Plants as water purification, resource and spatial element for peri-urban kampungs in Bandung

Abstract

My research is focused on the city of Bandung, Indonesia. Kampungs are the villages that make up a large part of the city. In the periphery kampungs are prone to many problems related to water, disappearing green due to rapid urbanization and dependency on the presence of textile industry. By means of three qualities of plants I conducted a research how green in the peri-urban kampungs can be saved. Waterpurification through phytoremediation in wetlands is researched and its benefits for the community. Secondly there is the use of plants as a resource to give economic incentives for the community. Plants can be used for food production and as a resource for building materials. The applicability of these building materials is researched. Lastly there is a research on the spatial possibilties of plants on an urban scale and on the scale of the building. In the end I conclude with a chapter in the integration of the different aspects in a strategy for peri-urban regions in Bandung.

Keywords phytoremediation, water treatment, bamboo, planting design, plants, agriculture, building material, kampung

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Department of Architectural Engineering, TU Delft, 12 january 2015

Contents

Introduction

Problem Statement

My research is focused on the city of Bandung, Indonesia. Kampungs are the villages that make up a large part of the city. Every kampung has its own strengths, opportunities, weaknesses and threats, which depends on the surrounding topomorfology, infrastructure and economic activity. My location is focused on a kampung in the southwest periphery of Bandung. Here the rural is still present in the form of scattered rice fields. While Bandung has industrialized around the textile industry more and more, the rice fields and a healthy agricultural practice have been in decline.(Figure 1[1]) The remaining farmers still irrigate their fields the same way they did 30 years ago. Despite the fact that settled industries and kampung growth changed the water quality drastically through discharge of domestic and industrial wastewater into nearby rivers and water streams. After the water has irrigated the ricefields it streams through the kampung as open sewerage and then back in the river. For the inhabitants this causes health hazards. Although the rice itself is boiled and relatively safe, the people working in the fields citizens living nearby and children playing between the fields are prone to health risks. (Kerstens, 2013, p. 2) The people living in the kampung do not see the pollution in the water streams as a problem. They actually dump most of their own waste into the river because it takes away the trash. Only when trash clogs the system and floods occur they acknowledge a problem. Besides throwing waste directly in the river, waste is being dumped on the streets and burned when enough has accumulated. The latter shows a lack of awareness for the consequences. The people do not see the risks for their health.

Figure 1 – Remaining fragmented agricultural areas in a section of Bandung periphery

Most of the population of the kampung do work related to the textile industry. 50% of its inhabitants even migrated to the kampung to work in the nearby industry. Migrant workers send most of the money they earn to their families. The inhabitants are dependent on the textile industry. Children growing up in the area are influenced by the strong presence of the factories and are lacking alternative opportunities for their future. Now the only existing primary school is overcrowded with 45 children in every classroom.
By 2031 the population in the already dense area will have increased with 37%. (Bandung, 2012, p. 12) This means an increase in children and pressure on the existing schools and on the already scarce green and public space that remains. Protecting and improving these green and agricultural areas is important for many reasons like preserving public space and green area, natural water purification, water buffering and retention, air purification, food production, heat mitigation etc. Besides existing benefits their are opportunities to improve local ecology, create an educational landscape, a connection with the agricultural history and nature for the community, local economic, recreation.

In this research paper my chosen location is exemplary for other rapid urbanizing peripheries of megacities. Around the globe densification and industrialization in peripheries have a destructive effect on sanitation and ecology due to a lack of planning in housing. These communities are often poor and not priviliged to have parks or proper infrastructure. (Stokman, 2008, p. 8)

[1] Own illustration

My focus in the research will be on how plants can be used in watermanagement, as a resource and as a spatial element. Important in this approach are the creation of awareness for water related problems, an economic alternative for a future generation and the use of plants as local building material, and the spatial and social component of green.

Objective

So from the above we can summarize four reasons for action

1. People that are largely **ignorant** to the problem and a **lack of primary schools.**
2. **Remaining fragments** of agriculture still present in a changed urbanized environment.
3. **The loss of green space** and with it agricultural history, disconnection of the new generations in relation to their landscape and food, related problems with water management due to a **densifying periphery**.
4. **Unbalanced economic activity** because of the dependency on textile industry.

A school where children besides general education learn about food and water in lessons and a stimulating environment can give other perspectives to the children growing up in the area. A new connection with the natural environment, water, food and material, is established.
Spatially visualizing different aspects of the water cycle can contribute to the experience and thus awareness for the problem. Besides this a safe place to play and public space is lacking.
Children that go to the school will have a broader understanding of their environment and what is possible and thus opens new perspectives for them.

New values have to be created for the remaining green space to make them survive in rapid urbanization. Economic, social and ecological values have to be integrated in the approach. Using the landscape to solve multiple problems is essential. A primary school and community buildinig can support the new developments in an educational, organizational and motivational way. Waste water from the new school and existing polluted water from the river and sewage inside the kampung will go through a filtering landscape that fertilizes plants and removes pollutants causing the bad water quality. The plants grown will also be a resource to the community to bind them in the development and maintenance of the area.

Nigel Dunnett points out many benefits for people from urban green. He also argues the economic benefits from employment needed for parks, play grounds and green areas. A very important aspect in this research is the educational benefit of green areas. Urban parks and green spaces can be an integral part of a curriculum or extra-curricular environmental education. Furthermore a green space or park can bring together a community by creating a common goal: providing informal recreation, area for children to play, educational resource, employment resulting in new skills, resource of the community, vocational education, organised community events. (N. Dunnett, 2002, pp. 79-92) Social aspects are essential for the success of intervention and should thus be integrated in all three aspects that I will discuss.

In this research paper I will try to answer the following question: How can plants play a role as building material, water management and spatial component in the peri-urban region of Bandung?

Relevance

Bandung is urbanizing fast. One of these locations where growth is expected is the Bandung Kulon, located in the south-west of Bandung. This area was formerly an agricultural area. Now it is known for its textile industry and the pollution in the area. Kampungs have grown organically around the industrial complexes and are expected to grow by approximately 35% according to the municipality.(Bandung, 2012, p. 19) Not only Bandung but many cities in the world are facing urban sprawl. My strategy in how to give the remaining green areas a multifunctional purpose could be applied in other cities that are dealing with similar problems. Other architects, urbanists and landscape architects can use the same tools to give new economic and spatial qualities for remaining green spaces in urbanizing city peripheries while also finding solutions for sustainable water purification and building materials.

Methodologies

The research is divided into 3 components that are derived from the problems discussed in the introduction.
Firstly there is a research on the current water situation of Bandung periphery and how plants can have an impact on the local watersystem. My focus here is on decentralized systems that are applicable in the climate of Bandung, Indonesia in a peri-urban situation. I did this with literature studies case studies and location analysis.
Secondly I look into how plants can be used as a resource (Building material, food, biomass). This is also done by literature studies and case studies. Here aswell I limit myself to species that are relevant to the local climate and resources that could be valuable to the community.
Lastly I look at the spatial possibilities of the plants. This is done with literature studies and research by design. The spatial possibilities will be limited to the plants researched.
The three seperate chapters are in the end concluded so we can have an understanding of how they can contribute to the value creation for green spaces for the community.
In all the above the economic, social and peri-urban context of Bandung is taken into account.

Plant use in water management

Plants can be used in water management, as sustainable building material and for the well-being of people. Besides these there are other benefits like air purification, water drainage, heat-island effect remediation, carbon dioxide sinks, biodiversity, etc. My focus in the following chapters lies on the former tree characteristics to deal with the most accute problems on-site.
I will introduce the context that we are dealing with to better understand the choice for plants as part of the water management system. After the 'status quo' there will be a summary of decentralized water systems that incorporate plants.

Figure 2 - Citarum and Cigondewah river in relation to Bandung City

Citarum and Cigondewah rivers (Figure 2[2])

Cigondewah is one of the many tributaries of the Citarum river. From to origin to the confluence with Citarum the CIgondewah gathers industrial, municipal and domestic waste. M. Fulazzaky's researched the quality of the Citarum river and he made a benchmark for different applications of the water. (Figure 3[3]) Water quality is measured with a lot of parameters including most importantly: Oxidized organic matter (COD, BOD etc), Nitrogen matter, Nitrates, Phosphorus matter, Suspended particles, pH, Microorganisms (coliforms), Metals, Pesticides. (Fulazzaky, 2010)
In table 1 you can see that the water in the tributary close to Cigondewah, due to its quality, can only be used for agriculture and livestock watering. Drinking water production, biological potential, leisure and aquatic sports, nor aquaculture use can be part of possibilities of the river due to its pollution. There are 3 things he doesn't take into account in his classification.

[2] Own illustration
[3] (Fulazzaky, 2010, p. 680)

Firstly Fulazzaky doesn't mention is the potential health hazards of working in irrigated rice fields for the farmers. Secondly he doesn't take into accounthow the river and irrigation system are in many places part of the urban fabric. This means people live around these severely polluted water systems which poses heightened disease risk and other health hazards.

Type of water uses	**Results of WQA analysis**									
	01a	01b	01c	01	03a	03b	03	08	09a	09
Biological potential function	red	red	red	red	yellow	red	red	yellow	green	yellow
Drinking water production use	yellow	red	red	red	orange	red	red	yellow	yellow	orange
Leisure and aquatic sports use	red	red	red	red	red	red	red	yellow	yellow	red
Irrigation use	blue	green	green	green	green	green	green	blue	blue	green
Livestock watering use	blue	blue	yellow	yellow	yellow	yellow	yellow	blue	blue	blue
Aquaculture use	red	red	red	red	red	red	red	yellow	yellow	red
Number of parameters analysis	33	33	33	33	33	33	33	33	33	33

Remarks of lacation: *01a* Wangisagara, *01b* Majalaya, *01c* Sapan, *01* Cijeruk, *03a* Dayeuhkolot, *03b* Brujul, *03* Nanjung, *08* Bendung Curug, *09a* Bendung Walahar, *09* Tanjungpura

Figure 3 – Table for wateruses and quality analysis results

Lastly he acknowledges there needs to be more research on the impact of heavy metal pollution on ecosystem. Even though the BOD and COD levels are known to be exceeding their limits by a factor 3 to 10, there is limited data on heavy metals. In a study conducted by Mott MacDonald was shown that of main concern are the heavy metals manganese(Mn), iron(Fe) and nickel(Ni). (MacDonald, 2011). Also chromium (Cr) is often related to textile waste streams. Most important though are the alarmingly high levels of nutrients (nitrogen, phosphorus) and coliforms (microorganisms). (Kerstens, 2013, p. 17)

Many parameters that define the water quality are exceeding their limit, which has major impacts on human health, ecosystems and economic activity. The above problems are part of the local water situation of many textile industry kampungs in the periphery of Bandung. One case study is the kampung we visited, Cigondewah. In the following chapter I'll go deeper in the current situation of the water situation of this kampung.

Existing watermanagement and waterfacilties in Bandung periphery exemplified by the case study of Kampung Cigondewah (Figure 4[4])

Figure 4 - Cigondewah kampung existing water systems

Water-usage is very dependent on the river and the groundwater. For washing inside the community mainly groundwater is used. The water is extracted with the use of wells. Problems with the groundwater are the pollution that infiltrated the sytem and the low water table due to high extraction rates by surrounding factories and communities. Some houses have municipal water connection for washing water, though this privilige is mainly available for richer families because fr this purpose it is too expensive. (Anindrya Nastiti, 2013, p. 5)
Fishing is very popular in Bandung and so is it in this kampung. They have a fishing pond where the water is kept clean from plastics, however the water is extracted from the river and thus has the same pollution.
The open sewage system, which combines grey- , black and rainwater into one stream, is visible through the whole kampung.
The natural watersystem of the area is under pressure because of the urbanization in the region. Similar to many cities in Europe where canals were being filled, this causes hightened risk of flooding. Already this is occuring in areas where ground levels are raised for large-scale factory complexes. The impenetrable ground and roof materials cause that surrounding villages to have more frequent flooding.
Furthermore normalization of waterdischarge and waterfiltration disconnects the initial relation that the people had with the water. The disappearance of waterinfrastructure is even stronger in developing countries than Western countries. (Stokman, 2008) The mainly agricultural people within the periphery were highly dependent on the watersystem for irrigation less than 50 years ago. Now irrigation is becoming less and less important in the urbanized regions. Which is not a problem per se, but in many cases the communities still use the polluted water for flood irrigation for rice which is problematic when children play and communities live around it.

