TECHNICAL RESEARCH PAPER

TRA-DIGITAL HYBRID

Using digital fabrications to create a hybrid design for developing countries

NADIA REMMERSWAAL
4115996

Architectural Engineering Graduation Studio
Delft University of Technology
Department of Architecture

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ABSTRACT

Can improved technology make a difference in under-served communities to improve the existing build environment in a cultural sustainable way and make possible endogenous solutions?
This research paper highlights the technical research done to answer this particular question. The research, that focusses on technical solutions to serve the urban poor of the Indonesian kampung, is aimed at providing both self-build solutions as self-sustaining manufacturing processes, making use of both Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM).
The research is twofold; first the kampung of Indonesia are researched; the site, building methods, materials and the make-up of the Indonesian house are discussed. Second, digital-manufacturing processes are researched using both general literature and reference projects. These reference projects are tested on eight sets of criteria to research their potential when applied in the Indonesian urban kampung. In order of priority they are; Durability, Multi Storey Height, Cost material, Cost Machinery, Local Assembly, Difficulty Assembly, Personalization and Local Materials.
From the technical research two most promising project-references were chosen and combined with local building methods in a hybrid to construct both re-usable CNC milled moulds for multi-storey construction, as for constructing bricks.

KEY WORDS:
Digital Manufacturing Processes, Kampung, Self-Build, Self-sustaining Manufacturing Processes, CAD, CAM, Urban Poor, Under-served Communities, Cultural Sustainable Way, Endogenous Solutions

INTRODUCTION

In the poorest areas of the urban kampungs of Indonesia, floods, earthquakes, polluted riversides, poor living conditions and risk of eviction are serious threats to the safety and health of the kampung-inhabitants (Reerink, 2011). For anyone walking around in these urban kampung it is clear that the current practice of unregulated self-build housing is not equal to the task of solving all these problems. Conventional vernacular building practices are lacking proper constructional knowledge, this leads to unsustainable living environments. Due to lack of access to long-term resources the conventional practice often invests precious capital into non-longevity structures. (Griffith et al., 2012)

In Indonesia, a new industrial revolution is brewing, the urban kampungs are modernising and most inhabitants look to the western world for new technologies. Each urban kampung, however poor, has access to internet, smartphones and tablets. Peinovich (2012) states that developing countries have the most to gain from cutting-edge technology available today. In his book 'Making Do', Steve Daniels states "The new Industrialization has the potential to rework globalisation in the favour of the informal sector, allowing them to grow on a foundation of indigenous innovation that both provides for the needs of the local economy and brings in new capital through investment and export." (Daniels & Bull, 2010)

Griffith et al. (2012) state that in these under-served communities there is a greater need for systems that offer ways of building infrastructure through repeatable production, using accessible and precision-driven technologies to mitigate the absence of professional labour. Also Peinovich (2013) states that there is great potential in the usage of CAD/CAM technologies combined with sustainable technologies to design safe housing in underdeveloped countries.

This paper will therefore research if CAD/CAM technology indeed has the potential to improve the current unsafe building construction of the kampungs of Indonesia. To research a CAD/CAM solutions the following **Overall Design Question** is formulated, this question is relevant to the overall graduation project:

> HOW TO USE THE POTENTIAL OF COMPUTER AIDED MANUFACTURING TO DESIGN SAFE, DURABLE AND AFFORDABLE SELF-BUILD HOUSING WITHIN THE URBAN KAMPUNG OF INDONESIA?

Herein fits the **Technical Research Question**, researched in this paper:

> COULD COMPUTER AIDED MANUFACTURING BE USED TO CREATE DURABLE, SAFE AND AFFORDABLE SELF-BUILD HOUSING?

If this technical research doesn't produce a suitable CAD/CAM solution with enough potential, technically, contextually or financially, a different solution will be pursued.

