REED AS A FAÇADE MATERIAL

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ABSTRACT

This paper is a set of design guidelines in applying Common Reed (Phragmites australis) in façade modules to meet the functional requirements that a façade has to provide. The design principles are derived from analysing Common Reed's physical performance in complying with different functional requirements. These requirements include fire-retardance, thermal insulation, maintenance ease, acoustic insulation and operational ease. When weaknesses or limitations are met, vernacular solutions are referred to suggest feasible interventions to improve and optimise reed's performance. Lastly, case studies on realised reed façades are conducted. The goal is to compare and contrast how different design approaches influence respective functional performances, architectural expressions and carbon absorption efficacy. These agendas conclude the reed facade design toolbox to promote reed as a sustainable façade material in contemporary architecture.

KEYWORDS:

Common Reed (Phragmites australis), façade, module, functional requirement

1. INTRODUCTION

The development of Common Reed (Phragmites australis) into standardised façade modules is of high significance. Firstly, reed is a native crop that absorbs CO2. As a natural sequestration agent, reed absorbs and stores large amounts of atmospheric carbon in the plant tissues through photosynthesis and helps retain the peat's carbon content (IUCN, 2017). The procedure of processing reed is also very straightforward, which involves harvesting, drying, sorting before applying on site. Since reed can be cultivated locally, this practice can substantially shorten the logistic chain. In other words, reed is a renewable material that leaves a minimum, or even negative carbon footprint, when cultivated and consumed locally. Apart from sustainability concerns, reed is lightweight and has an excellent performance in thermal and acoustic insulation. These inherent properties justify the relevance to develop reed into facade material that is compliant to functional requirements a facade is to provide.

Correspondingly, the development of reed façade modules is a precise answer to the Dutch Ministry of Agriculture, Nature and Food Quality calls for the development of high-quality wet crop products (Ministry of Agriculture, Nature and Food Quality, 2021). This development can establish new marketing opportunities to encourage agricultural entrepreneurs to switch to such cultivation. This is crucial in the Netherlands because the cultivation of wet crops such as reeds can mitigate land subsidence, peat oxidation and greenhouse gas release that is happening drastically in the North and West region due to pastoral agricultural activities (Beyer and Kürten, 2020).

However, to put the idea into practice, many functional issues need to be addressed and overcome. First, it is important to acknowledge the state-of-the-art: in contemporary Dutch building industry, the use of reed as façade material is low due to a lack of standardised overview showing reed's feasibility in complying with different functional requirements in building conventions. The decision is especially critical when it comes to the issue of fireproofing, thermal insulation, etc. According to Van Hemert et al. (1990, p.9), the earliest record issuing reed's fire hazard can be dated back to 1406. During the period, Gementee Leiden announced that for new houses whose side walls were higher than sixteen feet, a 'hard' roof (made of hard materials such as roof tiles or slates) is mandatory. This regulation is implemented to mitigate possible fire hazards caused by thatched roofs. On 20th May 1450, the use of thatched roof for new houses is banned (Van Hemert et al., 1990, p.9). Although regulations revised and reed thatches reappeared in small domestic projects nowadays, we see that there is still a lack of proper documentation on how reed's performance can be technically improved to comply with higher building standards. Due to a lack of standardisation, reed remains a craft of human labour, implying high building cost. Since reed thatches are custom-made by craftsmen, a reed thatch roof can cost around €95.50 per m2 (Vakfederatie Rietdekkers, 2021), compared to €50 per m2 of concrete tile roof or €45-55 per m2 of new bitumen roofing (Dakdekker-Weetjes, n.d.). Hence with its high expenses yet debatable functional performance, reed is not considered an ideal building material.

Recently, scholars, researchers and builders have initiated studies on reed as a building material. In academia, CINARK from Royal Danish Academy, Bouwtuin project from TU Delft and architecture school of Turku University of Applied Sciences has conducted explorations on reed from an architectonic lens. In practice, architects such as Kengo Kuma and Dorte Mandrup have also proven the feasibility of reeds in realised architectural projects. However, the technical principles in building with reeds remain relatively constrained within the practice of local thatcher. In other words, the integration between architectural design exploration and practical building requirements needs to be improved.

Therefore, this paper aims to study how reed can be applied in façade modules to meet the functional requirements a façade is to provide. In other words, how can reed be applied technically as a sustainable and vernacular façade material while being functional, affordable and architecturally pleasing.

2. PHYSICAL PERFORMANCE OF COMMON REED IN FULFILLING FUNCTIONAL REQUIREMENTS A FAÇADE IS TO PROVIDE

In this paper, the term reed is referring to the species Common Reed (*Phragmites australis*). The term facade is defined according to Building Decree 2012 as an external partition construction with an angle of inclination of more than 75 degrees. In this study, the façade's functional requirements are ordered according to its priority. For further clarification on part 2's conclusions, please refer to Appendix 1: Illustrated Design Principles.

2.1 FIRE RETARDANCE

Definition & Standard(s): Fire retardance refers to the ability of a material to slow down or halt the spread of fire. In this paper, the benchmark is set to comply with Building Decree 2012 fire class B. According to the Building Decree, the following provisions apply 1. The fire resistance of the entire facade package (reed + substructure) must have a fire-resistance, Rt of 60 minutes from the outside to the inside against fire penetration and fire spread. 2. The fire brigade must control the fire between 30 and 60 minutes after the start of the fire.

Physical Performance as Shown in Test: According to Vakfederatie Rietdekkers, the factor which largely influences reed's fire retardance is the construction method. A test was conducted by Vakfederatie Rietdekkers (2014) in Arnhem. The sample is a screw roof thatch (closed construction) fixed on a 19mm OSB plate, measuring 3m by 3m with a 20cm overhang finished with a ceramic ridge. It is a closed construction, meaning constructed with untreated reeds applied compactly on a substrate, no longer possible for oxygen intake from the interior. The sample is ignited from the rear fascia exposed to wind. The acquired Rt until the damage on the interior is 95 minutes. In the test, the fire smouldered rather than burned due to the suppressed oxygen supply of the closed construction. The test proved that reed applied in closed construction do achieve excellent fire-retardance.

Major Manipulating Factor: Construction method

How the factor affects architecture: The application of closed construction implies that the reed thatch will only be visible from the exterior view, whereas the interior reveals the substructure. One can no longer see the reed stalks from the interior. A closed construction also means that the ventilative properties of the reed are concealed, meaning inhabitants cannot feel the breeze under the roof. It is also relevant that the location of thatch should be at least 2.5m high from the ground or protected from possible fire hazards, implying less feasible to be applied in kitchen, restaurants or machine rooms.

Other remarks: Apart from the exterior reed package, higher fire safety can be provided from the interior substructure. Either by having a sandwich panel + plasterboard on the inside; or a sandwich panel + Fermacell Gypsum fibreboard or Promatect-H interior trim (Vakfederatie Rietdekkers, 2021). Both are simple and straightforward solutions, therefore, preventing unnecessary construction mistakes.

However, it is important to highlight the application condition of NEN 6068 states that roofs must be treated with fire retardant coating. According to Vakfederatie Rietdekkers, the use of non-impregnated reed thatched facades in closed construction do provide the same level of safety as envisaged by the Building Decree. Instead, the federation highlighted that the application of conventional fire-retardant coatings has many drawbacks: 1. environmentally harmful, due to high content of ammonium chloride, 2. susceptible to wear and tear, which implies periodic re-treatment is necessary. The coating application also demands high precision. When applied too thin, the coating will break down too quickly; if the coating is applied too thick, it can adversely affect the drying of the roof and can be detrimental to the durability of the reed package (Vakfederatie Rietdekkers, 2021). Thus, in the application of coatings, more criteria should be considered prior. Nevertheless, most Dutch municipalities accept closed construction as compliant with Building Decree in practice (Vakfederatie Rietdekkers, 2021).

2.2 THERMAL INSULATION

Definition & Standard(s): Thermal insulation refers to the capability of a material to reduce the transmission of heat between objects in thermal contact or range of radiative influence. The thermal insulation value of a material is gauged according to the basic formula R-value = d / λ. R-value = thermal insulative value (in m^2K/W), d = material thickness (in m), λ = heat conductivity coefficient (in W/mK). In other words, the lower the heat conductivity coefficient of a material, the better it insulates. From 1st January 2021, the new standard NZEB is implemented, entailing a higher energy benchmark on insulative performance for the façade, with a requisite R-value of 4.7 m^2K/W (Vakfederatie Rietdekkers, 2021).

Physical Performance as Shown in Test: The amount of stagnant air in the reed's hollow stem contributes to its insulating properties. Based on revised research conducted by Kiwa BDA, a 280mm reed thatch on a closed construction over 30 years, incorporating the factors of ageing, wear and tear, moisture content and temperature influences scores an R-value of 4.0 m^2K/W with a λ value of 0.070 W/m^2K (Vakfederatie Rietdekkers, 2021).

As compared to other insulating materials such as flax (λ = 0.040-0.055W/m^2K) (Van Dam & Oever, 2019), Rigid Polyurethane (PUR/PIR) (λ = 0.022/m^2K) and Rock Wool (λ = 0.037W/m^2K) (Unilin, n.d.), the insulative performance of reed is relatively mediocre. Since the λ value is a constant, the way to further increase the R-value relies on the thickness of the thatch: the thicker the thatch, the more stagnant air it holds, the higher the R-value. To meet the benchmarks, the thickness of the thatch has to be 330mm to achieve an R-value of 4.71 m^2K/W. However, increasing the thatch thickness to more than 300mm is not very recommended.

Major manipulating factor: Thickness of reed thatch

How the factor affects architecture: To provide enough insulation, a minimum of 330mm thick reed thatch is required. Architectural-wise, the thick envelope expresses sculptural mass, suggesting a sense of privacy and security. However, practicality-wise, this is not very recommended as the envelope will occupy a substantial volume of usable floor area. Thus, hybrid solutions are referred to, such as the integration of loam or clay. These composite of earth and fibres usually give a concrete tactile architectonic expression while providing excellent thermal insulation at a relative slender thickness.

