a weed which disrupts the quality of agricultural production, but on the contrary to the more intensive group of farmers, *Imperata* is regarded as the cover of land and cheap food sources for livestock and is a necessary material for the roof [2].

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The use of this natural material has the advantage that its natural resources are shared by nearby settlements so that the extraction is not spent much energy due to close proximity, more environmentally friendly because it is easy to biodegradable, rigid so that the earthquake-resistant and lateral loads in accordance with tectonic conditions in Indonesia, also maintain pride on locality as a feature and identity. With the location of natural materials that are not too far away, this makes each stage of the life cycle of buildings that require materials and resources, not producing too many emissions into the environment [3].The use of these reed roofs as a traditional material still makes this material very relevant to the life cycle as agreed by Paul Oliver that traditional wisdom and lore in a building, using renewable resources and indigenous skills, may still offer wisely managed, economically effective and culturally appropriate solutions to the world's housing needs [4].

The need for the use of natural materials on the roof as a dominant element needs to be maintained, thus reinforcing the local identity of the area. As the function, roofs are the dominant expressive element everywhere, because some building has no walls at all [5]. Understanding of the utilization of this reed material from the environment to its construction needs to be recognized as its potential as a material that has been used since a long time ago, so that this knowledge should be lowered to preserve the existence of the utilization of this material until in the future [6].

As a natural material, *Imperata* has the weathering potential that occurs in various life cycle processes due to the growth of bacteria or microorganisms due to high humidity levels. In general, information about humidity should be calculated as a weathering effect so that moisture retention is critical to the endurance of reeds, where water evaporation determines the age of the material and its construction [7]. He researched about to study the durability of this reed type against the action of wood decay organisms (fungi and insects) by observing the growth ratio of fungi on some types of reeds at an 80% moisture level for four weeks.

The process of reeds damage occurs from the surface to the inward and result in decay, so it could lead to material damage and not long-lived. Expressed by Haslam [8] that reeds are decayed chiefly by fungi and other small organisms, also by (particularly) sunlight.

Troya research [7] about the endurance of reed materials as a noise barrier in Vienna and Brischke [9] about the comparison of reeds treated thermally to reduce the growth of fungi and can decay the reeds and end the lifetime caused by moisture. Dosdall [10] also tested the strength of reeds material by heating at temperatures between 100 and 140 ° C for 2 hours and not only against weathering due to the fungus but also improving the material's resistance to bending strength and natural technical elasticity.

In the traditional long-lived architecture, the process is carried out in the utilization of material that aims to reduce the moisture that causes the growth of mushrooms that will reduce the age of reeds. This study aims to show:

1. The relation of temperature and humidity to reeds life cycle with its mechanical strength, by comparing starting at the time of extraction and maintenance period.
2. The different maintenance period which is attached to different houses, face with temperature, humidity, and mechanical strength.

With environmental awareness of sustainability, the characteristics of reeds need to be well investigated and enriched to provide better techniques for the community as users so as to retain the reed material as a roof.

2 Material and Methods

2.1 Case Study Location

Flores Island is still rich in settlements with traditional architecture that still adore everyday traditions with vast natural resources in various locations. Flores Island appointed as one of the 10 new tourist destinations by the government needs to increase the value of its locality as the character and identity of the area. According to research from Susetyarto [11] which macro observing 25 traditional villages in Flores, most still run the process of vernacular house building both in terms of tradition and anthropology, cultural and society behavior and natural conditions around it, so it can be seen that the treatment reeds in those villages are more or less the same. The village of Wae Rebo located in the Manggarai area of West Flores, which is the object of this research, is one of the villages that still maintain the use of natural materials and its construction skills in the use of reeds.

The construction process of Niang Gena Ndorom rebuilding together with all inhabitants after dismantling the old house which is 70 years old with most of the material is already obsolete and the condition has been tilted [12].