In the next paragraph will be explained how the research to answer this question is structured. From this research the two most potential reference projects were chosen to serve as inspiration for the design of CNC milled reusable moulding systems. This system could be used to produce reusable concrete formwork for self-build of the main construction, but also to produce brickwork and staircases. The next half year of graduation will be used to conduct research into this topic.

RESEARCH METHODS

The research presented in this paper is split in two parts, the first part focusing on the local building methods of the Indonesian urban kampung and the second part researching digital fabrication methods.

The local building methods were researched during the three week research-period that was spend in Bandung Indonesia. In advance as much as possible was researched on the city, kampung and inhabitants both online as in literature. Most of the data was collected by either observation of- or interviews in the kampung. In the kampung multiple informal interviews with inhabitants of the kampung were done during our visits. Three in-depth interviews were conducted with one former government official, Ramalis Sobandi, and two construction foreman, Pak Komar and Pak Mardi.

In the chapter on digital fabrication methods two research methods are applied, the chapter starts with the literature research. Three literary sources by Iwamoto (2009) , Hauschild et al. (2011) and Beorkrem (2013) are used to discuss structuring of research into digital fabrication methods. From these literary sources the structuring of research for this paper was chosen. Since the topic is relatively new, other forms of research were necessary. For this, relevant project references have been chosen to investigate. The research on these reference projects is structured by their materiality. By choosing different references per material-group, a catalogue of sorts has been created.

When picking out references to fit into this catalogue, three criteria were used to check if these project references could potentially be used in an urban kampung. They had to be **practically applicable** in the building of small scale building constructions like **dwellings**, and they had to either partially or fully make use of **digital fabrication techniques**. If not practically applicable, they would be of no use in the kampung of Indonesia. Since this research focusses on improving the build environment of the kampung, a dwelling-scale can be deemed suitable. As the technical research question on page 3 explains, digital fabrication techniques are the focus of this paper, this is therefore an important criteria. As seen on page 5, eight of these project references were chosen to investigate further.