[4] Own illustration

Water as a new quality for the periphery of Bandung

Reintegration of the watersystem with communities can reduce floodrisks, provide decentralized sewage treatment for clean surface which improves ecological and social circumstances. Also it creates awareness when the community collaborates with the improvements.
Possibilties of wetlands as a decentralized water treatment intrduces the possibility of green space as a multifunctional area with economical, ecological and social values that can help protect these areas from housing development. Clean surface water can have new values for the community. The water can be used to swim or refresh in the often hot weather, streaming water can be used as a spatial element; similar to the open sewage but with a higher quality and with reduced health risks. Fishermen can use it to hunt for their trophies or to breed fish for consumption. The ricefields have potential to be a water filter, however the community doesn't see its benefits yet. Their familarity with agriculture and riceproduction shows affinity with water and food related projects.
Now that we have taken a closer look on the watersituation in the periphery of Bandung I want to pose phytoremediation through wetlands as a possibility for water purification in the area. It is a lowcost solution and helps with preservation of green in the area. Furthermore it has potential to reintegrate the ricefields so they won't be lost in future developments. In the next chapter I will dive deeper into constructed wetlands, what is needed to run them and which plants are suitable to purify the water in the wetlands.

Phytoremediation

Phytoremediation combines the words phyton (plant) and remediare (to remedy), and it describes the proces where plants and bacteria in the root regions remove contaminants, like heavy metals, toxic organic compounds, and organic material. Plants that accumulated heavy metals can be used for composting or biogas production.

Decentralized water systems

By treating water on-site the community gets a direct connection with the water treatment, this also brings a feel of responsibility and understanding. Besides this they can get affordably clean water that can be used for different purposes like: washing, recreation and watering of plants. The improved situation and facilties can help the community motivate to keep the system working. For decentralized water treatment there are many facilities available : septic tanks, biogas reactors,

Settler (Figure 5[5])

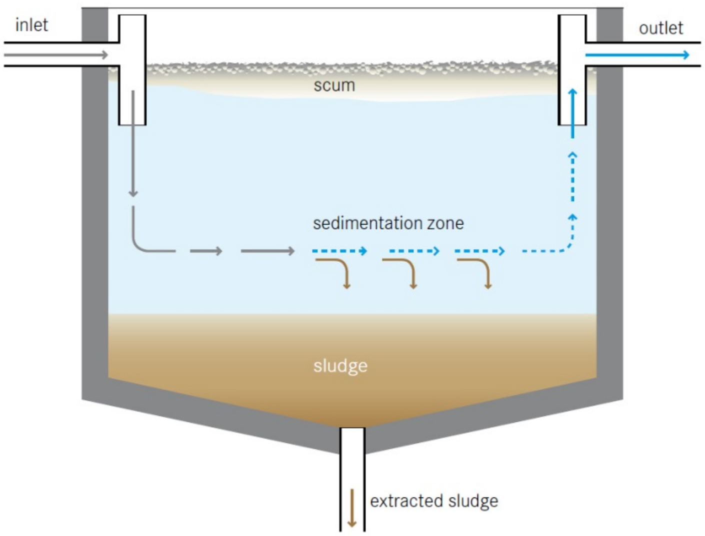

Figure 5 - Settler pond or tank

A constructed wetland is often preceded by a primary treatment unit. A simple solution for primary treatment is a stabalization pond or a settler. (Setty, 2006, p. 2) Because of clogging of the system it is very important to use this stabalization pond and that sludge is removed regularly. (E. Tilley & Zurbrügg, 2014, p. 102)

Constructed Wetlands

We can distinguish three types of constructed wetlands from the compendium of Tilley and Zurbrügg

- Free-water surface constructed wetlands (FSCW) (Figure 6[6])
- Horizontal flow constructed wetlands (HFCW) (Figure 7[7])
- Vertical flow constructed wetlands (VFCW) (Figure 8[8])

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[5] (E. Tilley & Zurbrügg, 2014, p. 102)
[6] (E. Tilley & Zurbrügg, 2014, p. 114)
[7] (E. Tilley & Zurbrügg, 2014, p. 116)
[8] (E. Tilley & Zurbrügg, 2014, p. 118)

A FSCW is the simplest of the three options. It aims to replicate natural wetlands, marshes or swamps. Solids settle, and pathogens are destroyed while the water flows slowly through the wetland. The plants and organisms in the wetland feed on the provided nutrients. Pre-treatment is important to prevent too many solids settling and clogging the system.(E. Tilley & Zurbrügg, 2014, p. 114)

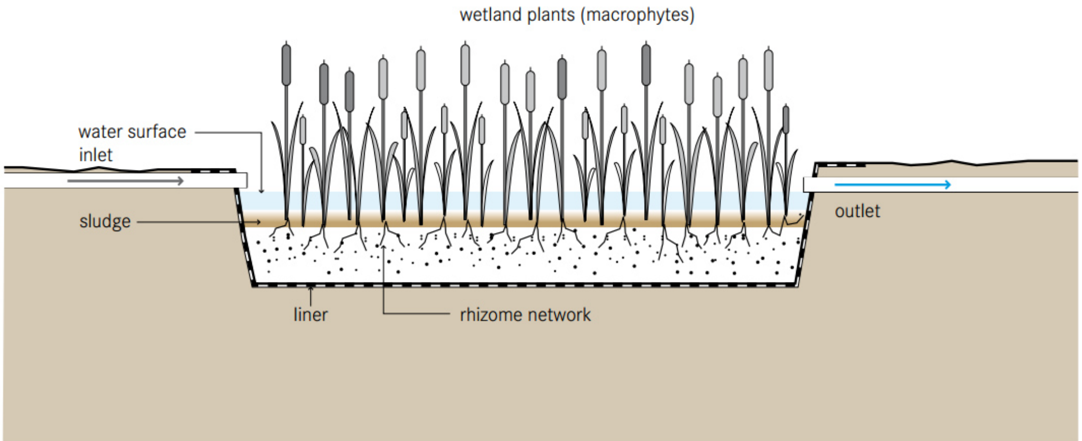

Figure 6 Free-water surface constructed wetland

A horizontal subsurface flow constructed wetland is a large gravel and sand-filled basin that is planted with wetland vegetation. As wastewater flows horizontally through the basin, the filter material filters out particles and microorganisms degrade the organics.(E. Tilley & Zurbrügg, 2014, p. 116)

A HFCW removes a significant amount of pollutants from grey or black water before it flows into the groundwater, river, or natural wetland. This prevents pathogens, bacteria, and non-biodegradable toxins to enter the surface water which helps sustain a healthier ecosystem and improved sanitary conditions. (Yocum, 2006, p. 1)

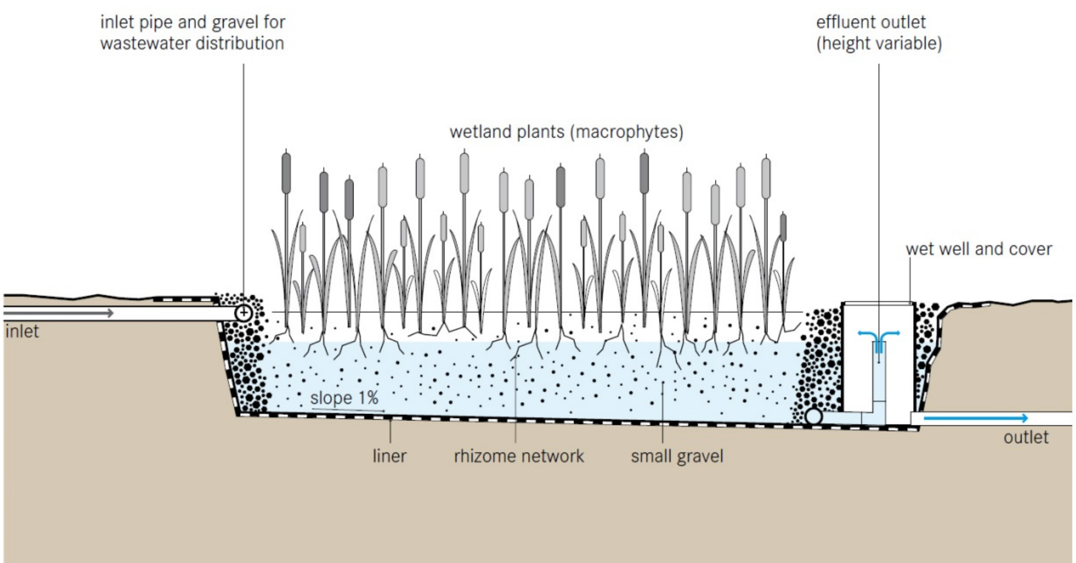

Figure 7 - Horizontal Subsurface Flow Constructed Wetland.

The above subsurface flow wetland prevents, compared to a FSCW, standing pools that give odours and mosquito breeding on the surface water. The technology is also very clean and the system itself is only visible in the plants growing on top, those plants can then be used as a spatial element. Different types of plants can be grown and be part of a bigger system. I will explain more on plant uses in the chapter about plants. Then the spatial implementations will be dealt with in the part about the school context where I will look into the implementation of the systems in the built environment where children play.

Wetland Systems have been tested to remove 65 to 85% of the Biochemical Oxygen Demand (BOD) with a retention time from 3 to 7 days. Ronald Crites furthermore defined space requirments for wetlands depending on the capacity. For a 400 family community this would mean a desired area of approx. 174 m2 depending on the reaction rates and consistency of influent.(Crites & Tchobanoglous, 1998) This shows that with a fairly small surface a lot of families can become indepent from conventional centralized systems

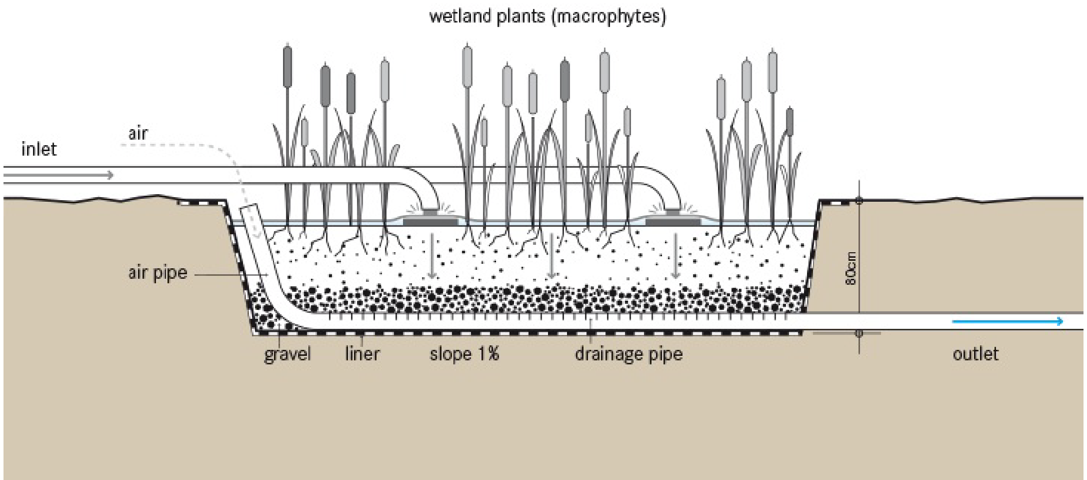

Figure 8 - Vertical Subsurface Flow Constructed Wetland (E. Tilley & Zurbrügg, 2014, p. 118)

Like the name suggests the difference in a VFCW is that water is poured from the top on the wetland, then it flows down through a filtration medium where solids are removed, bacteria can grow on its surface, and roots can find their grounding. The water is added in stages, so cycles between saturated and unsaturated state are realized; anaerobic and aerobic digestion is the result. (E. Tilley & Zurbrügg, 2014, pp. 118-119)
VFCW has less clogging and requires significant less space compared to the HFCW; 1 to 3 m2 per person. However there are more maintenance costs compared to HFCW and expert design and construction for dosing is needed.