2.3 Maintenance Ease

Definition & Standard(s): Maintenance ease is defined as the ease of preserving an optimal operative condition of the material, measured by the lifespan of the original material in time (years). In this paper, the targeted benchmark is 28 years of lifespan. The number is gauged comparatively with conventional natural roofing material: wood shingles that last about 30 years with annual upkeep (CeDur, n.d.).

Physical Performance in Practice: Reed is an organic material; it is crucial to understand that microbiological degradation affects lifespan. In other words, the higher the moisture content, the higher the degradation rate. Thus, efficient water drainage is indeed critical in prolonging a reed thatch's lifespan. To ensure good water drainage, the slope angle is crucial. The slope angle is the angle formed by the intersection of the line parallel to the thatch surface to the horizontal axis. According to Vakfederatie Rietdekkers (2006), a minimum 45 degrees slope is needed to ensure smooth water drainage, which can prolong the lifespan to an average of 28 years. In the case of 50 degrees, an estimated lifespan of 40 years is expected (Vakfederatie Rietdekkers, 2006).

Major manipulating factor: Slope angle

How the factor affects architecture: To achieve desired slope angle, reed stalks' orientation will be influenced, meaning the architectural visual expression. For instance, for a 45-degree slope, porous ends of the reed thatch will be much revealed, which may not be pleasant render from a close view for trypophobia personas. Contrastingly, a 90-degree slope gives a vertical expression on the façade due to the longitudinal stalk orientation, suggesting rhythm and order.

Other remarks: Besides, the microbiological degradation rate is also influenced by the intensity of daylight exposure. Therefore, for façades that do not receive direct sunlight, a greater inclination is recommended. To further prolong the thatch's lifespan, it is also critical to prevent internal condensation. The temperature difference between interior and exterior can induce moisture transport, which degrades the reed thatches. Therefore, a continuous vapour-proof layer is to be applied on the warmer interior face to prevent accelerated deterioration of the thatched roof due to moisture transport (Vakfederatie Rietdekkers, 2009).

2.4 Acoustic Insulation

Definition & Standard(s): Sound absorption coefficient(α) is used as the parameter for evaluating acoustic insulation. It is defined as the ratio of sound energy absorbed by a material(E) to the overall sound energy previously spread and reaching the surface of the material (Eo) (Li & Ren, 2011). In line with EN ISO 11654, the higher the absorption coefficient, the more the absorption. An absorption coefficient of 1 means total absorption, a coefficient of 0 means total reflection. In this paper, a benchmark of 0.8 α is set. This criterion is relevant to ensure an optimum acoustic comfort at interior spaces, located within an urbanised context where noise pollution is norm.

Physical Performance as Shown in Test: Reed thatches have excellent acoustic insulation properties due to their hollow stems. According to a study by Asbrubali et. al. (2016), the absorption quality is influenced by the stalk's orientation towards the incident sound waves. In the test, the reed stalks are arranged in different orientations towards incident waves. From the study, the absorption coefficient varies greatly from 0.17-0.8. Longitudinal (stalks parallel to the incident wave) configuration scores the highest index in absorbing high frequencies as sound waves propagate inside the channels are being attenuated most in the transmission. The densest Grounded (grounded into chips and compressed in random orientation) sample achieve the best sound absorption in the low-frequency quartile as sound waves are more difficult to penetrate through the material. Perpendicular, P (stalks normal to the incident wave with each adjacent layers having the same direction) and Crossed, C (stalks direction normal to the incident wave, with each adjacent layer's alternates in a right angle from the previous layer) samples showed relatively low absorption. This is because voids between adjacent stalks create slits that sound waves can pass through (Asbrubali et. al., 2016).

Major manipulating factor: Stalks' orientation

How the factor affects architecture: In the urbanised area, sound pollution is mainly caused by low-frequency noise such as road vehicles, aircraft and ventilation or air-conditioning units. Therefore, we see grounded panels as a relevant solution. Assuming an optimal performance level in fire retardancy and thermal insulation is achieved, grounded panels can be sandwiched as internal layers within substructures. Instead of influencing the architectural expression visually, it affects more in the technical building layer.

2.5 Operational Ease

Definition & Standard(s): Operational ease is defined as the convenience of moving or shifting the material into different configurations. This criterion is relevant because some façade panels need to be shifted to adapt to different daylight condition. Therefore, this paper gauge the mass of a reed thatch panel, measured in kg as the defining parameter. In other words, the lower the panel mass, the higher the operational ease. According to Health and Safety Executive Government UK (2020), the manageable load for a female is 7kg maximum and 10kg for the male. This standard entails that the maximum load for a single panel should not exceed 7kg for a single person to handle the operation at elbow height with an extended forearm.

Physical Performance in Practice: The criterion is relevant to gauge the design of different shading devices on the façade. The easier the operation, the more likely it can be powered without specialised mechanisms to encourage a low-tech operational system. Concerning this, pure reed thatch performs great with its average density of 234kg/m3 (Esteves et al., 2003) as compared to other conventional façade materials such as ceramic tiles (1700kg/m3) and 10mm plasterboard (950kg/ m3). However, with the integration of other materials, such as loam and clay to the reed thatch to achieve better insulative properties, the overall mass of the panel will be affected.

Major manipulating factor: Panel design (dimensions and integration of other materials)

How it affects architecture: To maintain the optimal operable ease of a single panel, the design of panels will directly affect the architectural expression. The design can be in the form of big continuous skin that is fixed to its position. It can also be designed into smaller individually operable sliding panels that create a playful, everchanging variation, allowing the grid of the windows or balcony to be temporarily shifted, disappeared or realigned, showing simultaneous existence of multiple functions. Apart from exterior architectural expression, the interior natural lighting condition will also be affected. The design will characterise how specific the panel operation will be in controlling the intensity of daylight penetration into the interior while being easily operated.

3. VERNACULAR SOLUTIONS IN IMPROVING COMMON REED'S PHYSICAL PERFORMANCE

3.1 FIRE RETARDANCE

To enhance the fire-retardance of the reed thatches, biobased coatings are referred to. According to Royal Danish Academy's CINARK's experiment (2020), three natural coating solutions are explored. The first coating is sludge paint made of resin, linseed oil, iron vitriol and rye flour. This paint has a red hue due to the iron oxide pigment in the paint. The second coating is lime paint, with casein and deer antler salt added. Both mixtures bound and hardened well on the reed. Also, they provide antiseptic properties and prevent UV degradation. The third type is an ancient Chinese clay mortar coating.

In the test, the reed thatch with sludge paint was difficult to ignite. Once ignited, it only took 80 seconds before the whole line-up was on fire. The lime paint was a little harder to ignite and burned reasonably poor with heavy smoke development. It is also worth mentioning that it burned evenly. The smoke generated shows a good signalling property to alert the surroundings in case of fire. Whereas in the test on clay mortar, the reed thatch could not catch fire at all.

However, the application of fire-retardant coatings should be well-considered prior due to its susceptibility to wear and tear as mentioned beforehand in part 2.1(Vakfederatie Rietdekkers. 2020).

How it affects architecturally: The coatings give a natural dye on the thatch, such as the sludge paint gives an intense red hue, the lime paint gives a beige undertone and clay gives a yellowish glow. These coatings offer variations in the colour of the reed thatch.

3.2 THERMAL INSULATION

Thermal insulation of the reed façade can be improved with the integration of other materials such as clay, lime or earth as hybrid composites. Since the design focuses on the façade layer, a lower density material is more relevant to avoid extra structural reinforcement and facilitate operational ease. This led us towards the decision of incorporating light earth into the thatch.

Light earth, is a mixture of earth and straw or other lightweight fill materials, which form the primary constituent of the mass (Volhard, 2016). The earth serves predominantly as the binding matrix for the aggregate. In this section, very lightweight light earth mixtures of around 300 kg/m³ are referred to, which is made possible only with very clay-rich earth.

According to Volhard (2016), the low thermal conduction of light earth is a factor of the high proportion of air enclosed in the voids in the mass and the minute pores of the straw. The coefficient of thermal conductivity, λ (W/mK), is directly dependent on the bulk density of the material. The bulk density in turn is determined by the mixing proportions and proportion by weight of the earth, as well as the degree of compaction.

Bulk density, d, (kg/m3)	Thermal conductivity, λ, (W/mK)	Thermal resistance R (m2 K/W) at a thickness of t = (mm)					
		100	150	200	250	300	350
300*	0.10	1.00	1.50	2.00	2.50	3.00	3.50
400*	0.12	0.83	1.25	1.67	2.08	2.50	2.92

Table 1. Thermal resistance, R-value for different thickness and densities of light earth. (Volhard, 2016)

From the table, we see a 100mm light earth with a bulk density of 300kg/m3 can provide an R-value of 1.00 m2K /W. In other words, the incorporation of light earth layer into the reed thatch can reduce the thickness of reed required to meet the 4.7 m²K/W benchmarks.

How it affects architecturally: The application of light earth will affect the overall thickness or mass of the façade module. If more light earth is added, less reed is needed to achieve the determined R-value. This also implies that the overall thickness can be reduced but the overall mass will be much increased. Therefore, different criteria should be considered before applications.

4. Applications of Common Reed in Architecture: Case Studies

This part comprises case studies on realised reed façade designs in multiple contexts. The facade modules are illustrated in the same 1:20 scale in isometric view to be analysed, compared and contrasted in terms of the aforementioned functional requirements and architectural expression. The result is a catalogue of illustrated spreadsheets on the façade designs, with annotated commendable design principles (see Appendix 2: Case Studies). Besides, the efficacy of carbon footprint mitigation in the façade modules is evaluated to show how the corresponding design fulfil their ecological responsibility (see Appendix 3: Carbon Absorption Calculation). A comparison matrix is provided (see Appendix 4: Comparison Matrix) to show an overview of all designs' physical performance.