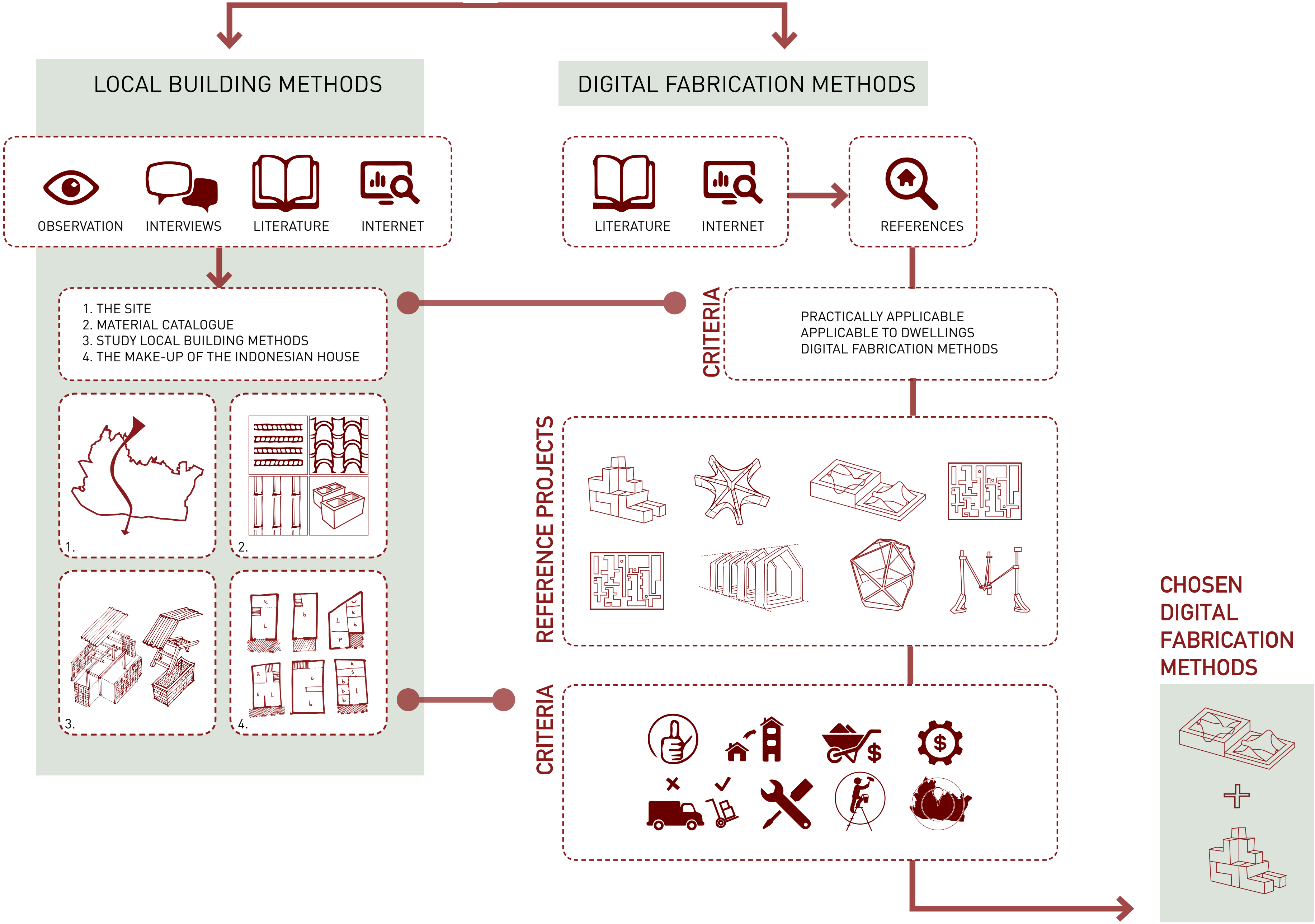
To study how these eight project references were applicable in the chosen context, they were tested against eight different criteria. In order of priority these criteria were; **Durability**, possibility for **multi-storey** height, material- and machinery **costs**, possibility of **local assembly, difficulty** level of assembly, room for **personalization** and the usage of **local** materials.

As is explained in the introduction, unsafe living environments are the reason this paper researches digital fabrication methods to check if they can be used to improve the current situation. A durable construction equals a safe construction, therefore durability has the highest priority of all these criteria. The ongoing urbanisation of Bandung has overcrowded the kampung, and a possible solution should facilitate therefore a multi-storey construction. Neither durable- nor multi-storey buildings can currently be constructed in the kampung. For this solution to be an improvement to current building practices, it must comply with both. Since the kampung inhabitants have limited financial means, the proposed solution must be suited to these means, both in used materials, as in used machinery. These are therefore chosen as the third and fourth criteria. The fifth criteria, local assembly, refers to the infrastructure within a kampung. Only scooters, bikes and hand-cars can reach into the kampung. The solution therefore needs to facilitate local assembly. The research focusses on self-build solutions, to achieve self-sustenance, the difficulty level of assembly, criteria number six, must therefore be suited to the local 'know-how'. Personalization and the usage of local materials are, although important, not of the highest priority in this research.

All eight reference projects were tested on these criteria on a scale from one to five, this enables not only a comparison between all references, but also shows if a reference project has the potential to be better than the current building practices of the kampung.
Since the chosen criteria are not effortless translated into a scale of one to five, per chapter a full argumentation is given per reference how the measurement of the scale is calculated. Important is that this scale is based on what possibilities the researched building method has in a kampung. This ensures that the full potential of the discussed digital fabrication method is researched in this paper. In the concluding chapter future research is briefly examined. The two most potential reference projects have been chosen to develop further.

Fig 1. Visualisation most important urban elements kampung Cigondewah (own ill.)