Co-composting (Figure 9[9])

Co-composting combines sludge, from for example the settler, and organic waste. The moisture and nitrogen content of the sludge is combined with the carbon rich content of the organic material. Important to note is that a good working co-compostng facility requires quite some knowledge and good execution to be succesful. It is also important to keep the facility close to where it is needed. (E. Tilley & Zurbrügg, 2014, pp. 132-133) With the composting proces heavy metals can be reduced with the help of earthworms, bamboo charcoal or other agents. (J. Singh, 2012, p. 42) The compost is a valuable resource for local agriculture and food production. A facility running next to constructed wetlands could be feasible if enough organic matter and sludge is provided.

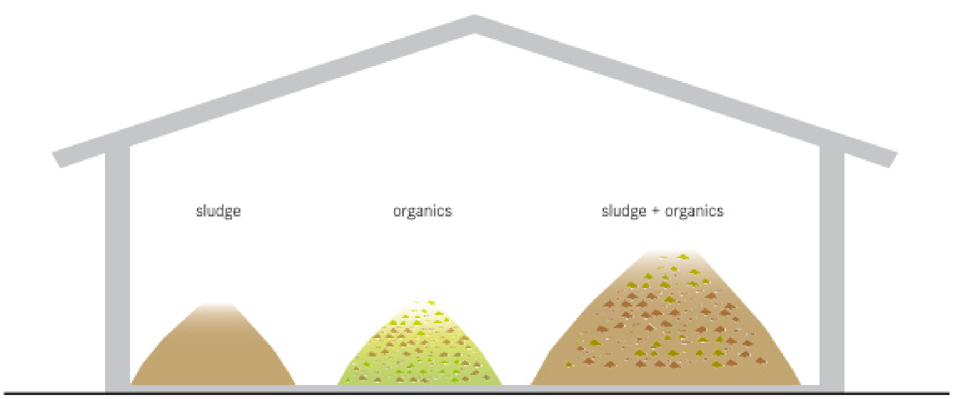

Figure 9 - co-composting facility requiring sludge and organics

[9] (E. Tilley & Zurbrügg, 2014, p. 132)

Plant species usable for waterfiltration

Nature is able to purify the pollutants that humans throw at it. However it takes time, space and certain landscapes and plants to deal with the pollutants. Every plant has their own capabilities to utilize the pollutants as a nutrient. Some plants take the phosphorous and nitrates, others are good at accumulating heavy metals. This chapter will look at different native plants that can be used to remediate the pollution.

Bamboo

Many experiments are being conducted to see how bamboo can play a role in phytoremediation. One important case study is about the use of bamboo in the south of France. Phytorem, a company with patented technology in the use of bamboo in waterpurification, has made a pilot project where waste from the wine industry is filtered to acceptable levels with bamboo.
In this project there has been a setup to clean the vast amounts of wastewater produced by the wine-sector in the region. Treatment is done with the unconventional bamboo technique developed by Phytorem. Besides phytoremediating properties bamboo prevents water run-off and evaporation and helps raise the groundwater table.(Janssen, 2000, p. 39)

Common Reed

Phragmites karka is one of the indiginous reed species to South-East Asia. It has a lot of capability to remove heavy metals from the water and soil. According to Muhammad Aqeel Ashraf the plant is able to extract metals like: Lead(Pb) Copper(Cu) Zinc(Zn), Arsenic(As), and Tin(Sn). Accumulation of the heavy metals occurs in the roots, leaves and shoots. The reed has a potential for biomass with 19 tons/ha. Which is the highest of the filtering plants studied. (M. A. Ashraf, 2013, p. 204)
Furthermore there has been research for the reed in vertical subsurface flow constructed wetlands. Which is very promising according to Denny Kurniadie. He found that the CW is capable of reducing Biological Oxygen Demand(BOD), Chemical Oxygen Demand (COD), total-N, NH4-N, PO4-P and total coliform bacteria to an accepted level. (Kurniadie, 2011, p. 17)

Rice

Ricefields can be constructed as a FSCW which is a common way to irrigate ricefields. Problems of mosquitos can be tackled with fish that eat the larvae.
There have also been tests with HFCW's and from their results its proven to reduce BOD, COD and ammonia (NH_3) (Meira, 2013, p. 4) Rice has a lot of potential

Waterhyacint

Certain plants are hyperaccumulators of heavy metals. Waterhyacint is one of those species and could thus be used to remove heavy metals from the water. Afterwards they could be composted or used in biofuels. Caution needs to be taken when using these plants since they can be invasive.

Case studies

Constructed wetland for a peri-urban housing area, Bayawan City, Philippines (U. Lipkow, 2010)

The case study consists of a social housing project of 676 housing units (3380 people), a daycare center, health care center, multi-purpose hall and a community center. The majority of the new inhabitants are fishermen and a new initiative of organic farming was started to diversify their economic activity.

The project was a collaberation of German and Filipino experts and the city of Bayawan. Users were not involved in the design of the system, but they were involved in the decision to not only treat water in a septic tank but also in decentralized waste water treatment facility. During the implementation phase there was a close collaberation with the community through a village association.

The main existing water treatment was 67 septic tanks that each treated water for 6 to 10 houses. The overflow of the septic tanks flow into one common sump (to remove oils etc.), to be redistributed over 4 header tanks that will distribute the water over the first wetland, a vertical flow wetland. Then gravity brings the water to the second wetland which is a horizontal flow wetland. The effluent is then collected in an elevated tank where it is used for irrigation for vegetables and flowers. (Figure 10[10]) The water has been tested to be perfect for 'fertigation' (fertilizer+irrigation). Though E.coli still remains too high for unrestricted irrigation. Besides irrigation the water is used in the production of concrete. The elevated water tank can easily fill trucks or irrigate gardens with the help of gravity. The firebrigade can also use the water in case of fire.

The size of the two wetlands together measures 2680m^2 which approximates an average of 0.9m^{2}p/p. This is a low design figure because per capita flowrate was expected to be low. Also tropical temperatures and pre-settling in septic tanks contributes to lower demand on the wetland. Even so the E.coli remains high and there is room for discussion in how more surface could improve waterquality.
For the construction of the wetlands a concrete basin was used to prevent infiltration with high ground water levels.

The total construction costs was 160.000 EUR including consultancy. The maintenance is 3500 EUR per year which consists for 3300 in labour costs. The labour consists of pumping and distribution, management of treated effluent, management of plants (cutting reeds once a year), inspection and repair of equipment, regular inspection of the system, effluent sampling and waterquality control. The related costs in human resources a fairly low and provide a steady income for some members of the community

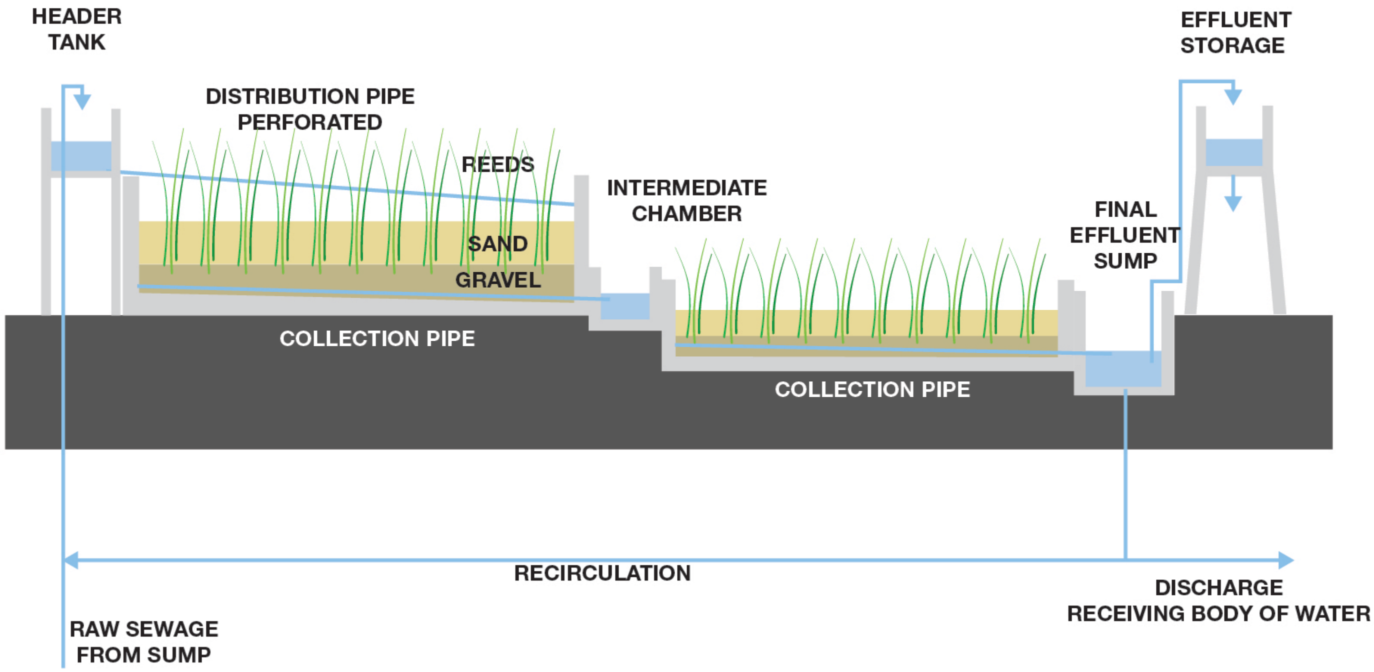

Figure 10 – Setup of the constructed wetlands in Bayawan City

[10] Own illustration

Plants as a resource for the community

Trees, grasses and other plants have been used for construction since human history began. These renewable resources proved vital for our survival and still do in many regions of the world. In the last century our construction methods were focussed on more durable materials like brick, concrete and steel and natural materials started to play an undervalued role. In recent times we are starting to revalue natural materials for their low footprint on the earth and inherent qualities. Furthermore technical innovation makes an increase in longlivity possible. Next to building materials plants can provide vegetables, fruits, seeds, grains etc. which are essential in our diet. Plants are thus a vital resource to humanity. In this chapter I will discuss different plants and their suitability for application. My research pointed in the direction of bamboo as a potential buildingmaterial and their will be a focus on bamboo because of this reason.

Research on building materials will focus on the application in dome since it is in line with my design concept for a primary school. In the design the domes act like cells with different functions that are connected with eachother by pathways. The negative space is used for water purification, gardens and playground. The whole is placed in a productive landscape of bamboo, trees and gardens.

Bamboo

As a building material

There are many species of bamboo and we will focus on two of the most common structural bamboos in Indonesia. Gigantochloa apus and Dendrocalamus asper are bamboo species that have widespread availability and good growth circumstances in Java. Up to 1000 culms/hectare can be obtained every year.

In Indonesia bamboo has been used for centuries as a building material. It has proven to be reliable for houses, bridges, scaffolding etc. However in modern day architecture it is rare to find bamboo buildings.
One of the biggest issues with bamboo is its image. It is seen as 'the poor man's timber'. (Larasati, 2007)
Concrete, bricks, glass and steel, on the other hand are dominating new urban developments. The potential of the strength of bamboo and its widespread availability with its ecological benefits requests for a revaluation of this 'poor man's' material. New inventive ways to use bamboos together with the right marketing approach can pave the way for a new public acceptance for the material. There are many references available where bamboo is given a modern look while still being useful in construction and design.
One approach is to combine old and new materials, like John Lin has done in a house in rural China.(Figure 11[11]) He uses modern concrete for the structure, *traditional mud bricks* for the interior and common fired bricks in the exterior. A similar approach is possible for bamboo. Li Xiaodong designed a Bridge school at Pinghe where he uses a contemporary steel frame to last for a very long time and combined it with a bamboo façade to join local materials with the contemporary.(Figure 12[12]) Moreover the bamboo façade will last for a shorter time and can be cheaply replaced with the locally grown plant.
Another example is the wNw bar by Vo Trong Nghia Architects. He uses striking structural design to give character to the bamboo material. (Figure 13[13])