5. Conclusion

To conclude, Common Reed is a highly relevant and adaptable material to be applied in façade modules. Through proper documentation and studies, we see that many perceived challenges can be overcome without the need for complicated or sophisticated interventions. Such as the much debatable fire-retardance issue can be resolved with closed construction, a relatively straightforward solution that only involves the addition of enclosed sub-structure to the structural members. By applying bio-based fire-coatings adopted from historical references, we see that fire retardancy can be improved besides giving a natural dye to the reed. Corresponding to thermal insulation, we acknowledge that reed's performance is not as competent as other conventional insulative material. Nevertheless, thanks to reed's fibrous, light-weight properties, reed can bind easily with light-earth material which has excellent thermal mass to improve its performance. In terms of maintenance ease, we see that the optimal slope angle ranges between 45-90 degrees, with an expected lifespan of 28 years and above. This convinces that reed can be applied in multitudes of design form to suggest a wide variety of visual expressions while being well maintained. Regarding acoustic insulation, the study shows that grounded reed panel performs great in absorbing low-frequency noise. This outcome is highly relevant in tackling urban area's sound pollution as most urban noises range within the low-frequency quartile. The panel can be a straightforward integration in the building layer, which can be left exposed or plastered over. Since reed is a lightweight material (234kg/m3), the reed panels can be explored into multiple forms while stays within manageable operational ease.

From the case studies, we learnt relevant design principles applied in various realised projects. For instance, from Forma6's Francoise-Helene Jourda office building, we see the feasibility of applying reed on a 6-storey office building facade with the aid of stainless-steel fasteners and gauge wire bracings. In Kengo Kuma's Yusuhara Marche, we see the inclined reed thatch modules at 60-degree inclination offers excellent maintenance and operational ease. It also gives an expression of layered rhythm and order to the marketplace façade. From the Farmhouse in Twente, we see the straw-cross bracings offers extra wind resistance while renders a unique diagonal lattice on the facade. Lastly, the design's efficacy in carbon absorption is evaluated. These findings conclude an overview of how different design approaches affect the module's functional performance, architectural expression and carbon absorption efficacy.

Therefore, it is clear that this paper fulfils its objective to provide a set of design principles in guiding the application of reed in façade modules to comply with the functional requirements a façade is to provide. From the study, we conclude that Common Reed is a competent material in fulfilling functional requirements and ecological responsibility while being architecturally pleasing.

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GLOSSARY

Façade /fəˈsɑːd/ noun
(derived from the Vulgar Latin facia, meaning face) the principal font of a building. A façade is assumed if there are external partition constructions with an angle of inclination greater than 75º.

Functional /ˈfʌŋ(k)ʃ(ə)n(ə)l/ adjective
relating to the way something operates or works in accordance to its objective of invention. A functional invention is something useful and practical based on technical measures.

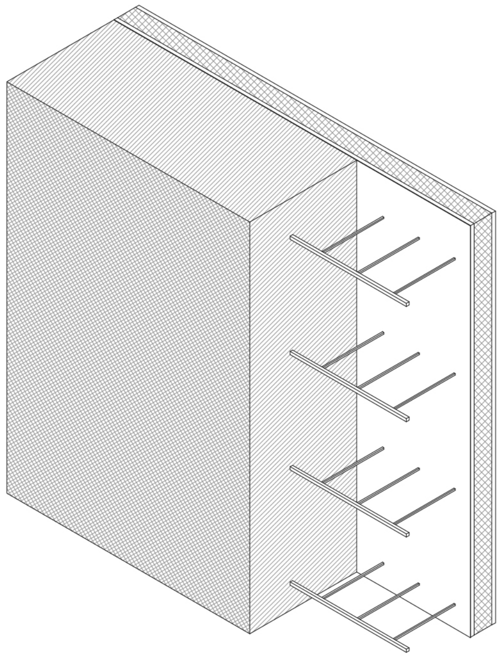
Module / ˈmɒdjuːl/ noun
a set of standardized parts or components that can be assembled to form a complete, independent structure.

Reed /riːd/ noun
a tall, slender-leaved plant of the grass family, which grows in water or on marshy ground. In this paper, the term reed is specifically referring to the species Common Reed (Phragmites australis).

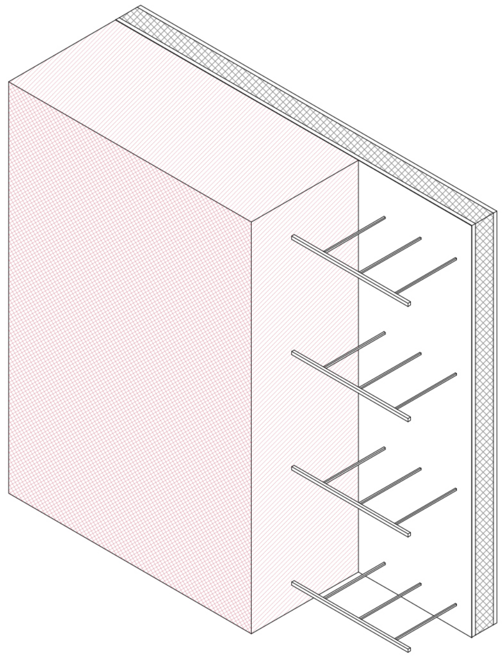
Sustainability /səˈsteɪnəb(ə)l/ noun
(criteria) concerned with the act of conserving and maintaining an ecological balance by avoiding the depletion of resources.

Vernacular /vəˈnakjʊlə/ adjective
(of architecture) concerned with the act of improvising available local resources, such as materials, craftsmanship, technology, etc. Includes the revitalising of olden building practices or techniques, which are relatively primitive but practical. Most of the time, people have simply forgotten that the best resources we have are historical references, neglected in time.

Appendix 1: Illustrated Design Principles



Benchmark Fire Retardance Criteria



Revised Fire Retardance Criteria (Incorporated Vernacular Solution: Sludge Paint Coatings)

FUNCTIONAL REQUIREMENT: Fire Retardance

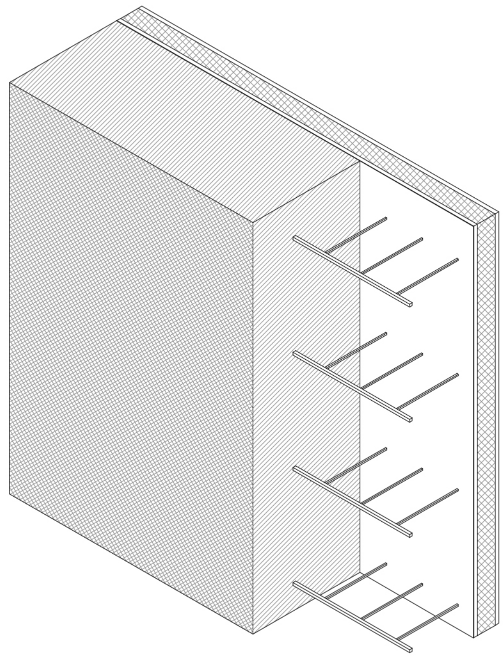
DEFINITION: The ability to slow down or halt the spread of fire. Measured in Retardance Time, Rt, in minutes (min)

STANDARDS / BENCHMARKS: Building Decree 2012 Fire Class B: 1. The fire resistance of the entire facade package (reed + substructure) must have a fire-resistance, Rt of 60 minutes from the outside to inside against fire penetration and fire spread. 2. The fire brigade must control the fire between 30 and 60 minutes after the start of fire.

MAJOR MANIPULATING VARIABLE (FACTOR WHICH INFLUENCES ITS PERFORMANCE): Construction Method

SCALE : 1:15

Appendix 1: Illustrated Design Principles



300mm
untreated
reeds

Stainless steel
wire

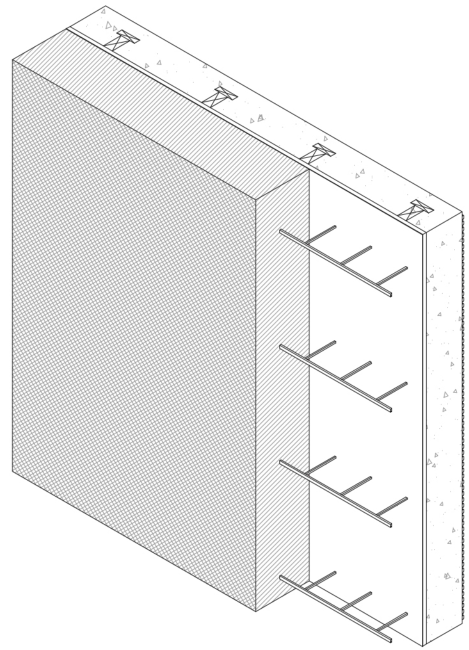
Stainless steel
threaded screw
at 280mm
interval

Debricoat Lapfix
self-adhesive membrane

Promatech-H Fire class
A steam-hardened
calcium silicate board,

**Mineral wool
insulation panel**

Benchmark Thermal Insulation Criteria



180mm
untreated
reeds

Stainless steel
wire

Stainless steel
threaded screw
at 280mm
interval

Debricoat Lapfix
self-adhesive membrane

Promatech-H Fire class
A steam-hardened
calcium silicate board,

**100mm clay-rich light
earth, bulk density, d=
300kg/m3**

**Reed lath, t=+/-10mm, 70
pc./m, fastened with zinc
plated narrow gauge wire**

Revised Thermal Insulation Criteria
(Incorporated Vernacular Solution:
Light Earth Hybrid)

FUNCTIONAL REQUIREMENT: Thermal Insulation

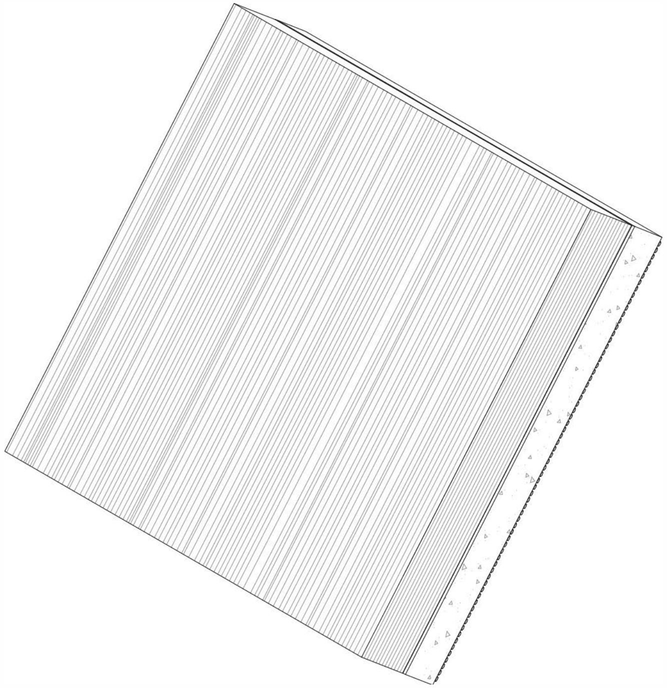
DEFINITION: The capability of a material to reduce the transmission of heat between objects in thermal contact or range of radiative influence.
Measured in thermal insulative value, R-value in (m^2K/W)

STANDARDS / BENCHMARKS: According to NZEB, a requisite R-value of 4.7 m^2K/W need to be complied.