Fig.1. Aerial View Wae Rebo
(source: Suwandi Chandra, nationalgeographic.com)

The reeds used as building materials of this house are taken from Mules Island (Nusa Molas) which is about 15 km from Wae Rebo and across the sea about 30 minutes by boat. On this island, inhabitants take as many reeds as needed and collected to be transported again by boat and motorcycle and continued on foot to Wae Rebo. For the construction process, the reeds are assembled into ready-made bonds, then directly divided into houses to be placed above their fireplaces to dry [12].

The reeds are rolled up and then removed again when the supporting construction is ready. By mutual coarse, it is installed on the bamboo frame that surrounds the building. The process of roofing begins from the lowest level in layers until it rises to the top, a new house will be used for years. Maintenance of the reeds roof in local knowledge is to bloat the roof of the reeds every day through the activity of the stove in the house. In addition to cooking, the smoke and heat also reduce the moisture of the roof of the grass due to weather changes.

2.2 Observation and Interview

Observations were made at Wae Rebo to observe the reeds physical conditions at the growing site in the neighborhood of Wae Rebo as well as in indigenous homes that have been exposed to smoke as a local effort to reduce moisture and retain the material for longer.

Interviews were conducted with the traditional elders of Wae Rebo, where they had the experience and knowledge of the reeds life cycle, from extracting, construction process, to the knowledge of the physical properties of reeds.

2.3. Field Measurement

The measurements of the lifecycles of reeds are aimed at comparing the moisture effect on the mechanical strength of the grass in each stage of its life cycle. Measurements were taken at the location of extraction, storage, and construction as well as the use and maintenance of reeds. Since this process has been going on for years, it is assumed that the conditions of the reeds life cycle are the same, so that measurements can be made at certain times, not measurements at the stage of the construction process that takes longer. The data will be performed by using the Extech Hygrometer to measure the temperature and humidity of the room and Draminski HMM to measure the temperature and humidity of the reed material.

2.3.1. Extraction Location

Measurements at the extraction site were conducted on Mules Island (Nusa Molas) which is about 30 minutes by boat across Dintor which is about 15 km from Wae Rebo. The island is a source of reeds used for homes in Wae Rebo over the last ten years.

Reeds are taken by using a sickle with a span of a hand (20 cm) from its roots. Humidity measuring was made during the day at 16.30 for a sample of reeds with a 5 cm handheld.

Fig 2. Measure humidity at Mules Island

2.3.2. Construction Location

Measurements were made at *lobo* level from Niang Gena Jengkong. The location of this *lobo* is as high as 250 cm from the tent level, surrounded by reed roofs and placed on wooden boards that become *lobo* mats on a stove that lights up in the morning, afternoon, and evening. These reeds were taken from Pulau Mules two months earlier and smoked to dry.

The Draminski HMM used to measure during the afternoon at 14.00 inside on a bundle of reeds sheets with a diameter of 50-60 cm and a roll of reeds that had been tightened in rattan.

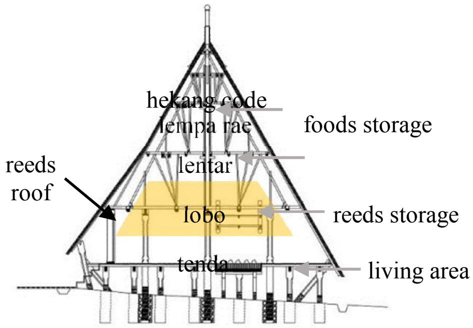

Fig. 3. Section of Niang Gena Jengkong (source: Monica Louis)

Fig. 4. Bundled of reeds (a). Construct reeds on the rattan (b).

Fig. 5. Measuring material humidity at *lobo* using Draminski HMM

2.3.3. Use & Maintenance Location

Measurements were made on three houses with different reeds ages, namely Niang Gena Ndorom which was in 2009, Niang Gena Jekong which was built in 2011 and Niang Gena Mandok which was built in 2013, by measuring the humidity level of room and reeds material for three days with a certain time interval at 7:00, 13:00, 17:00 hours and 20:00 hours. It placed on the reeds roof inside the gathering area around the stove.