Figure 11 - Self-sufficient house in rural China by John Lin

Figure 12 - Bridge school by Li Xiaodong

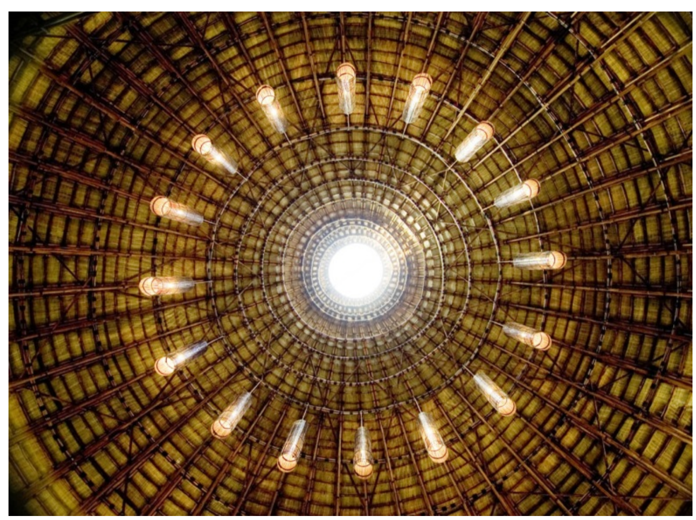

Figure 13 - wNw bar by Vo Trong Nghia Architects

[11] http://www.rufwork.org/index.php?/project/07-shanxi-village-house/ 26dec2014
[12] http://static.dezeen.com/uploads/2009/12/dzn_Bridge-School-by-Li-Xiaodong-1.jpg 26dec2014
[13] http://votrongnghia.com/projects/wnw-bar/ 26dec2014

Processed vs Raw

There is different ways you can classify bamboo use within the building industry. On the one hand there is the traditional utilization of the raw form in culms. Research in trusses and connections are common and show a lot of potential. On the other hand there is the standardized bamboo materials, which is done by processing the material into laminated beams (Glubam), boards etc.
Although manufactured bamboo has benefits including strength, structural reliability and standardized measurements, it is many times more expensive and according to S. Rittironk it is 4 times more expensive than regular wood. However the structural qualities make it more efficient thus needing 1.5 times less material. He also mentions that the costs might be higher but it is a good way to boost local bamboo production and fight the bad stigma bamboo has in many developing countries (Rittironk & Elnieiri, 2008)
In the periphery of Bandung I want to focus on the use of the raw material combined with other materials because it is easier to produce and it can be done on a smaller scale. For laminated bamboo a factory and a lot of knowledge is needed. Besides that the cost still plays an important role in the decision. Though we might focus on the traditional raw form we also focus on the use in dome constructions. Which is an uncommon application of bamboo and is done to give new character to the material while also spanning large areas. I also included prices for raw bamboo to give an indication of costs for its use.(Figure 14[14])

Species Treated (VSD)	*Diameter*	*Length*	*Rp. (2012)*	*Euro (Dec '14)*
D. asper	12-14	500-600	125.000	7,85
D. asper	>14	500-600	140.000	8,79
G. atroviolacea	6-8	500-600	29.000	1,82
G. atroviolacea	>8	500-600	31.000	1,95
G. apus	4-6	500-600	24.000	1,51
G. apus	>6	500-600	26.000	1,63
Species Untreated	*Diameter*	*Length*	*Rp.*	*Euro (Dec '14)*
P. aurea	1.5-2	300	6.000	0,38
P. aurea	>2	300	7.500	0,47

Figure 14 - table of pricing for treated and untreated bamboo

[14] Own illustration

Preservation

The structural qualities of bamboo are undisputed and exceed in tensile strengths and elasticity those of many woods and steel. To improve the performance of bamboo preservation techniques are necessary. Some traditional methods are: (Larasati, 2007)

Clump curing: here the culm is cut and left in the corresponding clump for a few days.
Water storing: leave the bamboo soaked in water for 1-3 months
Smoking: In Japan bamboo is often smoked above a fireplace.

A more thorough way of treatment is the Vertical soak diffusion (VSD). (Figure 15[15]) In this treatment the sap in the bamboo is replaced with Boric Acid or Tim-Bor, by filling the culm with the solution for 13 days in a row. Then the bamboo has to dry for 4-6 weeks. Gravity helps the Tim-Bor to enter the bamboo.
Another good method to treat it is the Boucherie method. Under pressure a solution replace the sap of the bamboo to guarantee durability.

Besides treating the bamboo it is also possible to detail the construction in such a way to limit degradation of the bamboo. For example it is possible to place bamboo columns on a concrete or stone foundation to prevent moisture infiltration and thus fungal attacks.

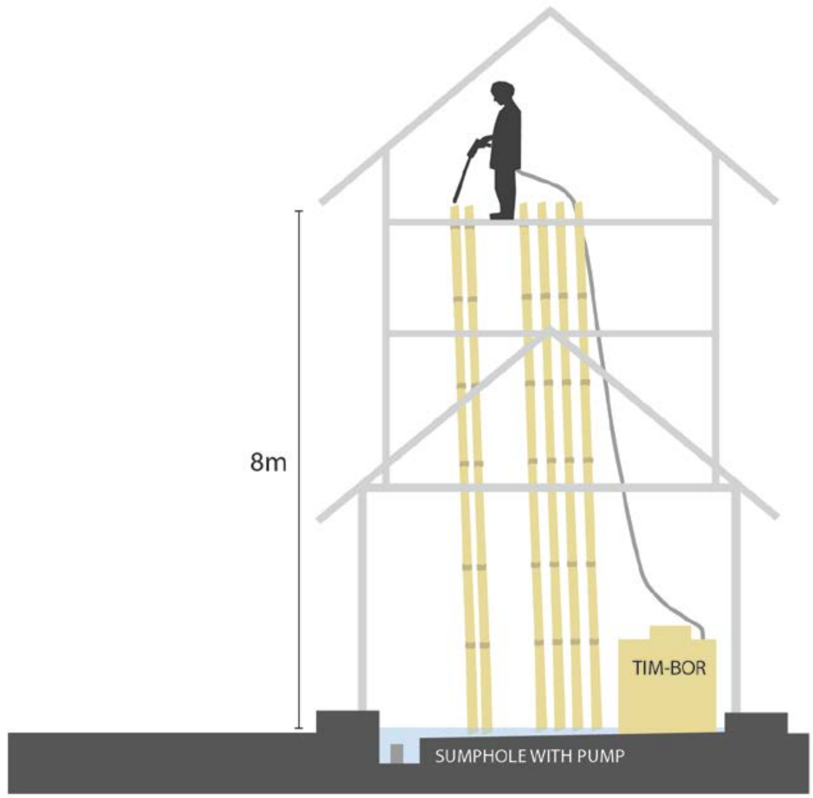

Figure 15 – Vertical soak diffusion setup

[15] Own Illustration

Traditional bamboo construction (Jayanetti & Follett, 2008)

There is a long history of building with bamboo. Most of this architecture has its origin in rural areas where it was built as vernacular architecture. I will focus this part of the research on dome structures and will thus focus on joints and structures. The traditional house construction where bamboo has been used a lot through history is seen by the inhabitants as an outdated way of construction. Discussing the techniques used in those constructions is irrelevant to my research because firstly I am not dealing with housing and secondly I want to focus on dome construction. Some notions on traditional methods are interesting non-the-less: foundation technology and joint techniques. Detailing determines for a large extent the suitability and durability of a bamboo construction. Protection against vermin and wetting is very important for bamboo contructions. Cavity construction should be prevented and wall/ floor constructions should not create concealed areas with the bamboo construction. (Figure 16[16])

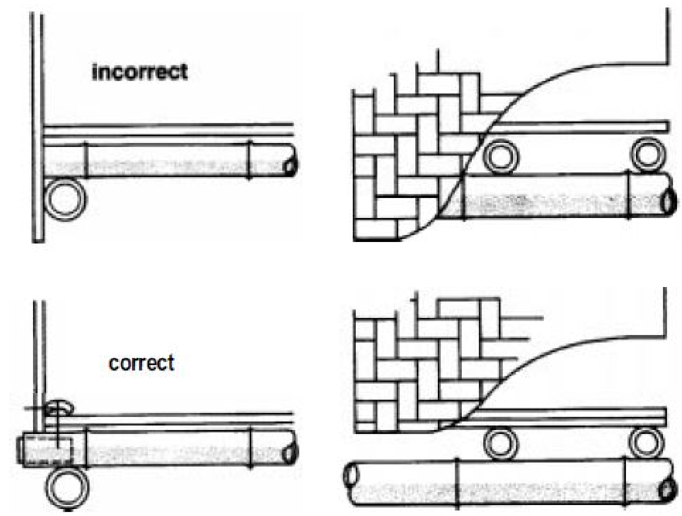

Figure 16 - Preferred beam/joist end detail

Some of the foundations often found are: (Figure 17[17])

- Bamboo with direct ground contact (not a good idea)
- Bamboo on rock or preformed concrete footings
- Bamboo incorporated into concrete footings
- Bamboo on steel shoes
- Bamboo reinforced concrete

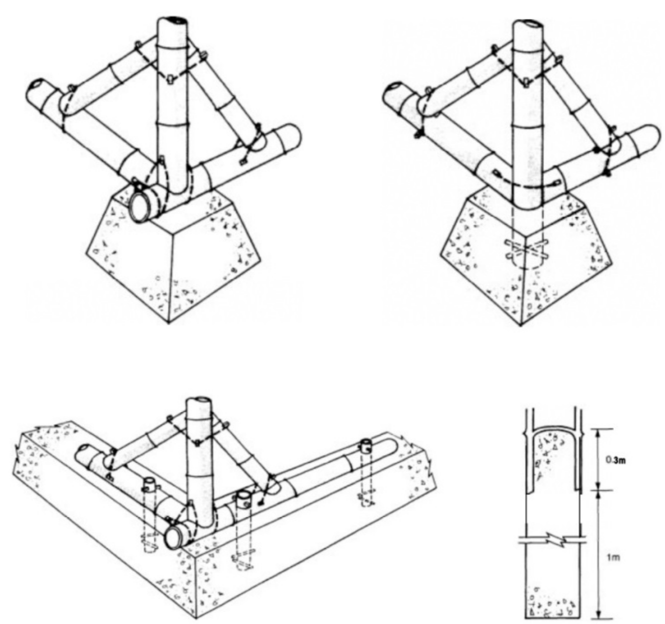

Figure 17 - Bamboo foundations

Keeping bamboo of the ground is essential if you want to protect it from decay.

To make bamboo joints there are is a range of traditional joints (annex I) and newly developed joints (annex II) For bamboo domes some of those connections will be crucial to understand and apply in the right way.
Some of the new connection methods could be useful for constructions with a higher demand on the structure and joints. The Herbert Shear Pin Connector could help where I need multiple alteral bamboos to make larger spans.
In the wNw bar Vo Trong Nghia uses traditional rope and dowel connections to assemble the main ribs of the dome.

16 (Jayanetti & Follett, 2008, p. 48)
17 (Jayanetti & Follet, 1998, pp. 25-26)

Catenary and dome structures

Besides the traditional way of building bamboo the material could be used to make more intricate forms like I will discuss in this chapter. Structural systems and their compatibility for Bamboo wil be discussed here.

Form-active

Heino engel discusses form-active structural systems in his book 'Tragsysteme'; one of these systems is the catenary cupola. (Figure 18[18]) The concept uses the principle of the optimum arch that is created by the furnicular lines when a dead load is applied. When hung upside down the perfect tensile furnicular line is created and when turned around its optimal for compression. The system has double curvature and in both directions the optimal furnicular lines are formed. This structure could be used for spanning a large area with benefits being that the sides can be left open

One example of a catenary dome is a bamboo pavilion in Mexico. (Figure 19[19]) It spans 16.2 x 18.6m which totals a surface of 303 m^2. In the edges a reinforcement of tensile steel wires is used. (Figure 20[20]) Also they chose to combine 4 bamboo culms in one direction. Rectilinear on those beams cross two beams in between the former beams. Wires and Herbert Shear Pin Connectors are used to keep the crossings together and flexible.