MAJOR MANIPULATING VARIABLE (FACTOR WHICH INFLUENCES ITS PERFORMANCE): Thatch thickness

SCALE : 1:15

Appendix 1: Illustrated Design Principles



Benchmark Maintenance Ease Criteria
(45 degree slope)

180mm untreated reeds fastened vetically on **45 degree** inclined substructure

Stainless steel wire

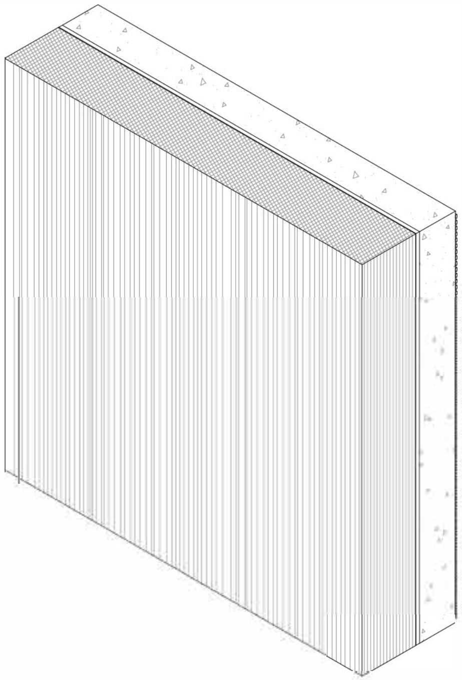
Stainless steel threaded screw at 280mm interval

Debricoat Lapfix self-adhesive membrane

Promatech-H Fire class A steam-hardened calcium silicate board,

100mm clay-rich light earth, bulk density, d= 300kg/m3

Reed lath, t=+/-10mm, 70 pc./m, fastened with zinc plated narrow gauge wire



Revised Maintenance Ease Criteria
(90 degree slope)

180mm untreated reeds arranged vertically on **90 degree (plumb)** substructure

Stainless steel wire

Stainless steel threaded screw at 280mm interval

Debricoat Lapfix self-adhesive membrane

Promatech-H Fire class A steam-hardened calcium silicate board,

100mm clay-rich light earth, bulk density, d= 300kg/m3

Reed lath, t=+/-10mm, 70 pc./m, fastened with zinc plated narrow gauge wire

FUNCTIONAL REQUIREMENT: Maintenance Ease

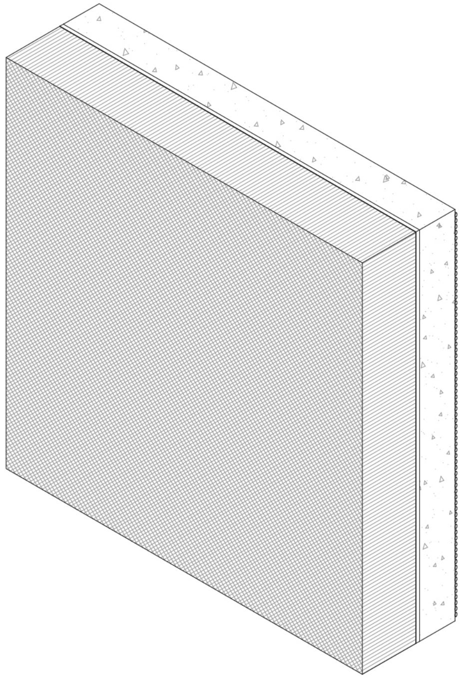
DEFINITION: The ease of preserving an optimal operative condition of the material. Measured in the lifespan of the original material, time (years).

STANDARDS / BENCHMARKS: Minimum 28 years

MAJOR MANIPULATING VARIABLE (FACTOR WHICH INFLUENCES ITS PERFORMANCE): Slope Angle

SCALE : 1:15

Appendix 1: Illustrated Design Principles



180mm untreated reeds arranged in **lateral direction** to incident sound waves

Stainless steel wire

Stainless steel threaded screw at 280mm interval

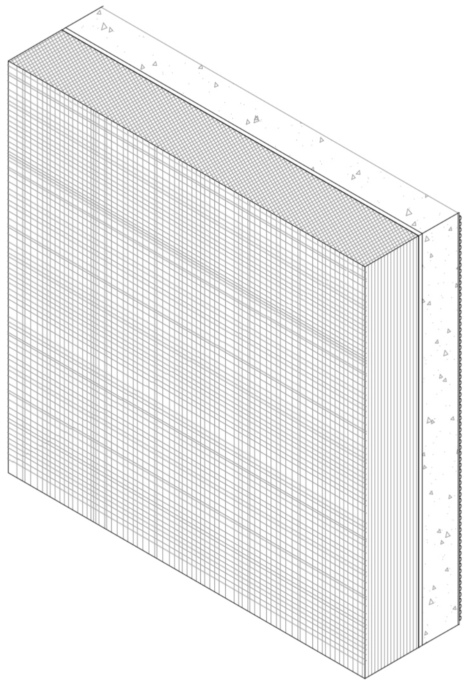
Debricoat Lapfix self-adhesive membrane

Promatech-H Fire class A steam-hardened calcium silicate board,

100mm clay-rich light earth, bulk density, d= 300kg/m3

Reed lath, t=+/-10mm, 70 pc./m, fastened with zinc plated narrow gauge wire

Acoustic Insulation Criteria
for High Frequency Absorption



Grounded reed insulation panel

Stainless steel wire

Stainless steel threaded screw at 280mm interval

Debricoat Lapfix self-adhesive membrane

Promatech-H Fire class A steam-hardened calcium silicate board,

100mm clay-rich light earth, bulk density, d= 300kg/m3

Reed lath, t=+/-10mm, 70 pc./m, fastened with zinc plated narrow gauge wire

Acoustic Insulation Criteria
for Low Frequency Absorption

FUNCTIONAL REQUIREMENT: Acoustic Insulation

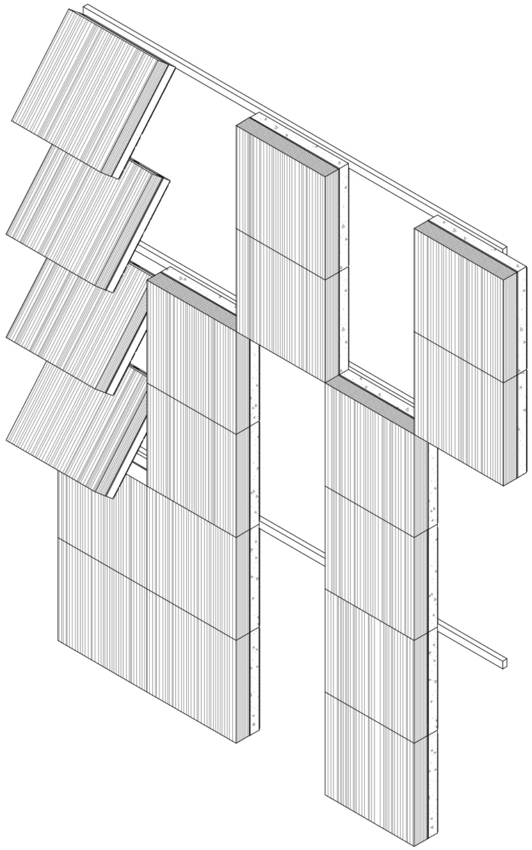
DEFINITION: The ratio of sound energy absorbed by a material(E) to the overall sound energy previously spread and reaching the surface of the material(Eo).
Measured in sound absorption coefficient(α). 1=total absorption, 0=total reflection

STANDARDS / BENCHMARKS: Minimum 0.8 sound absorption coefficient.

MAJOR MANIPULATING VARIABLE (FACTOR WHICH INFLUENCES ITS PERFORMANCE): Stalk’s orientation (direction towards incident sound waves)

SCALE : 1:15

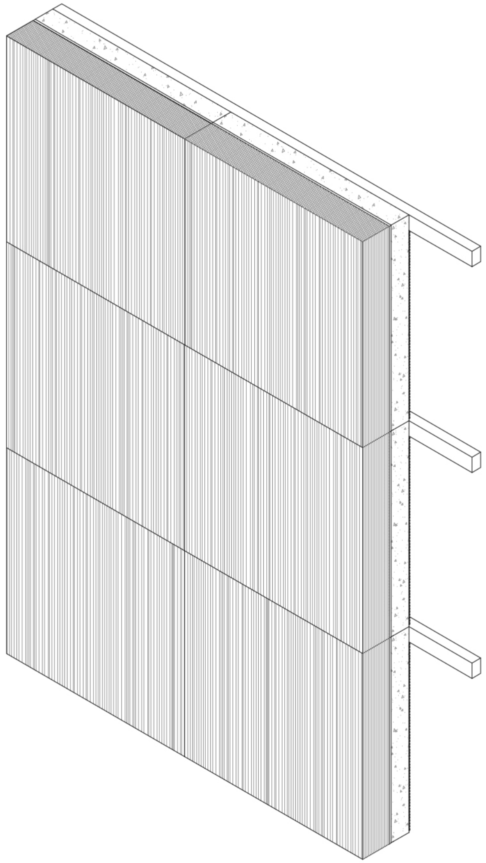
Appendix 1: Illustrated Design Principles



500mm x 500mm
individual panel, fixed on top-rail / sliding rail
*subject to change according to different design iteration

Slimmer rail

Operational Ease Criteria
(Smaller individual panel design)



1000mm x 1000mm
individual panel, fixed on sliding rail
*subject to change according to different design iteration

Thicker rail

Operational Ease Criteria
(Bigger individual panel design)

FUNCTIONAL REQUIREMENT: Operational Ease

DEFINITION: The convenience of moving or shifting the material into different configurations. Measured in the overall mass of a single panel, in kg.