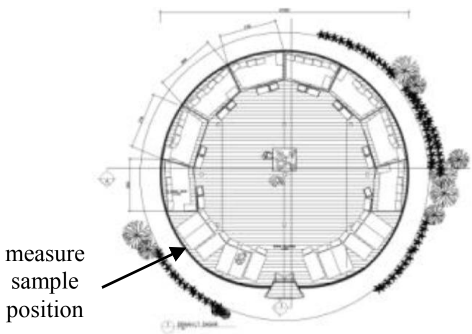

Fig. 6. Mbaru Niang plan (source: Monica Louis)

Fig. 7. Mbaru Niang with reeds roof

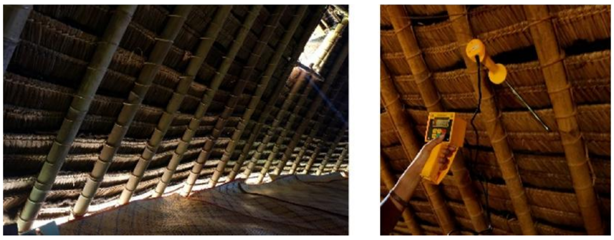

Fig. 8. Inside Mbaru Niang (left) Measuring humidity (right)

2.4. Laboratorium Measurement

Measurements to determine the mechanical properties of Imperata cylindrica are carried by bringing the reed samples from Wae Rebo to be tested in the laboratory to find out the tensile strength of the reeds. There are 15 samples from various stages of reeds life cycle taken from extraction site, reeds drying location, reeds storage location, reeds construction location at a different age. From each location are taken several strands packed in containers to be brought to the laboratory.

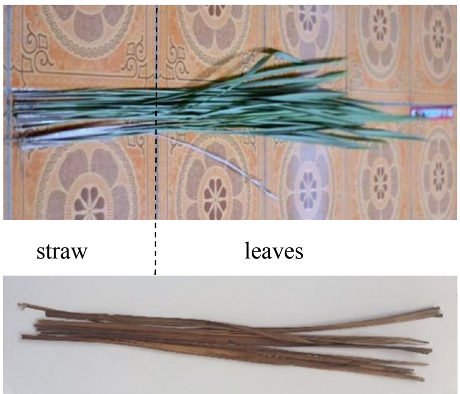

Fig. 9. Harvested reeds – 110 cm length (above)
Leaves sample of reeds – 30 cm length (down)

Before the test, the reeds were left in the laboratory with room temperature 24^0C and 65% humidity. From each stage is separated the straws and leaves of reeds because it is estimated to have a much different tensile strength. Straws or leaves of reeds are cut along 10 cm as a material test specimen of 4-6 sheets.

The tensile forces and the displacements of the reeds were assessed with using a Shimadzu AG-IS 20 kN universal testing machine with a measurement range of strength values up to 20 kN. This machine is designed to test rubber belts, cotton fabrics, and polyester cords and available in QC Laboratory in PT. Seiwa Indonesia, Cibitung, Bekasi.

The tested specimens were shaped as strips with the same length of 10 cm. However, the width may vary as the leaf specimens are wider than sticks. Leaves have approximately 5-10 mm in width while straws are around 1-2 mm in width. The reeds (straw/leaves) was placed in metal clamps of the machine as pictured. In order to prevent the delicate plant material damage in the area of the clamps, a slice of rubber was taped inside clamps.

Fig. 10. Placing in the clamps of the Shimadzu AG-IS 20 kN Machine unit (left) Clamps (right)

The computer program used to read this tensile test is Trapezium which will output data in the form of tables and graphs of initial load to peak load before the reeds are broken. Of the six samples in each group of data tests, the average load values were obtained from the four best samples (in Newton). The tensile strength was calculated from the following equation:

$$Tr = F \cdot A{-}1\ (Pa) \qquad (1)$$

F – maximum force needed to break the rhizome (N);
A – cross-sectional area of rhizome at the point of rupture (m^2).