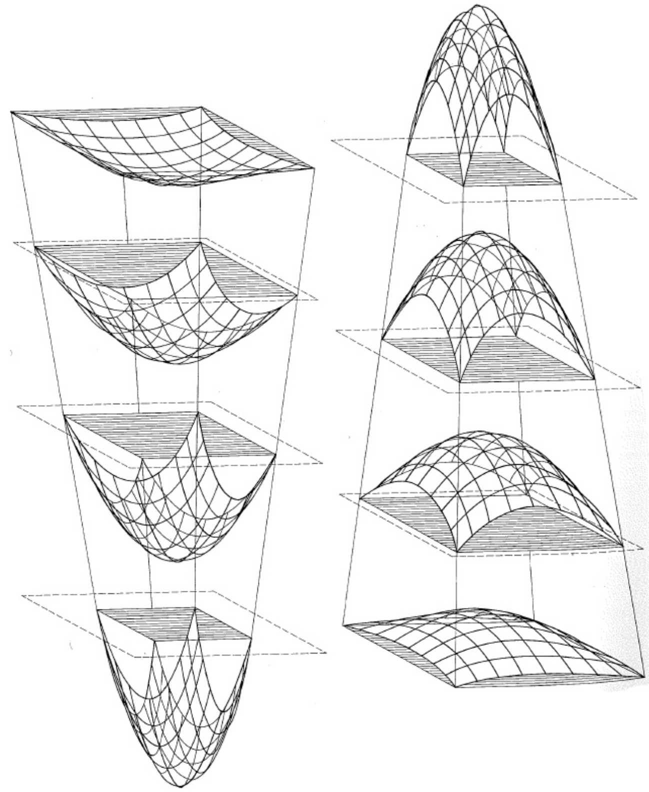

Figure 18 – Different heights for catenary cupola (Engel, 2001, p. 122)

Figure 19 – Bamboo pavilion by Carpas Y Lonas El Carrousel S.A. de C.V.

Figure 20 - structural joint detail bamboo pavilion

[18] (Engel, 2001, p. 122)
[19] http://www.ifaipublications.com/iaa/articles/2011_1306_bamboo_pavillion.html 10jan2015
[20] http://www.andrescasares.com/#!__english 10jan2015

Dome structures(Figure 21[21])

There are many types of domes with different amounts of layers and they are defined by their elements that arch in all directions. (Surrey, 2015) The wNw bar by Vo Trong Nghia is an example of a Ribbed dome. (Figure 23[22]) Also by the same architect, Diamond island community hall, consists out of a combination of the ribbed and lamella dome. (Figure 22[23])
It is proven that bamboo dome structures are structurally possible and there is still a lot of different types untested with bamboo. The results are beautiful and innovative and can give new quality to the bamboo material to convince people that see it as regression.

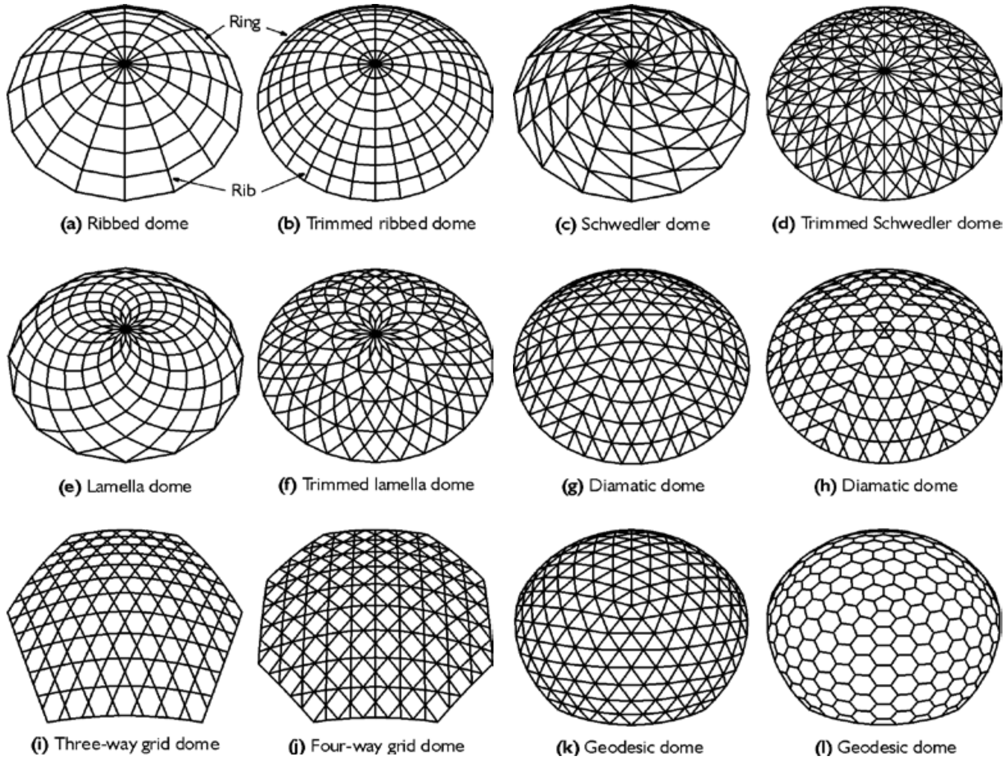

Figure 21 - Dome structures

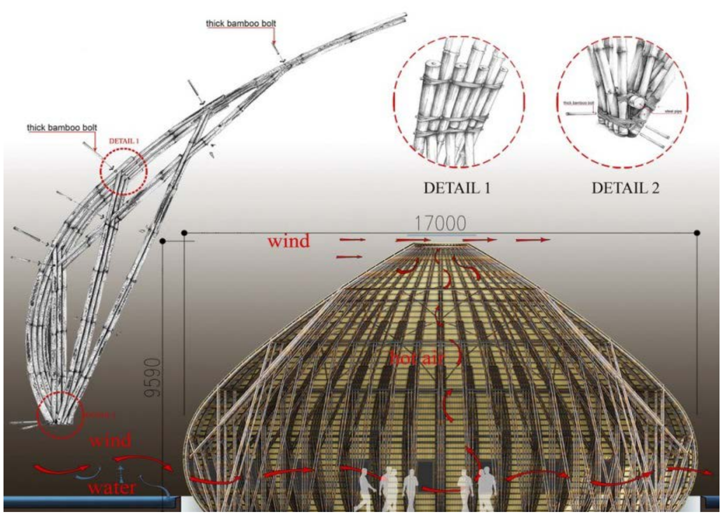

Figure 23 - Ribbed dome and construction details wNw bar


Figure 22 – Ribbed dome with lamella dome

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[21] (Surrey, 2015)
[22] http://votrongnghia.com/projects/wnw-bar/ 5jan2015
[23] http://aasarchitecture.com/2014/07/bamboo-domes-vo-trong-nghia.html 5jan2015

Bamboo as food

Bamboo shoots are a good source of protein and grow on the rhizome of the bamboo. Although these shoots would grow into large bamboo culms if not taken away for food it is not harmful to harvest them selectively. It also is a way to maintain the bamboo plant so it won't expand too much. The harvesting could be done by the persons taking care of the bamboo and directly sold to the community or cooked within the school. The availability of extra sources of food is a good thing and improves the local diet.

Bamboo as Biomass

Bamboo also creates large amounts of biomass in the form of culms(65%), branches(17.5%) and leaves(17.5% that can be used for biofuels, fodder or compost. (Janssen, 2000, p. 41) When grown with other plants in the vicinity the organic matter of the bamboo could be of use when co-composted with sludge from the water treatment

Common reed

Reed as building material

Traditional thatch

Reed is used as a thatching material throughout South-East Asia. It is dried and then fumigated against pests. Then it is rinsed and dried again. Traditionally bamboo sticks are used to attach the thatching, however other materials can be used for the same purpose. (Figure 24[24]) Another way to attach the thatch is to have horizontal laths in the roof structure and apply the thatch on those laths afterwards with metal wire and hooks to keep the wire in place. (Figure 25[25])
Thatch, like bamboo, has a problem with image when used in the traditional way. Form and application methods can play role in changing this image.

Figure 24 - Thatch with integrated horizontal laths

Reed as biomass

Since reed is a natural plant material it can be composted.

Rice

Rice as food
Rice is a the staple food of Indonesia and essential to the diet. Besides cultural heritage it is still one of the vital resources of the country which is becomming more dependent on imports for rice.

Rice as biomass
By products of the harvests like the straw and husks can be used as biomass for composting etc.

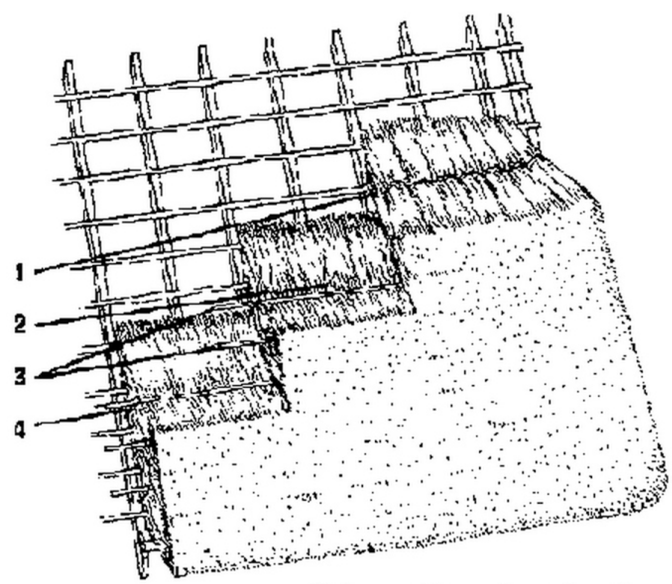

Figure 25 - Thatch on horizontal laths

[24] http://www.worldbuildingsdirectory.com/project.cfm?id=1344 6jan2015
[25] http://en.howtopedia.org/images/5/54/Biomass_Roofing_p06b.gif 6jan2015

Trees

Fruit, spices and timber

Smallholder and forest industries tend to grow only a few tree species. Firstly this is because only 10% of all tree species have their properties documented and secondly it has to do with availability of germplasm, ease of management and propagation, and promotion by governmental and non-governmental parties. In West Java the traditional tree farming system, *dudukuhan,* can be separated into four types: timber, mixed fruit-timber-banana-annual crops, mixed fruit timber, and fallow. There is a clear species domination in the dudukuhan systems, namely Maesopsis eminii (22.1 %) and Paraserienthes falcataria (14.4 %) and by banana varieties (Musa spp. 26.8 %). Diverse species account for the remainder of the systems, including Artocarpus heterophyllus (4.0 %), Archidendron pauciflorum (3.6 %), Nephelium lappaceum (3.3 %), Mangifera odorata (1.7 %), Parkia speciosa (2.2 %), Sandoricum koetjape (1.6 %) and D. zibethinus (1.5 %). It has been theorized that productivity can be increased when polycultures based on four to five species are cultivated. (Narendra, Roshetko, Tata, & Mulyoutami, 2012) We can derive from the above that there is a lot of potential in growing different species among each other. There is a vast amount of trees that can have economic effects for small holder farms.

Mangosteen, Jackfruit, Durian, Guava, Ramboostan, Gnetum, Cocos, Mango, Santol, Langsat, Sugar Palm, Kueni, Avocado, Kemang, Bread fruit, Longan and Citrus are some of the fruit trees on West Java that can be cultivated.
Coffee, Ngapi nut, Clove, Nutmeg, Football fruit and Stinky bean are some of the spice trees found on West Java that can be cultivated.
Albizzia, Manii, Mahogany, Shorea, Needlewood, Red Cedar, Mangium, Pepau, Teak, Neem, Gmelina, Magnolia, Rasamala, Dita bark, Pine, Cadamba, Camphoor, Rubber, False elder, Litsea and Leucaena are some of the timber species found on west Java that can be cultivated.
According to a research the following five species show a lot of potential for small holder farms:
Magnolia (timber), Gmelina (timber), Santol (fruit), Durian (fruit) and Stinky bean (spice). (Narendra et al., 2012)

Trees could play a vital part in providing resources for the community. Food, spices and timber prove to have economic benefits for smallholder farms and could also be integrated into a peri-urban context of Bandung. Priority then not only lies in production but also in the creation of space. In the next chapter we will see how trees be used for this goal.

If planned ahead certain trees can have benefits as food and spatial component while in the end of its life can act as a building material for the community or sales. Although some tree species might take between 30-40 years before they can be used in construction, they can benefit the community throughout their lifetime. We can thus see some trees as a long term investment with more than solely economic values.

Since timber in construction takes a longer time and a larger area than bamboo my focus as a building material lies not with wood. Though it is a building resource and could be used in construction.

Conclusion plants as a resource

Different plant species have shown to be suitable building materials in Bandung region. Modern application methods are important when using the materials to accomplish social acceptance. Also showing the possibilities to local communities to win their trust can help. The natural materials can of course not substitute materials like concrete, bricks and other common materials. Although they can be used as an addition to current arsenal. Furthermore it can provide a new use to the green spaces within peri-urban Bandung. Incorporating bamboo, reed, food and timber production can create value for the areas and give new economic perspectives to parts of the community. Important is the local use of the resources because of its small scale. Local application in public buildings, bridges and other structures can bind the community behind the project and also give them a feel of responsibility in maintaining the green space that gives them the resources.