STANDARDS / BENCHMARKS: Maximum 7kg load to be operated for a single person to handle at elbow height with extended forearm.

MAJOR MANIPULATING VARIABLE (FACTOR WHICH INFLUENCES ITS PERFORMANCE): Panel design (dimensions and integration of other materials)

SCALE : 1:15

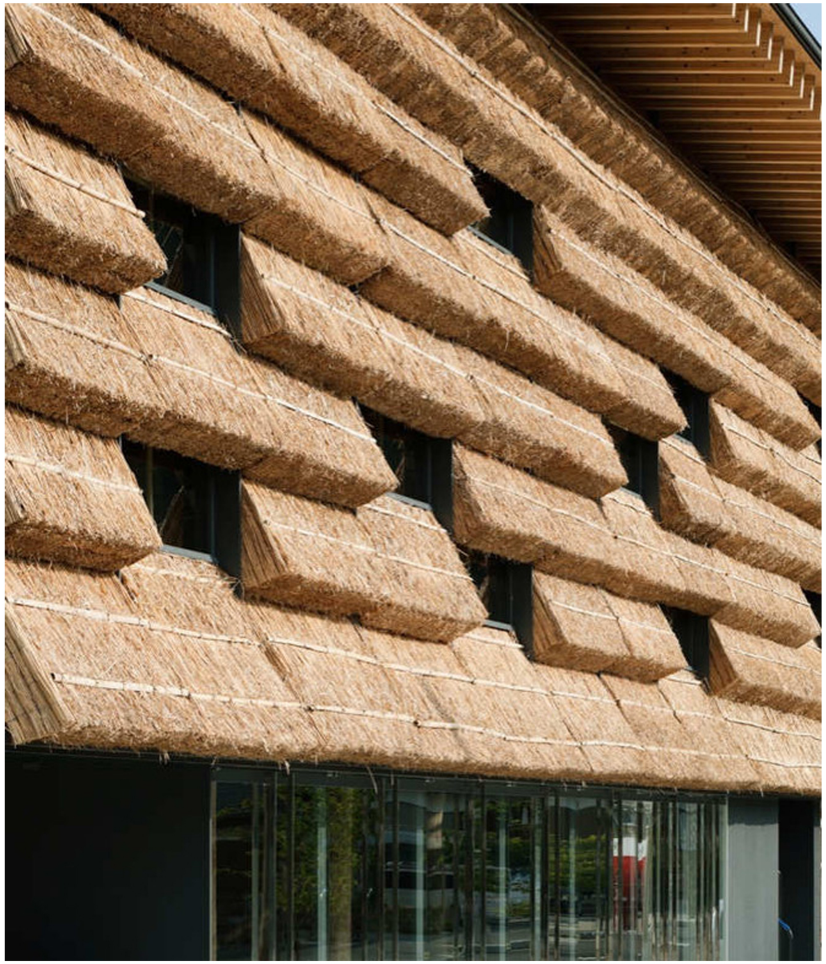
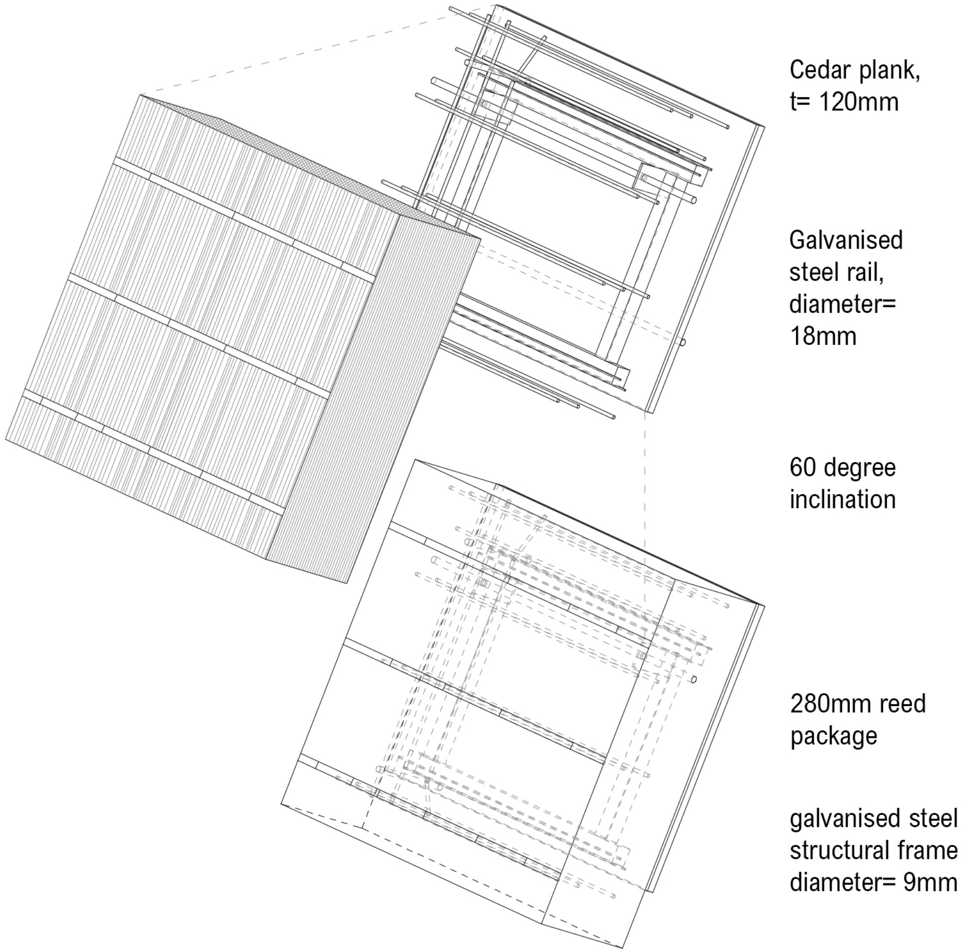


Figure 1. Yusuhara Marche/Kengo Kuma. From Archdaily by Ota T., 2012 (https://www.archdaily.com/199790/yusuhara-marche-kengo-kuma-associates/5004e39728ba0d4e8d000be0-yusuhara-marche-kengo-kuma-associates-photo?next_project=no).



FACADE CODE: F01

TITLE OF FACADE:

Pivoted reed package module
Yusuhara Marche, Kengo Kuma and Associates.

SCALE : 1:20

BUILDING PROGRAMME TYPE: Market place, hotel

CLIMATE & CONTEXT: Temperate, Japan

STRUCTURAL MEMBERS: Fixed galvanised steel rail

PERCENTAGE OF REED USED IN SINGLE MODULE: 90.47%

EVALUATION ON FACADE TYPE AS COMPARED WITH BENCHMARK OF 1000mm x 1000mm x 300mm UNTREATED REED THATCH:

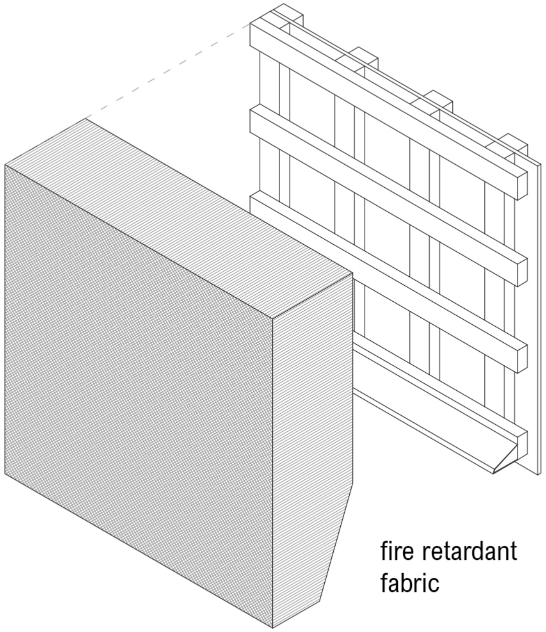
	Poor		Satisfactory (similar as benchmark)		Excellent
FIRE RETARDANCE:	☐	■	☐	☐	☐
THERMAL INSULATION:	☐	☐	■	☐	☐
ACOUSTIC INSULATION:	☐	☐	■	☐	☐
MAINTENANCE EASE:	☐	☐	☐	☐	■
OPERATIONAL EASE:	☐	☐	☐	☐	■

NOTES:

Easy maintenance due to modular pieces which can be detached individually. 60 degree inclination ensure smooth water drainage. High flexibility in different configurations and designs.

AMOUNT OF CARBON ABSORBED*: 20.21kg per module

Figure 2. DORTE MANDRUP WADDEN SEA CENTER. From Divisare by Coast, R. H., 2018 (https://divisare.com/projects/395006-dorte-mandrup-rasmus-hjortshoj-wadden-sea-center?utm_campaign=journal&utm_content=image-project-id-395006&utm_medium=email&utm_source=journal-id-217).