From the measurement results of this tensile test is converted to units of Pascal (N/m^2) and compared between humidity levels that have been obtained from field measurements. The trend line, equations describing the trend line, and the value of tensile strength were determined. One-way analysis of variance was performed in order to assess the differences between the sample of different time of *Imperata cylindrica* at extraction phase, construction phase and use maintenance phase.

3 Result & Discussion

According to interviews with Rafael, the indigenous elders, the reeds get a drying treatment reduce the weight while carried on also reduce the moisture so it does not quickly decay. The freshly picked reeds are then dried and aerated to reduce the water content before use. Reeds are handling in big bundled transporting from the field to the village.

Tabel 1.
Measuring Temperature, Humidity and Tensile Strength

Location		Temp (^{o}C)	RH (%)	Reeds Temp (^{o}C)	Reeds RH (%)	L (m)	W (m)	Load (N)	Tensile Strength (x 10^4 N/m2)
Extraction	Straws	25	72	25	17,82	0,1	0,002	86,97	43,49
	Leaves	25	72	26,1	17,82	0,1	0,006	30,11	5,02
Drying	Straws	26	70	26	12,3	0,1	0,002	59,30	29,66
	Leaves	26	70	26	12,3	0,1	0,006	52,96	10,71
Storing	Straws	26,9	69	27	9,31	0,1	0,002	33,59	16,79
	Leaves	27	69	27	9,31	0,1	0,008	42,52	7,09
Use & Maintenance									
Gena Mandok 5 years	Straws	26,16	63,64	25,8	9,35	0,1	0,002	64,76	32,38
	Leaves	26,16	63,64	25,8	9,35	0,1	0,008	49,49	6,19
Gena Jekong 7 years	Straws	27,02	61,29	26	10,11	0,1	0,007	87,25	12,46
	Leaves	27,02	61,29	26	10,11	0,1	0,007	25,05	3,58
Gena Ndorom 9 years	Straws	24,09	63,41	24,41	10,22	0,1	0,007	47,06	6,72
	Leaves	24,09	63,41	24,41	10,22	0,1	0,007	39,59	7,08

In non-dried reeds, there is a fungus that can cause material damage as described by Troya [7] comparing several species of reeds and weathering and susceptibility of reed against different decay-causing fungi.

From the measurement results, obtained the results of the humidity values for reeds at the extraction location is higher than the values of this parameter at the construction location. The natural drying technique by the Wae Rebo community reduces the moisture level of the material. The location of reeds extraction in open fields affects higher moisture rates, while when it has been moved into the *lobo* to obtain further drainage above the burning stove.

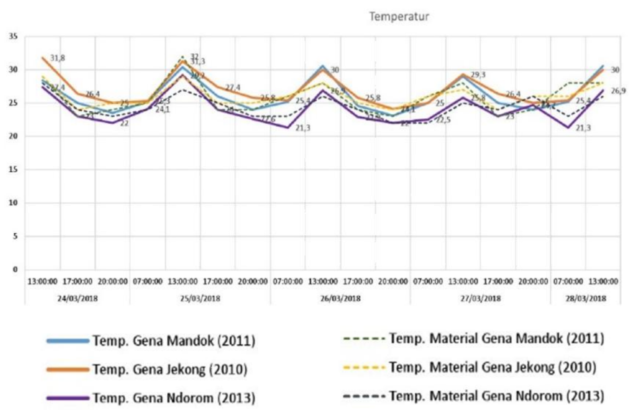

Fig. 11. Chart of Temperature 3 Niang in different ages (^{o}C)