Bamboo shows a lot of potential as building material because of its structural capabilities and growth rate. Especially when applied in an innovative way. As shown structural form, combinations with modern materials and rhytm can have a positive effect on the appearance of bamboo. Other materials like thatching with reed are also interesting especially when it is a by product of constructed wetlands with reed.

Plants as a spatial element

Buildings have surfaces and edges that define and create space, the green building blocks have the same possibilities to form space. The empty space that the solid forms define and create are often just as important as the solid forms themselves. (Figure 26[26])There are different scale levels for planting form and outdoor spaces. In order of scale we could look at belts of trees, woodlands and forest fragments that accomodate large-scale uses. Then there are the smaller scales where planting continues to play a role in structuring the landscape. Play areas, neighbourhood parks, walkways, private gardens and other spaces where planting plays a role all require a certain degree of definition, shelter and privacy. In this chapter I will go deeper into how bamboo, reed, rice and trees can become spatial in the green oasis of the periphery of bandung. I will limit myself to bamboo, reed and trees in general. The current remaining green spaces are dominated by patches of ricefields with defining walkways/ dykes on the edges to maintain the rice. On some of the small dykes banana trees are lineairly planted. Sporadicly a tree randomly silhouettes the background. (Figure 27[27]) Taking into account this existing spatial framework of green space is important when interveining because of cultural heritage and existing irrigation methods.

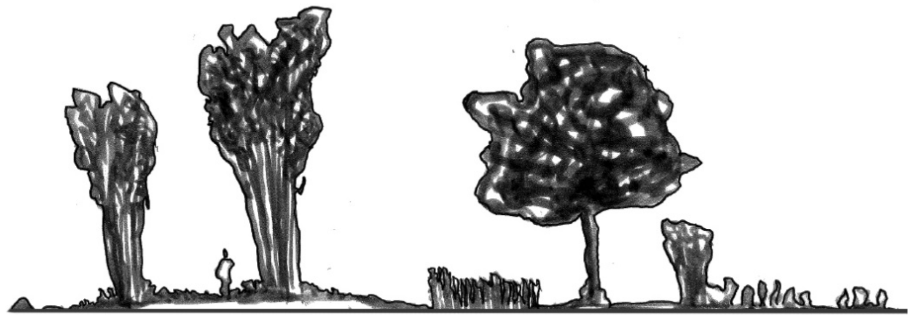

Figure 26 – Plant create spaces like walkways, gardens, play areas etc.

Figure 27 - Typical situation of remaining green in the Bandung periphery

Dynamics

Plants, designed or natural, are always in a state of flux. Its composition changes through time. Rice is a good example for this. It grows in different fases and changes with the cycles, from small seedling towards full grown rice that turns brown when it is ready to be harvested so that the land returns to the initial empty space. Even a natural forest has change because of dying trees and newborn seedlings. The growth and development is affected by many factors like: weather, neighbouring species, ph, disease, human pressure. Besides plant development there are cycles that affect appearance like flowering and plant longlivity, some have diurnal rythms others have anual rythms. (Robinson, 2004, p. 12)

[26] Own illustration
[27] Own illustration

Aesthetics, functionality and environmental tolerance

As defined by Morrison plant selection is defined by aesthetics, functionality and environmental tolerance. We have looked at the functions like waterpurification and resource. Morrison defines also under function aspects like shade, windbreak, visual screening or framing and erosion and sedimentation control. Aesthtics are about form, texture, color and seasonal changes. Use, ecology and aesthetics influence the placement when designing with plants. (Morrison, 2008, p. 117) In this chapter I will go deeper into how the used species will spatially manifest themselves and how I can further play with uses not mentioned before (wind barrier, visual screening or framing and erosion control) and aestethics.

Points, lines and patches (Figure 28[28])

I define three main archetypes that can be transformed or combined in many different typologies: points, lines, and patches. These archetypes come in many variations and combinations but I want to point out some of the characteristics and uses in landscape design and in the built environment.

The point

The point is an individual plant that is spatialy seperated or stands out in texture/ form/ size. The scale of the point can differ: It can be a single tree or a cluster of plants. It depends on the context and the scale level if it is regarded as a point.

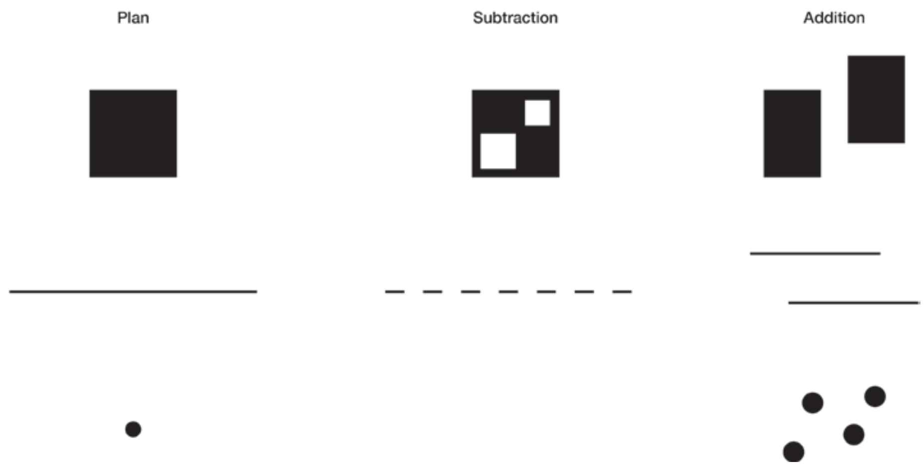

Figure 28 – points, lines and patches

The line

The line can be an edge, a wall, a corridor etc. It can connect or disconnect. Also combining lines can create space in between.

The patch

A patch in nature is often an area with many different species and it is also the most natural form how plants manifest themselves. The edge of a patch is often perceived as a line element.

The three elements above are often not visible in its pure form but in combinations. We can use them in our design to give direction, create space or

[28] Own illustration

Bamboo

There is many types of bamboo and as mentioned before we will focus on the Dendrocalamus Asper and Gigantochloa Apus (Figure 29[29]), both clumping bamboos (they grow in clumps opposed to the more spread out running bamboo). The bamboo species reach maturity within 5 years.

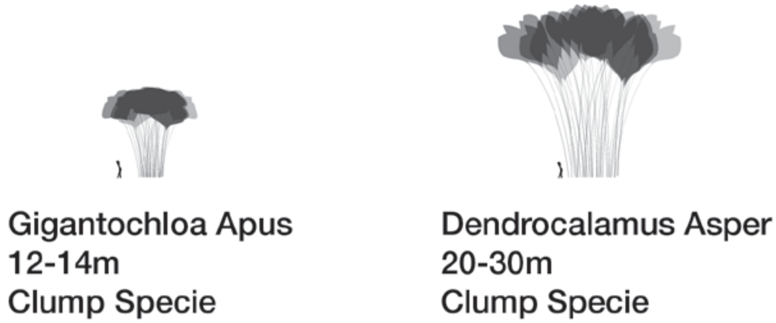

Figure 29 - Size and spatial point

Other uses

Clumping bamboo has a good resistance to wind and can thus be used as a windbreak. The rhizomes occupy the ground and form the rootsystem of the bamboo. It is very dense and prevents other plants from growing which also makes weedcontrol very easy Bamboo also prevents erosion and can be planted for example on a pond wall to prevent it from eroding. The size makes it able to block visual objects if not wanted or frame others. Factories in the Bandung periphery could be visually blocked this way.

Aestethics

The shear sizes of the two species make them suitable as a spatial point. Isolated bamboo tends to grow wider because of the space and sun they have. They can form a reference/ meeting point or a place for shade under the tropical sun.
To harvest building materials and food from the bamboo it is required to plant the trees atleast 6-8 m apart. A lineair effect can still be created although it will not create a closed edge.
If we want to use the bamboo for water purification and material production you might want to plant high quantities of bamboo clumps. Patches of bamboo will thus be useful. Keep in mind that almost nothing grows under the bamboo due to its extensive rootsystem. In this scenaria it is hard to create a polyculture with bamboo The image of the bamboo forest shows it could become an interesting space when corridors are subtracted from the patches. Thatch is used to create the fence following the path.in the image. (Figure 30[30])
There are also other local (smaller) bamboo species that could be planted. They could form hedges and other lower spatial elements.

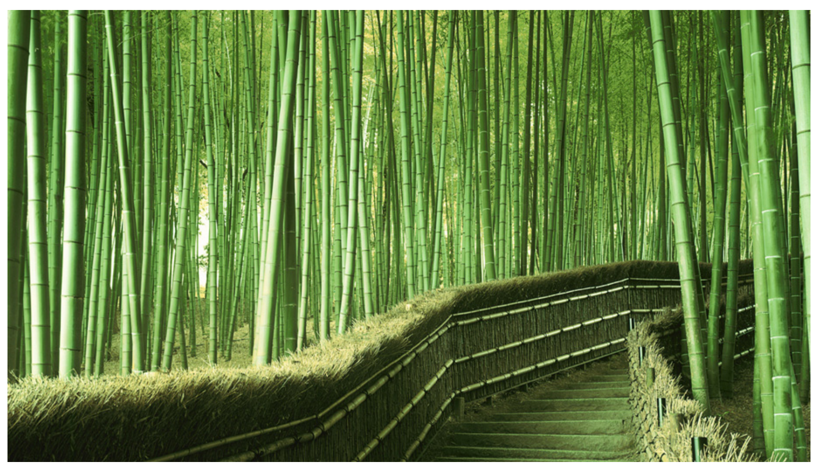

Figure 30 - Bamboo park

[29] Own illustration
[30] http://nimbuseco.com/2012/11/bamboo-forest-travel/

Common reed

Reed can grow quite high, 1-3m. When used in a HFCW VFCW reed takes up patches and can be seen as green walls that define the peripheries of the CW. Sometimes it is chosen to use FSCW. Here the reed can be placed in more natural ways, among the edges of the water bodies, and less dense. (Figure 32[31]) Though the efficiency is higher in the denser systems it can be blended better in the natural environment with the latter. A lack of space quickly makes the dense patches more interesting. Together with rice fields they could alternate existing patches besides that they can fill the space in between building functions for the school I am designing. In Figure 31[32] you can see how a subsurface flow CW can blend into a garden.

Figure 31 - Typical Subsurface flow CW

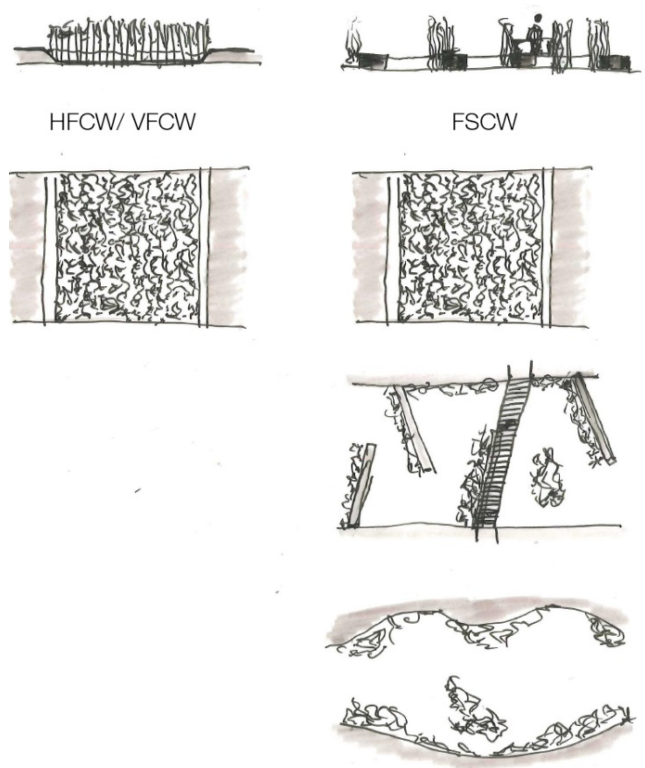

Figure 32 - Constructed wetlands have different design possibilities

Rice

Since rice is similar to reed ill explain probably in the same chapter with a small mention towards its difference Typical for rice is its agricultural nature which defines the spatial qualities of the crop. During the growth period the size and color changes. (Figure 33[33]) When the land is prepared for new plantings to ponds lay empty. Just like mentioned in reed the cultivated rice manifests itself in patches of intense rice cultivation. They are already present and defined by the dykes that surround them.