FACADE CODE: F02

TITLE OF FACADE:
Seamless reed thatch in closed construction. Wadden Sea Center, Dorte Mandrup A/S

SCALE : 1:20

BUILDING PROGRAMME TYPE: Exhibition center

CLIMATE & CONTEXT: Temperate, Denmark

STRUCTURAL MEMBERS: Timber substructure

PERCENTAGE OF REED USED IN SINGLE MODULE: 96.15%

EVALUATION ON FACADE TYPE AS COMPARED WITH BENCHMARK OF 1000mm x 1000mm x 300mm UNTREATED REED THATCH:

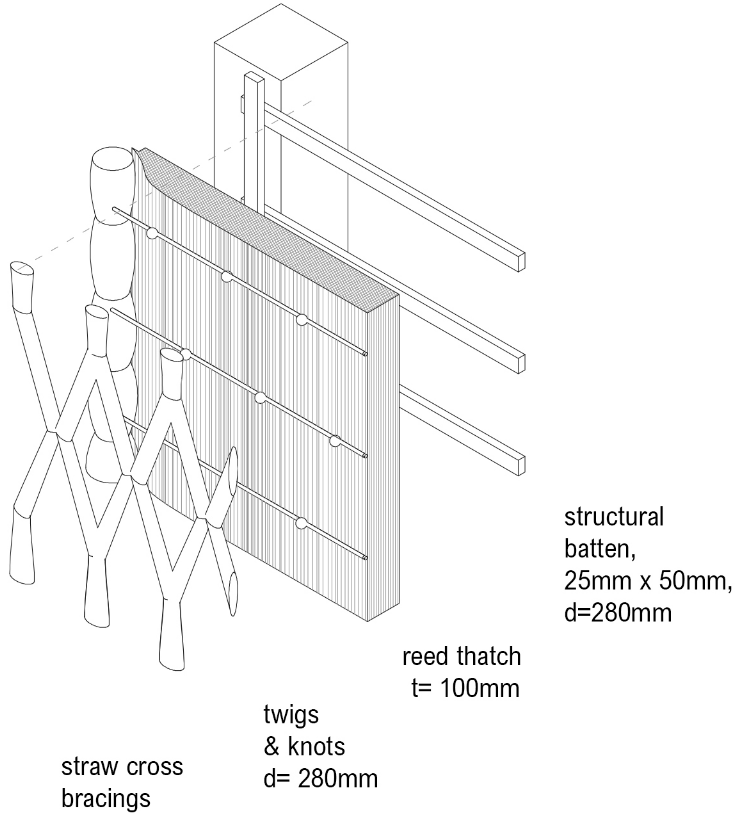
	Poor		Satisfactory (similar as benchmark)		Excellent
FIRE RETARDANCE:	☐	☐	■	☐	☐
THERMAL INSULATION:	☐	☐	■	☐	☐
ACOUSTIC INSULATION:	☐	☐	■	☐	☐
MAINTENANCE EASE:	☐	☐	■	☐	☐
OPERATIONAL EASE:	☐	☐	■	☐	☐

NOTES:

Optimum performance, high sculptural value whereby the thatch can be sculpted according to substructure's form of various designs and expressions.

AMOUNT OF CARBON ABSORBED*: 21.45kg per module

Figure 3. Een wandafwerking met gekruiste strobindingen. Orvelte (Dr.). From *Het Weke Dak.*(p. 19) , by Hemert, M. V., Rooden, M. W. J. V. & Dijkstra, H. T., 1990, Rijksdienst voor de Monumentenzorg, Zeist.



FACADE CODE: F03

TITLE OF FACADE: Reed thatch with straw bracings. Farmhouse at Twente, Unknown.

SCALE : 1:20

BUILDING PROGRAMME TYPE: Farmhouse

CLIMATE & CONTEXT: Temperate, the Netherlands

STRUCTURAL MEMBERS: Timber substructure

PERCENTAGE OF REED USED IN SINGLE MODULE: 81.11%

EVALUATION ON FACADE TYPE AS COMPARED WITH BENCHMARK OF 1000mm x 1000mm x 300mm UNTREATED REED THATCH:

	Poor		Satisfactory (similar as benchmark)		Excellent
FIRE RETARDANCE:		■			
THERMAL INSULATION:		■			
ACOUSTIC INSULATION:	■				
MAINTENANCE EASE:			■		
OPERATIONAL EASE:			■		

NOTES:
Good wind resistance reinforced by straws in diagonal cross bracings, a unique architectural expression. However, overall performance is low, due to open construction (less fire retadance), slim thickness (lower R-value) and lateral stalk direction (lower acoustic absorption cooeficient).

AMOUNT OF CARBON ABSORBED*: 7.21kg per module

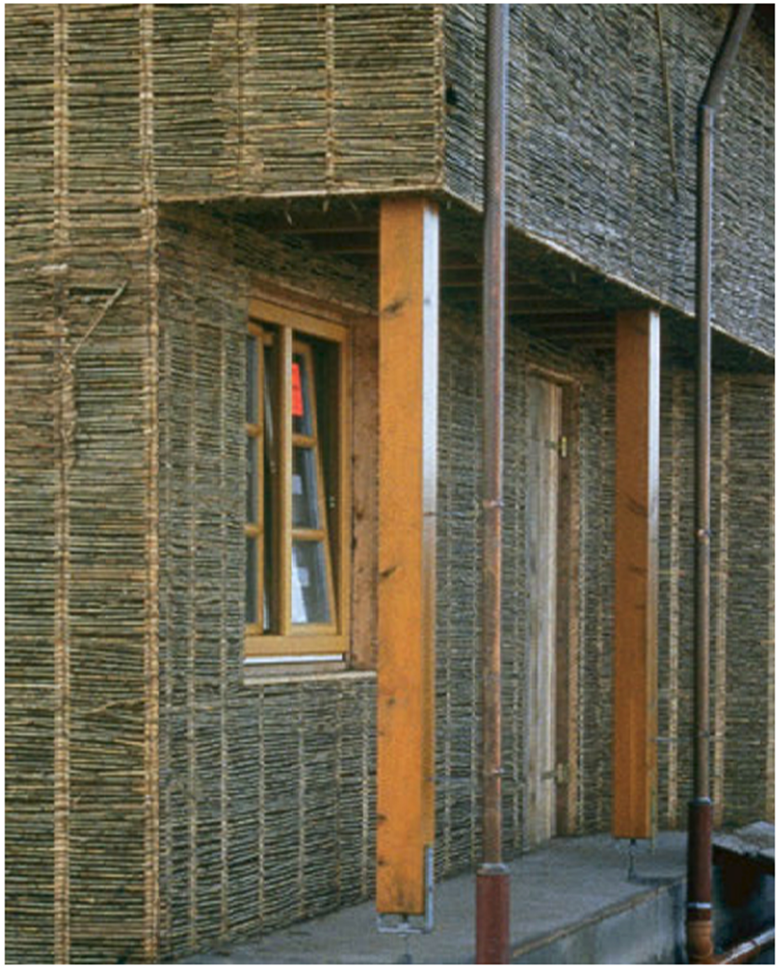
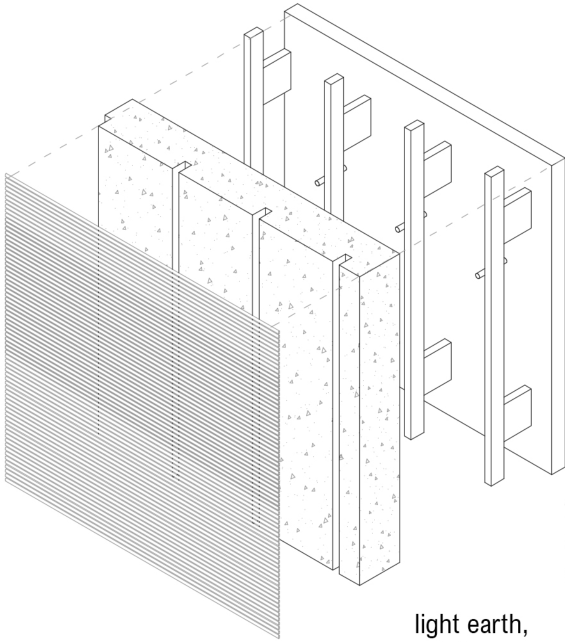


Figure 4. Lost formwork for woodchip light earth using reed plaster lath. From *Light Earth Building.*(p. 94), by Volhard, F., 2016, Birkhäuser.



FACADE CODE: F04

TITLE OF FACADE:

Reed lath light earth composite wall. Unknown, from Volhard's Light Earth Building

SCALE : 1:20

BUILDING PROGRAMME TYPE: Residential

CLIMATE & CONTEXT: Temperate, Germany

STRUCTURAL MEMBERS: Light earth structural wall

PERCENTAGE OF REED USED IN SINGLE MODULE: 0.01%

EVALUATION ON FACADE TYPE AS COMPARED WITH BENCHMARK OF 1000mm x 1000mm x 300mm UNTREATED REED THATCH:

	Poor		Satisfactory (similar as benchmark)		Excellent
FIRE RETARDANCE:	☐	☐	☐	☐	■
THERMAL INSULATION:	☐	☐	☐	☐	■
ACOUSTIC INSULATION:	☐	☐	☐	☐	■
MAINTENANCE EASE:	☐	☐	☐	☐	■
OPERATIONAL EASE:	■	☐	☐	☐	☐

NOTES:

Excellent hybrid solution which harnessed the strength of light earth to improve reed's limitations. However, it is of low operational ease as it is a permanent solution and the reeds are seen as a lost formwork.