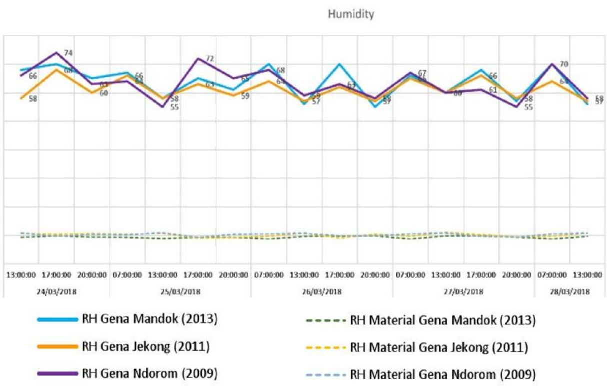

Fig. 12. Humidity chart of 3 Niang in different ages (%)

Measurements taken during three maintenance periods of Gena Ndorom (2009), Gena Jengkong (2011) and Gena Mandok (2013) manually for four days showed changes in the temperature of the room and the temperature of the reed material which was quite stable inside the house, with the highest temperatures at midday and the lowest temperatures at night as shown at Fig. 9. There was no significant difference in room temperature even though these niangs were of different ages. In the daytime, temperatures of reeds are lower 1-2^{0}C than the room temperature, at night the temperatures of reeds are 1-2^{0} higher than the room temperature.

The difference in humidity level trends between the three different age niangs during the maintenance period still shows the same trend as the extreme day or night, but in the reeds material which was measured by Draminski HMM, humidity shows a stable trend, not too big a difference in day and night.

Starting from extraction to storage shows a decrease in humidity with a small different number but followed by a significant drop in tensile strength. From this, it is seen that the process of moisture reduction with natural drying will affect the strength of reeds. The values of tensile strength could be compared with the data obtained by W. Kowalik that the ratio of reed strength to summer and winter conditions notify that the reeds at winter with high humidity have higher tensile strength than in when summer with low humidity [13].

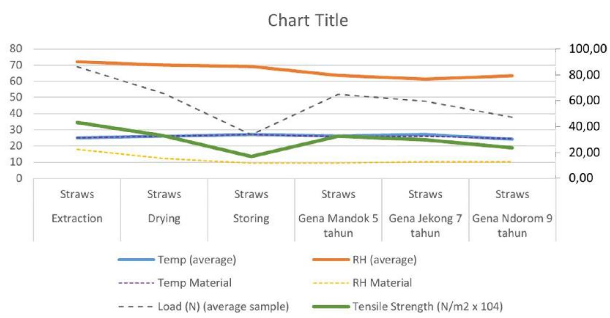

Fig. 13. Tensile Strength grafik related to humidity (x 10^4 N/m^2)

Imperata cylindrica on Mules Island has a tensile strength value of 43.09 x 104 N/m^2, higher than the Phragmites australis grass ever tested by Dabaieh, 2015 of 32.17 x 10^4 N/m^2 [14]. Despite the humidity down, with wind draining, the tensile strength is still at 32.63 x 10^4 N /m^2. It can conclude that the reeds of this Mules island have a good quality.

Fig. 11 shows that tensile strength increases from storage to maintenance phase, as treatment changes from drying naturally to drying by heating from the stove. However, measurements of three niangs namely Gena Ndorom (2009), Gena Jengkong (2011) and Gena Mandok (2013) obtained the decreased of tensile strength as the longer the reeds are installed on the roof.

From the chart at Fig. 10 show that the average humidity trends in both room and materials in different maintenance periods are three years, showing almost the same number. This time determined does not affect the humidity of room or material. It was also observed that the 9-year-old reed (Gena Ndorom) had 23.53 x 10^4 N / m^2 lower tensile strength than the 7-year-old Gena Jengkong x 10^4 29,74 N / m^2 and the 5-year-old Gena Mandok 32,38 x 10^4 N / m^2 which is heated every day and heated. These results do not show the same trend as the Dosdall study [10] which suggests that there is an increase in the value of bending strength and the limits of elasticity of reeds in the 120-160^{0}C temperature range. From the daily treatment of reeds in Wae Rebo, it is seen that the heating in the traditional house aims to drain the reeds so as not to damp, but if the heating is done at temperatures above 160^0 C, it can decrease the tensile strength of reeds.