Figure 33 - Change of rice through cultivation cycle

[31] Own illustration
[32] http://www.rothecologicaldesign.com/images/wastewater_system.png 7jan2015
[33] Own illustration

Climbing plants

Climbing plants can define space by covering any kind of framework. The climbing aid will define the definite form and space the plants create. Pergolas, walls, roofs, poles, arches, and domes could be covered by the green material to define space.(Figure 34[34]) The climbing plants can be used to provide shaded areas, visual barriers or sound insulation. In Indonesia there are many climbing plants like: Passion fruit (edible), etc.

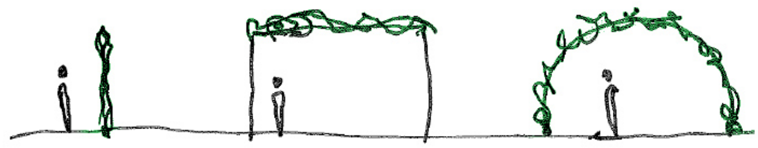

Figure 34 - Climbing plants as spatial element: Wall, Roof, Dome

Conclusion for the spatial aspects

All the species researched show potential to be used as a spatial element, however its use is limited to the extent that their other functions allow. So a balance ought to be found between watertreatment, resource and spatial element. One of the primary existing spatial element are the rice patches. This patch-like structure also has possibilities for bamboo and reed. Furthermore the different plants can be used to define corridors, playgrounds, parks, gardens and public space while also dealing with levels of privacy. Besides urban scale we should also take into account the building scale. This would deal more with the form created in combination with the buildings and its composition.

[34] Own illustration

Conclusion & discussion

The three seperate chapters on different ways to approach plants are connected on many levels. Combining the functions of the plants and green in the area can convince the community to invest in its development in a sustainable direction, because approaching plants as an integral part of development can create value for the diminishing green areas. The multiple interests created for the fragmented green areas make sure that the community can make the best use of its environment which is essential in making it into a peoples-place. Inside the rapidly changing context the planting design of the intervention can restore and maintain a sustainable relationship between the community and its environment. Lastly we should not forget about the aestethic values that can be created with the planting design, which can contribute to the psychologicall well-being.

For watermanagment the research shows a lot of potential, however it is to the designer to integrate the different technologies in a way that adds value. That is where the spatial component comes into play. Important in integrating the plants spatially is the current situation of the green spaces. The plateaus of rice that benefit irrigation are very present and a valuable element to maintain. In the water purification process different fases can be distinguished which can be reflected in spatial manifestation. Also this gives opportunities to give social values to some of the stages. Integrating the material into the design of public buildings can help create acceptance of traditional materials that are now seen as inferior. It can also reconnect identity to local landscape. How a building of these local materials can be realized in a waterpurifying landscape is to the architect.
Plants as a resource reconnects natural materials to the community while also providing economic value for the community. Structures within the community can be constructed with the materials grown on site, of cours to a limited extent, to show how nature can still be a valuable asset. On the other hand food can be grown while also providing gardens that become a learning experience, spatial component and community asset. The jobs needed for the implementation of the above and the change of environment can give alternatives to the community for textile industry related futures. In *annex III* I applied the different flows from my paper onto the kampung of Cigondewah. The community is important to be included so they can provide volunteers, workers, teachers etc. As seen in the diagram.

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Annexes

Annex I

Traditional Bamboo joints (Jayanetti & Follet, 1998, pp. 63-71)

Traditional joints include the following methods and are based on lashing or tying, with or without pegs or dowels :

- Spliced joints
- Orthogonal joints
- Angled joints
- Through joints

Splice Joints(Figure 35[35])

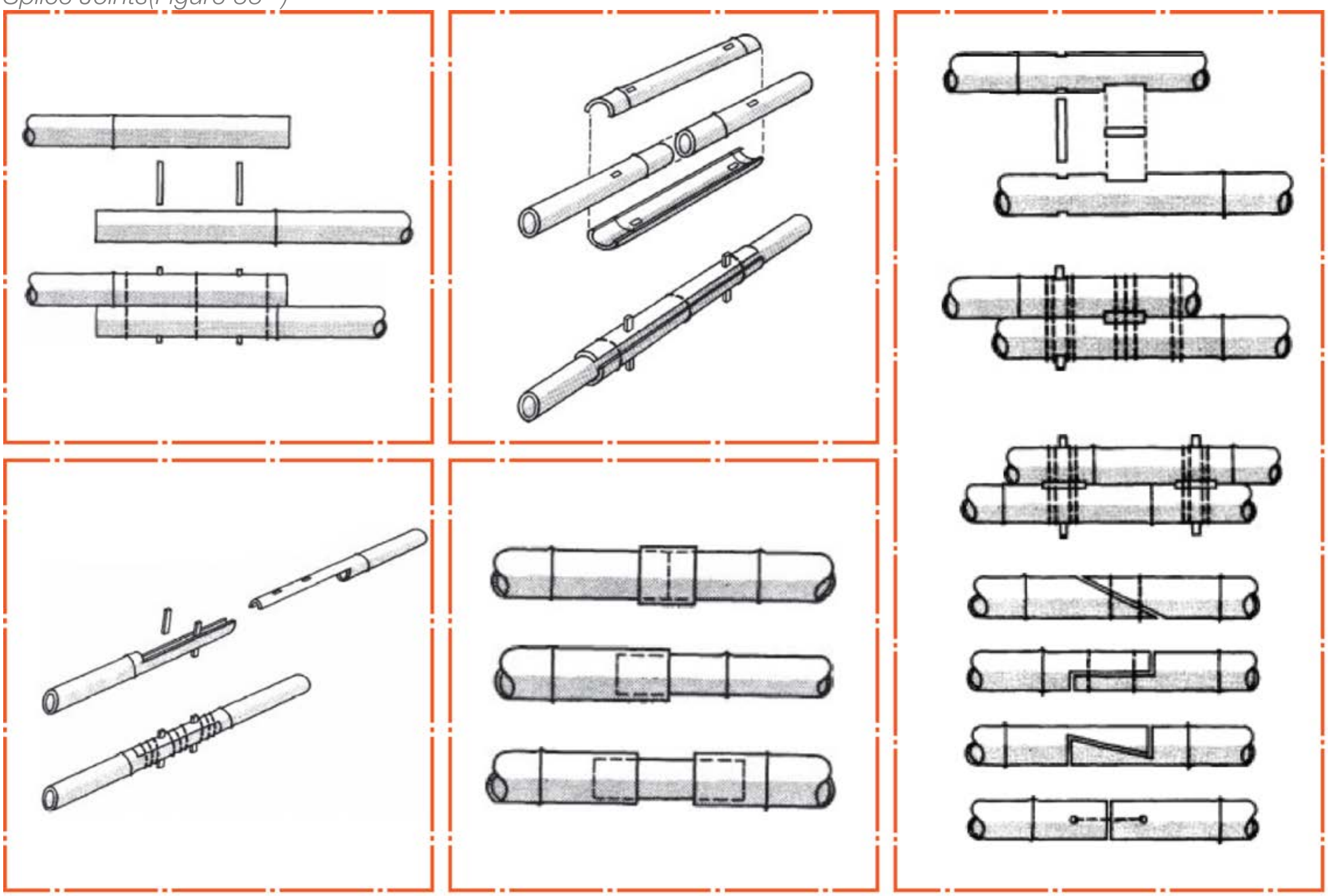

Figure 35 – Different types of splice joints

Joining two or more culms in line is called splicing. The above figure shows four different ways of joining: Full-lapping, catnapping, Butt-joint with side plates, and sleeves and inserts.

[35] (Jayanetti & Follett, 2008, pp. 64-66)

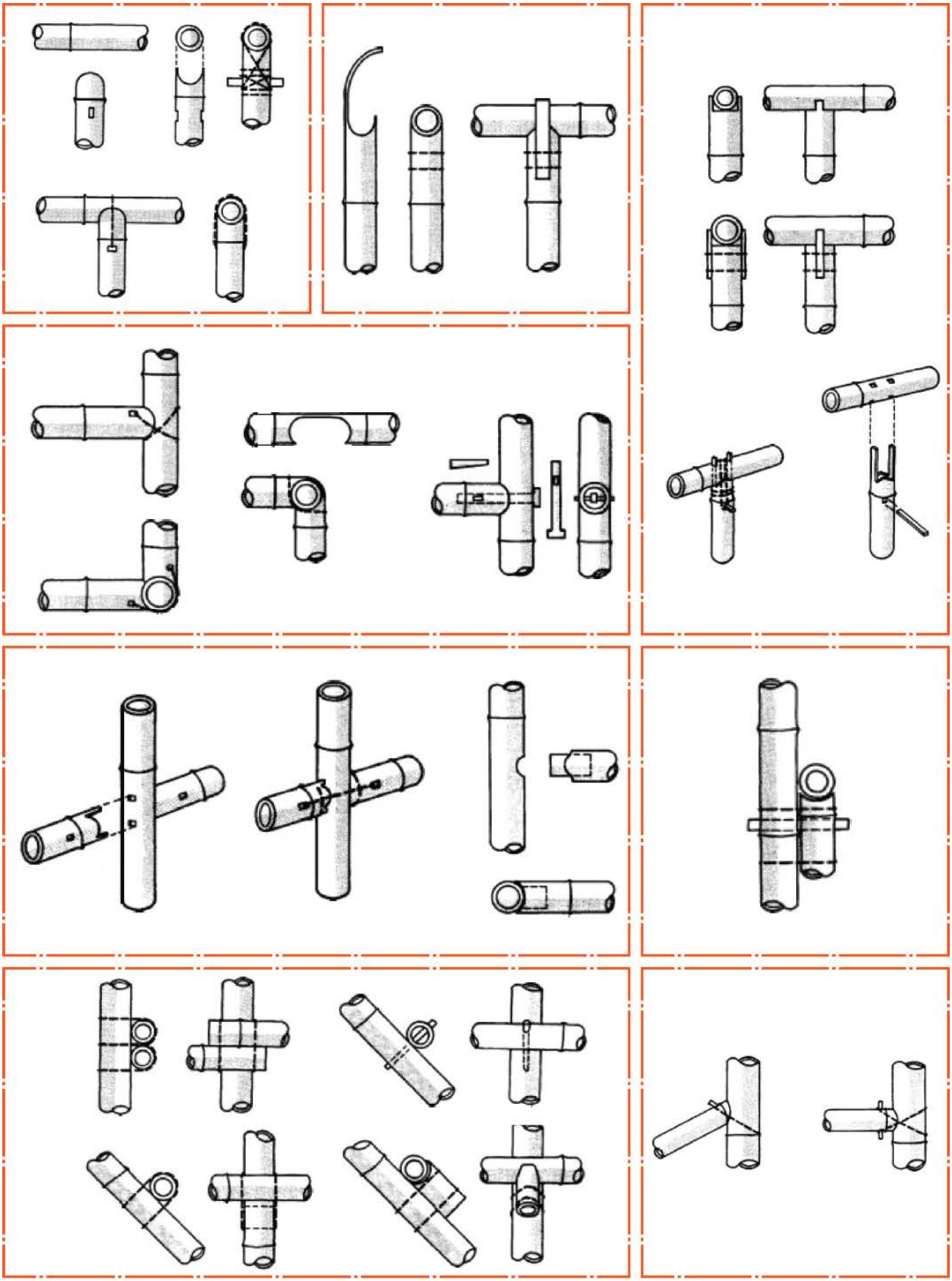

Figure 36 - Various saddle (butt) joints, double butt joints, insert joint and crossover joints

Orthogonal Joits (Figure 36[36])

The orthogonal joints are the most common types of joints and they include joints that meet or cross at right angles. These can be subdivided into two types. The Butt joint, which simplest form is a horizontal meber rests directly on top of a vertical member, and the Crossover joint, which are formed when two or more members cross at right angles. Examples and variations of both types can be seen in Figure 36.

Angled joints (Figure 37[37])

These are formed when 2 or more members meet or cross at other than right angles.

Through Joints (Figure 38[38])

If two members have different diameters they can be joined by drilling a hole in the bigger and inserting the smaller bamboo joint. A dowel can secure the two members.