AMOUNT OF CARBON ABSORBED*: 0.45kg per module

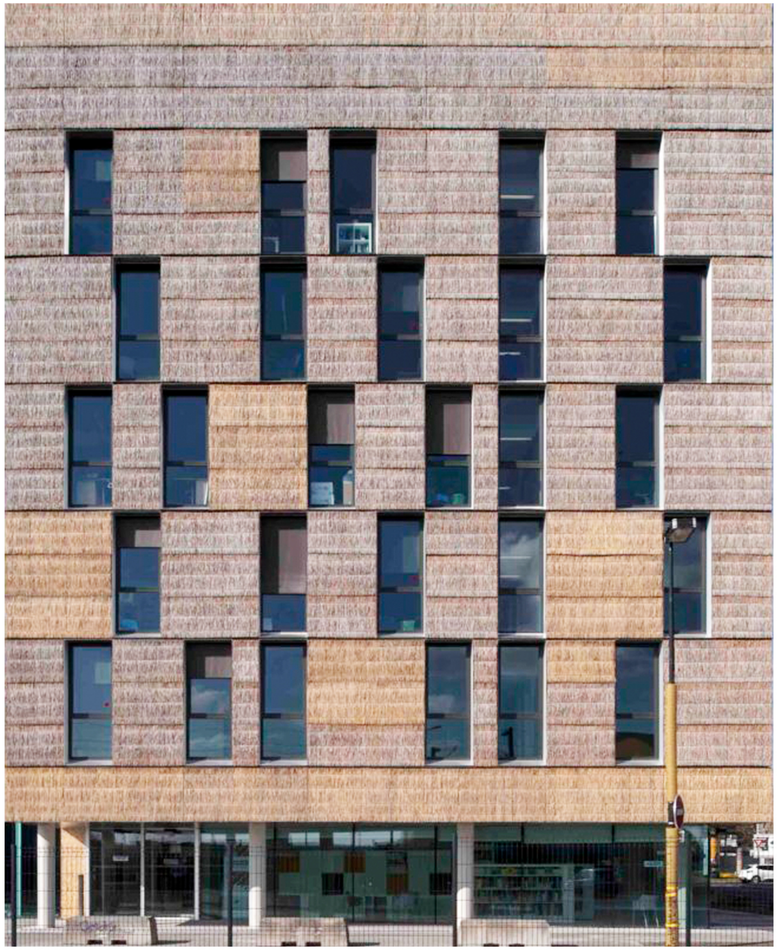
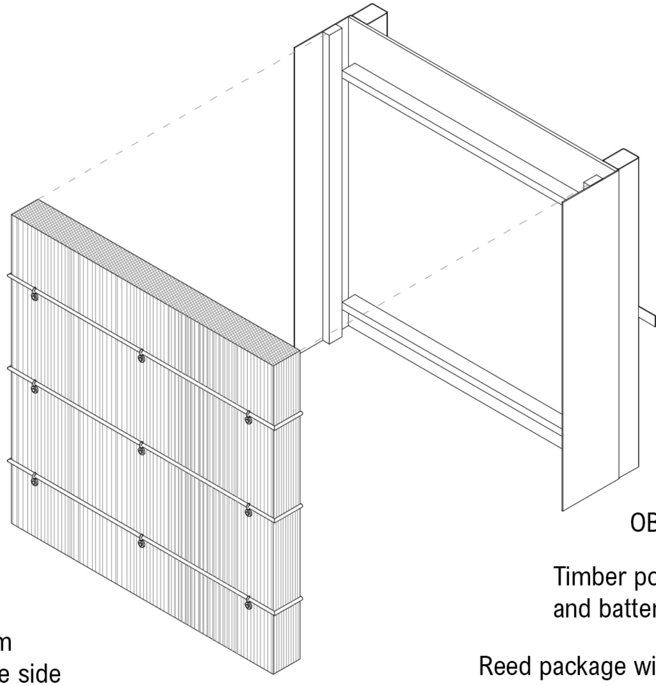


Figure 5. Immeuble de bureaux Françoise-Hélène Jourda Nantes. From Forma6 by Miara, P., n.d. (http://www.forma6.net/projet/architecture/immeuble-de-bureaux-3/).



FACADE CODE: F05

TITLE OF FACADE:

Reed thatch facade panels
Françoise-Hélène Jourda office building, Forma6.

SCALE : 1:20

BUILDING PROGRAMME TYPE: Office building

CLIMATE & CONTEXT: Temperate, France

STRUCTURAL MEMBERS: Steel hollow section

PERCENTAGE OF REED USED IN SINGLE MODULE: 45.22%

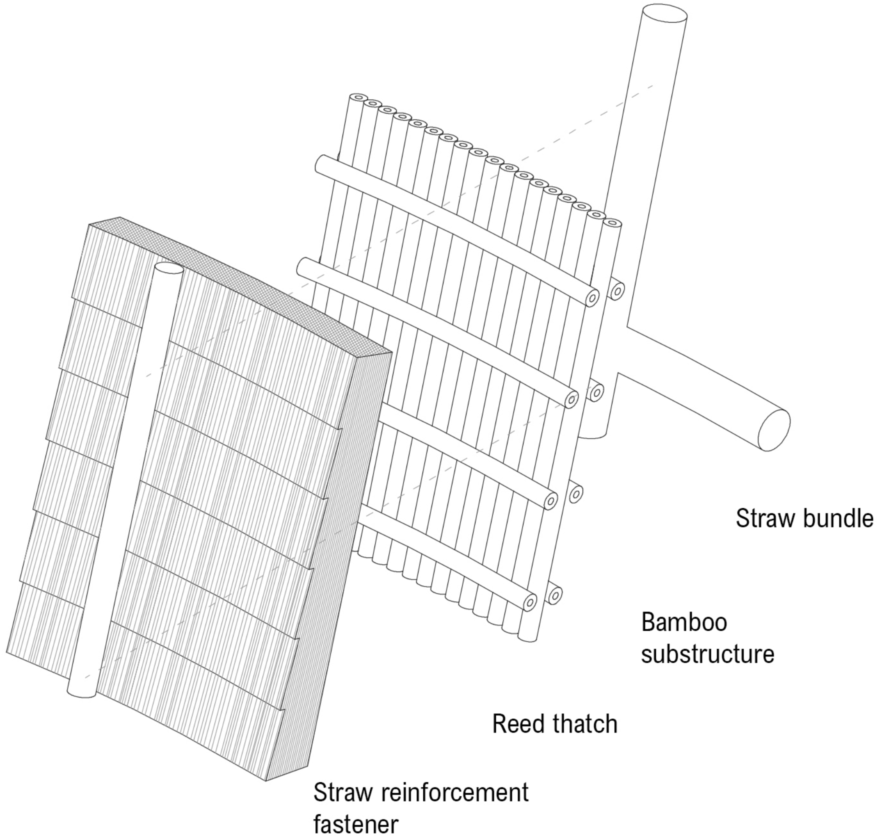
EVALUATION ON FACADE TYPE AS COMPARED WITH BENCHMARK OF 1000mm x 1000mm x 300mm UNTREATED REED THATCH:

	Poor		Satisfactory (similar as benchmark)		Excellent
FIRE RETARDANCE:			■		
THERMAL INSULATION:		■			
ACOUSTIC INSULATION:		■			
MAINTENANCE EASE:					■
OPERATIONAL EASE:				■	

NOTES:
Reaslised in a 6 storey high office block. The vertical stalks arrangement ensure superior water drainage, along with the side flashing panels that prevents water seepage into the thatch implying longer lifespan. It is also lightweight thus reducing the need of extra structural reinforcement.

AMOUNT OF CARBON ABSORBED*: 7.21kg per module

Figure 6. TOSHIKO MORI THREAD ARTIST RESIDENCY AND CULTURAL CENTER. From DIvisare by Baan, I., 2015. (https://divisare.com/projects/284611).



FACADE CODE: F06

TITLE OF FACADE:
Reed thatch on bamboo substructure
THREAD Artist Residency & Cultural Center,
Toshiko Mori Architects

SCALE : 1:20

BUILDING PROGRAMME TYPE: Cultural Center

CLIMATE & CONTEXT: Tropics, Senegal

STRUCTURAL MEMBERS: Bamboo on concrete columns

PERCENTAGE OF REED USED IN SINGLE MODULE: 69.80%

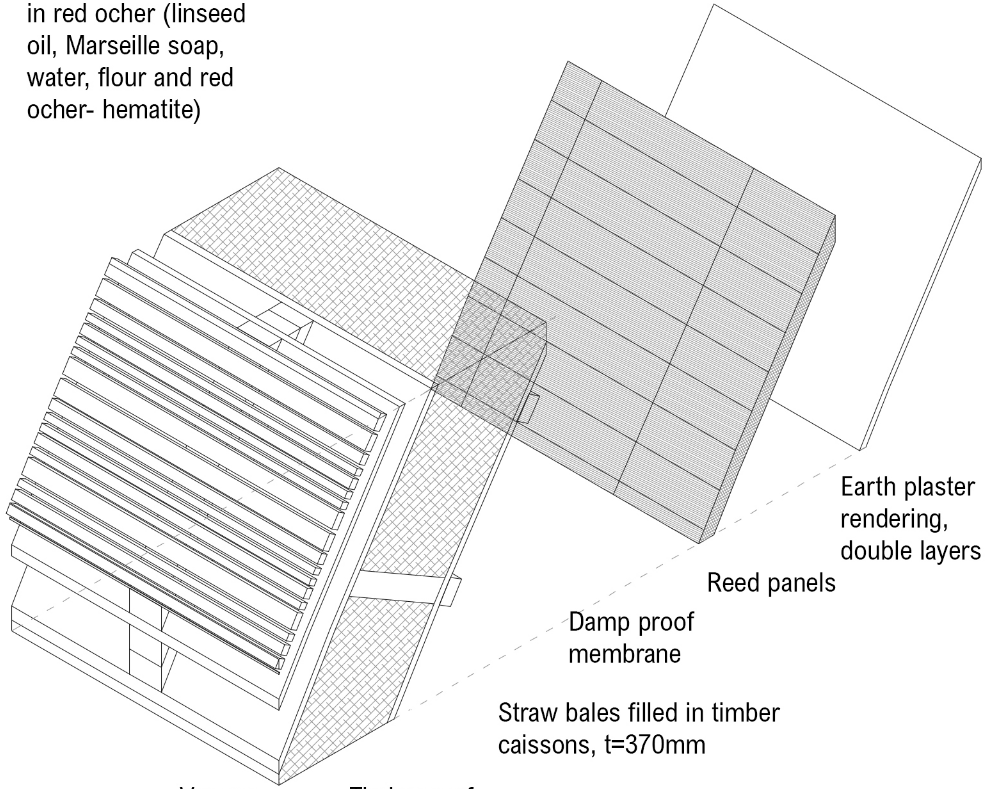
EVALUATION ON FACADE TYPE AS COMPARED WITH BENCHMARK OF 1000mm x 1000mm x 300mm UNTREATED REED THATCH:

	Poor		Satisfactory (similar as benchmark)		Excellent
FIRE RETARDANCE:	■	□	□	□	□
THERMAL INSULATION:	■	□	□	□	□
ACOUSTIC INSULATION:	□	■	□	□	□
MAINTENANCE EASE:	□	□	■	□	□
OPERATIONAL EASE:	□	□	□	■	□

NOTES:
Creates flowing organic form according to substructure’s curvature, made possible with bamboo’s excellent bending properties. The warping form is used to direct rainwater to a water collection system.

AMOUNT OF CARBON ABSORBED*: 8.67kg per module

Figure 7. LA CAVE DE L'ŒUF. From Fibra Award by Goussard, C., 2013. (https://www.fibra-award.org/portfolio/la-cave-de-loeuf/).