4 Conclusion

Imperata cylindrica as a traditional material used on the roof of Wae Rebo building is still feasible to be used as construction material, because source on Mules Island produces fine reeds, with low humidity but still has a good tensile strength value, between 43.09 x 10^4 N/m^2 to 32.63 x 10^4 N/m^2 when dried. The drying process decrease the humidity from 17,82% until 9,31% and stable. The water content at extraction comes from the reeds body itself which then evaporates in the drying process is aerated or heated and create a dry and strength reeds, once its humidity come On the extraction phase until the storage of dried reeds the lower humidity of the reeds then the tensile strength decreases.

Reeds have increased tensile strength from dry-only storage phases to constructed use in buildings, with heating treatment from the stove in the building every day, and increased humidity after being constructed on the roof and influenced by daily weather., so the trend of decreasing the value of tensile strength is steeper than the decreasing trend in the maintenance period. Age of older reeds roofs has lower tensile strength values than younger ones.

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References

[1] K. Heyne, Tumbuhan Berguna Indonesia, jil. 1, Jakarta: Yayasan Sarana Wana Jaya, 1987.

[2] Dove, M. Martopo, S., Manusia dan Alang-Alang di Indonesia, Yogyakarta: Gadjah Mada University Press, 1987.

[3] P. Graham, Building Ecology, Victoria: Blackwell Science, Ltd., 2003.

[4] P. Oliver, Encyclopedia of Vernacular Architecture of the World, Vol 1, UK: Cambridge University Press,, 1997.

[5] R. Waterson, "Indonesia, East," in *Encyclopedia of Vernacular Architecture of the World, Vol.2.* , UK, Cambridge University Press, 1997, pp. 1083-1125.

[6] I. Juwono, "Enhanced Treatment of Reeds as Natural Materials for Use in Traditional Housing," *International Journal of Technology,* vol. 6, pp. 1117-1123, 2017.

[7] Troya, M.T. Rubio, F. Prieto, M.J. Lorenzo, D. Fernández-Cabo,J.L. Schöftner, R., "Short communication. Natural durability of reed (Phragmites australis) against wood decay organisms: relation to other forest species.," *Investigación Agraria: Sistemas y Recursos Forestales,* vol. 18, no. 3, pp. 289-295, 2009.

[8] S. Haslam, The Reed. Phragmites australis (Cav.) Trin. Ex Steud., Cambridge: British Reed Growers Association, 2009).

[9] Brischke, C. Hanske, M., "Durability of untreated and thermally modified reed (Phragmites australis) against brown, white and soft rot causing fungi.," *Industrial Crops and Products 91,* vol. July, no. 15, p. 49–55, 2016.

[10] Dosdall, R. Jülich, W. Schauer, F., "Impact of heat treatment of the water reed Phragmites communis Trin.used for thatching on its stability, elasticity and resistance to fungal decomposition," *International Biodeterioration & Biodegradation,* vol. 103, pp. 85-90, 2015.

[11] M. Susetyarto, Arsitektur Vernakular: Keberlanjutan Budaya di Kampung Bena Flores, Sukoharjo: Penerbit Padepokan Seni Djayabhinangun, 2013.

[12] Y. Antar, "Wae Rebo: Kelahiran Kembali Arsitektur Nusantara," in *Pesan Dari Wae Rebo*, Jakarta, Gramedia Pustaka Utama, 2010, p. 113.

[13] Kowalik, W. Pachuta, K. Jeznach, J., "Selected biometric and mechanical properties of the common reed," *Land Reclamation,* vol. 48, no. 4, p. 289–297, 2016.

[14] Dabaieh, M. Sakr, M., "Building with Reeds: Revitalizing a building tradition for low carbon building practice.," in *ICOMOS Thailand International Conference*, Bangkok, 2015.