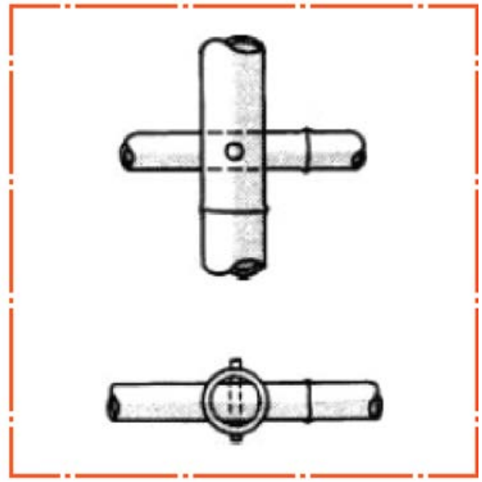

Figure 37 - Through joints

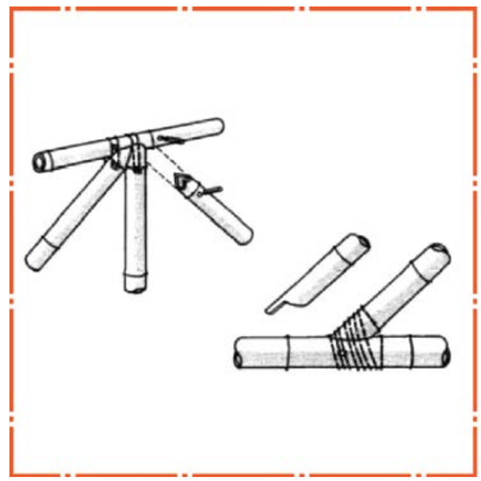

Figure 38 - Angled joints

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[36] (Jayanetti & Follett, 2008, pp. 67-71)
[37] (Jayanetti & Follett, 2008, p. 71)
[38] (Jayanetti & Follett, 2008, p. 71)

Annex II

New developments (**Figure 39**[39])

Improved joints have been developed though it depends on availability of materials, cost and skilled labour if they can be used. In this chapter I will discuss some of these developments and how they could be used.

Gusset plate

Plates are used for joint assemblies. They are often stronger and stiffer than traditional joints

ITCR joint

A joint developen in Instituto Tecnologico Costa Rica (ITCR) In this joint plywood is inserted in slots that are sawn into the bamboo. Glue is used to fasten the connection. It is quite hard to have consistent quality joints in the field.

Arce joint

Wooden inserts reinforce the ends and form the joints. Small deviations of diametr are possible because of slits sawn into the bamboo.

Filled joint

This joint is a variation of the Arce joint and uses a wooden plug that joints the two bamboo ends. Afterwards it is filled with a resin to bind them. If needed holes can be drilled to fasten it with bolts. Another material that can be used is concrete mortar that is poured in the joint. The bolts should then be placed before pouring the concrete.

Das Clamp

This clamp is a steel band with bolt eyes that is fitted around the bamboo members. It is very suitable for bamboo in one plane, like trusses.

Herbert Shear Pin Connector

Sections of bamboo reinforced with thin gauge steel sleeves are bolted together. Pop rivets fix the sleeves to the bamboo. It is a strong connection but laterally unstable and thus unsuitable for in-plane connections

Gutierrez joint

This joint uses the compressive and bending strength of the bamboo and lets the steel bar deal with shear and tensile stresses. The bar protrudes both ends of the bamboo culm and is there welded to a steel plate.

Steel or plastic insert connectors

The jubillee clip joint or expanding insert connectors are two types of insert connector joints. These joints can be used for joining angled culms or culms in line.

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[39] (Jayanetti & Follett, 2008, p. 77)

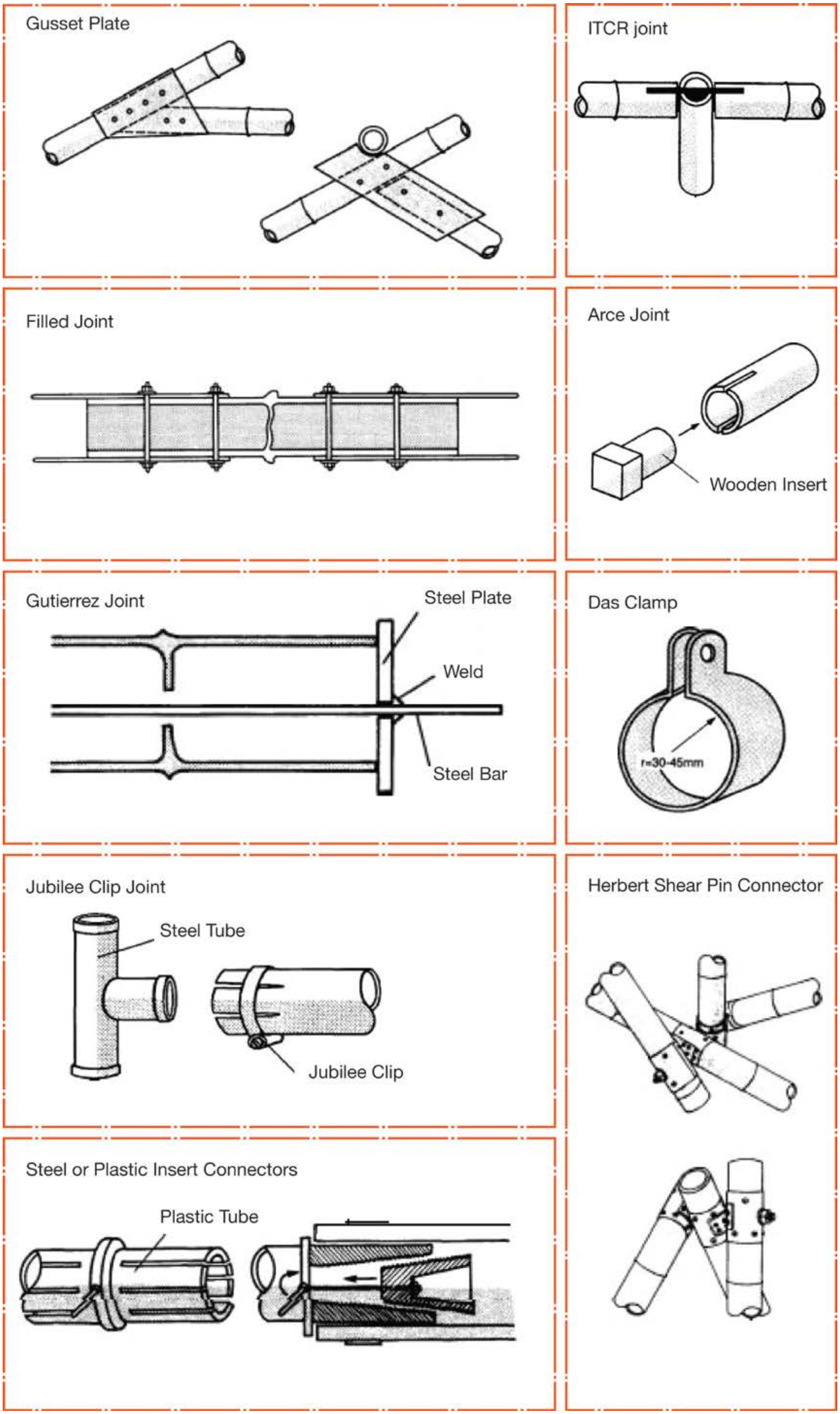


Figure 39 - New developments in bamboo joints

Annex III

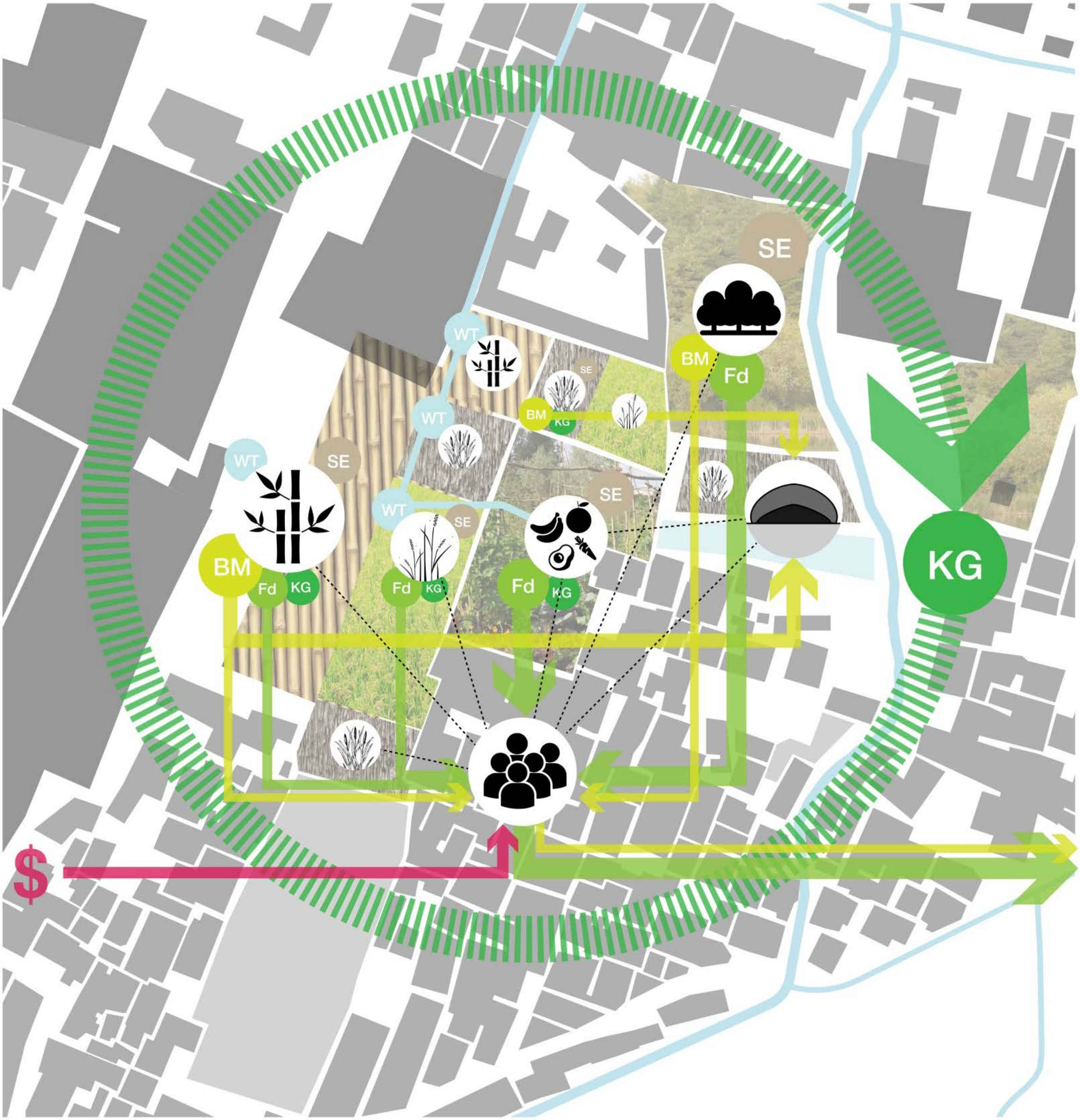
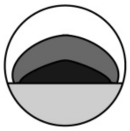


Figure 40 - Watermanagement and resource flows applied on case study Cigondewah



400m²
600m² outside

Primary school and community building

Water treatment with constructe wetlands
Education
Community facility
Gardens
Fishpond

4300m²

Bamboo

Water treatment
Bamboo production 430 culms/ year
Bamboo shoot production
Biomass production
Public bamboo park

4500m²

Agroforestry

Fruit production
Timber production
Public Park

1400m²

Reed filters

Watertreatment: Helophyte filters with subsurface flow
Thatching materials
Biomass

2000m²

Rice fields

Watertreatment: Free surfacewater flow
3000kg rice/ year (1500$/ year net.)
Biomass

1500m²

Community gardens

Water treatment
Food production

Kampung community

Workforce
Teachers
Volunteers
Partners

WT **Watertreatment**

BM **Building material**

Fd **Food**

KG **Biomass (compost etc.)**

SE **Spatial element**

$ **Income from sales**

Figure 41 - Legends