FACADE CODE: F07

TITLE OF FACADE:

Reed plaster reinforcement mesh
La cave de lóeuf, Atelier Zero Carbone Architectes

SCALE : 1:20

BUILDING PROGRAMME TYPE: Wine Cellar

CLIMATE & CONTEXT: Temperate, France

STRUCTURAL MEMBERS: Arched timber frame

PERCENTAGE OF REED USED IN SINGLE MODULE: +/- 7.57%

EVALUATION ON FACADE TYPE AS COMPARED WITH BENCHMARK OF 1000mm x 1000mm x 300mm UNTREATED REED THATCH:

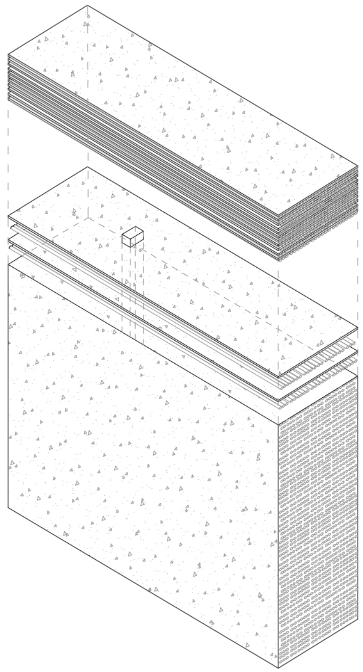
	Poor		Satisfactory (similar as benchmark)		Excellent
FIRE RETARDANCE:	☐	☐	☐	☐	■
THERMAL INSULATION:	☐	☐	☐	☐	■
ACOUSTIC INSULATION:	☐	☐	☐	☐	■
MAINTENANCE EASE:	☐	■	☐	☐	☐
OPERATIONAL EASE:	■	☐	☐	☐	☐

NOTES:

Excellent fire retardance, thermal and acoustic insulation due to the incorporation of straw bales and earth plaster rendering. Achieved high hygrothermal stability which is crucial in wine cellar.

AMOUNT OF CARBON ABSORBED*: 3.62kg per module

Figure 8. Easy to build monolithic wall made of layers of earth and reed fibre mortar and layers of reed, with simple framework (just to define vertical alignment) and wood pillars. From *Energy efficiency. Performance of buildings* (p. 19) , by Faria, P. & Ana, B., 2017, Research Gate.



FACADE CODE: F08

TITLE OF FACADE:

Reed Fibre Mortar
Unknown, local practice in Ethiopia, researched by Bras, A. & Faria, P.

SCALE : 1:20

BUILDING PROGRAMME TYPE: Residential

CLIMATE & CONTEXT: Tropics, Ethiopia

STRUCTURAL MEMBERS: Inherent structural integrity

PERCENTAGE OF REED USED IN SINGLE MODULE: +/- 50.00% varies*

EVALUATION ON FACADE TYPE AS COMPARED WITH BENCHMARK OF 1000mm x 1000mm x 300mm UNTREATED REED THATCH:

	Poor		Satisfactory (similar as benchmark)		Excellent
FIRE RETARDANCE:	□	□	□	□	■
THERMAL INSULATION:	□	□	□	□	■
ACOUSTIC INSULATION:	□	□	□	□	■
MAINTENANCE EASE:	□	□	□	■	□
OPERATIONAL EASE:	■	□	□	□	□

NOTES:

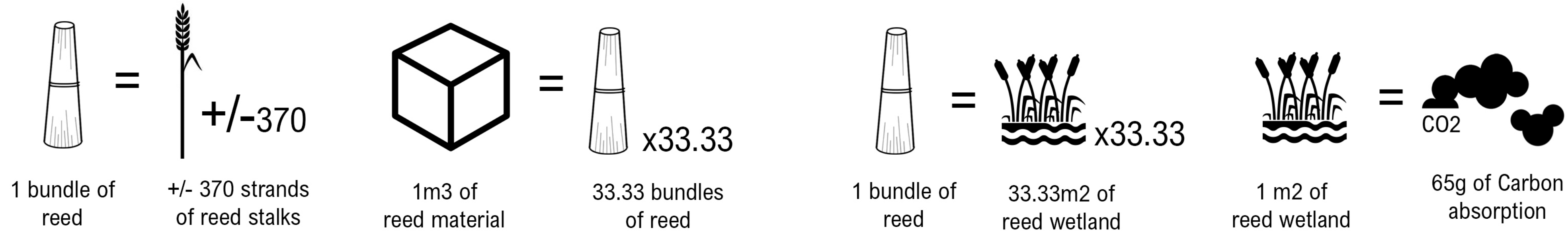
Reed is pounded and grounded into fibres to be mixed in the mortar mixture as aggregates. A local practice, therfore varies from case to case.

AMOUNT OF CARBON ABSORBED*: 10.83kg per module

Appendix 3: Carbon Absorption Calculation

According to a research by Zhou, L., Zhou, G. & Jia, Q. (2008), the net CO2 intake of reed wetland in their study is -65 g C/m-2 year-1. The context is Panjin Wetland Ecosystem Research Station (121 54 E, 41 08 N), China. This freshwater tidal wetland, is referred as a comparative gauge due to its flat terrain, with homogeneous vegetation dominated by P. australis, mean annual temperature of 8.6 Celcius and annual precipitation of 631mm. The intake period of 1 year (the growth period for reed to grow, mature and harvested) is assumed in all calculations.

Below are relevant figures in the calculation:



1 bundle = 0.55m circumference
= 0.175m diameter
1 stalk = +/- 0.008m diameter
1 bundle = +/- 370 stalks

for a 1m x 1m x 0.3 m reed thatch,
10 bundles are needed
0.3m3 mateial = 10 bundle
1m3 material = 33.33 bundle

10,000m2 wetland = 300 bundle
33.33 m2 wetland = 1 bundle

Net CO2 intake of reed wetland is -65 g C/m-2 year-1.

Formula:

Amount of reed applied in the module (m3) X 33.33 bundles/m3 = Amount of Bundle used

Amount of bundle used X 33.33m2 wetland area required/bundle = Amount of wetland area (m2)

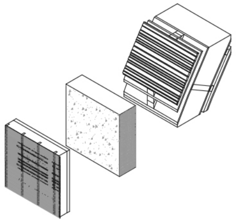
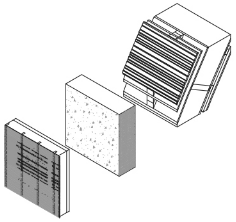
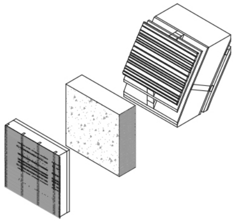
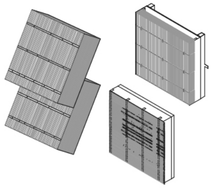
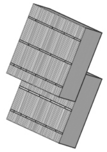
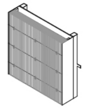
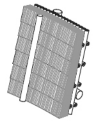
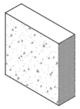
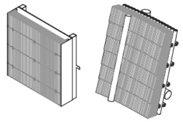
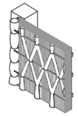
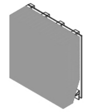
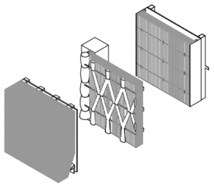
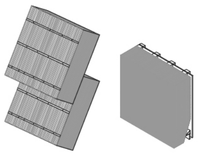
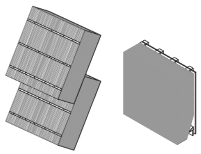
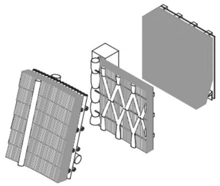
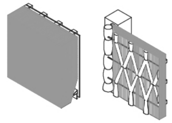
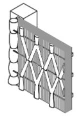
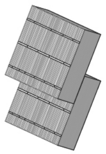
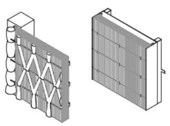
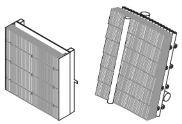
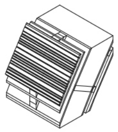
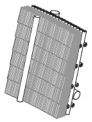
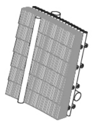
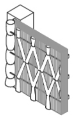
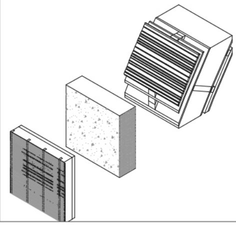
Amount of wetland area (m2) X 0.065kg C/m-2 year-1 = Amount of Carbon Absorbed (kg)

* In F04, amount of reed applied is clearly stated as +/- 70 stalks per module, thus the amount of bundle used is calculated in 70 stalks/ 370 stalks per bundle = 0.21 bundle

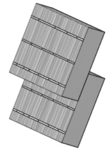
Façade	Reed Applied, in Volume (m3)	Amount of Bundle Used	Reed wetland required, in Area (m2)	Amount of Carbon absorbed, in Mass (kg)
F01	0.28	9.33	310.97	20.21
F02	0.30	10.00	330.00	21.45
F03	0.10	3.33	110.99	7.21
F04	70 stalks*	0.21	7.00	0.45
F05	0.10	3.33	110.99	7.21
F06	0.12	4.00	133.32	8.67
F07	0.05	1.67	55.66	3.62
F08	0.15	5.00	166.65	10.83

Appendix 4: Comparison Matrix

SCALE : 1:100

Requirements/ Criteria — Performance	Fire Retardance	Thermal Insulation	Acoustic Insulation	Maintenance Ease	Operational Ease	Others: Wind Resistance	Flexibility in Form Expression
Excellent							
Good							
Satisfactory							
Fair							
Poor							

Legends: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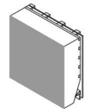
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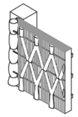
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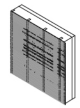
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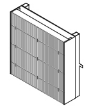
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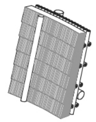
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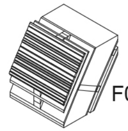
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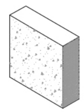
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