RESEARCH METHODS



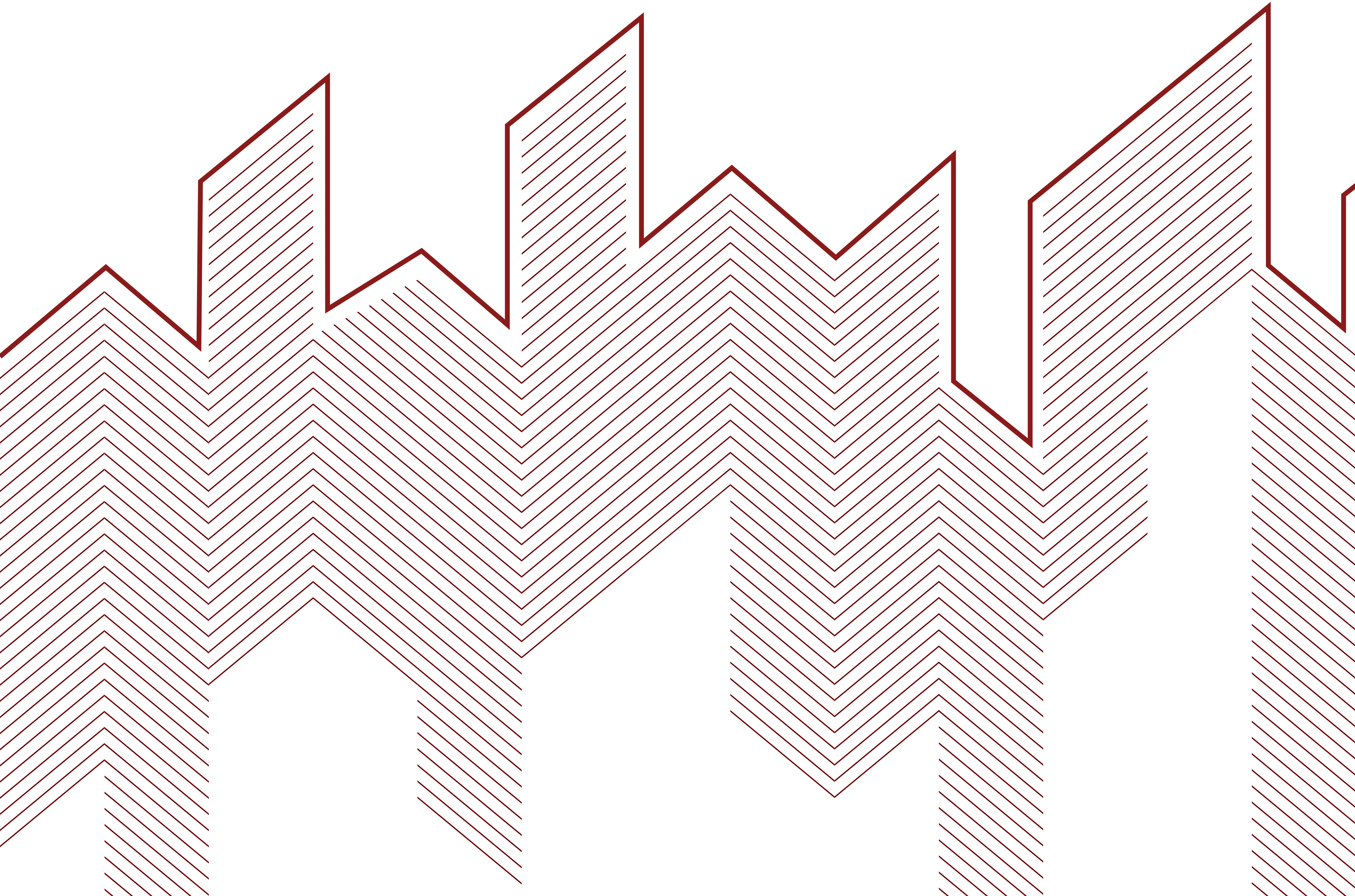


TABLE OF CONTENTS

A. RESEARCH LOCAL BUILDING METHODS

- THE SITE
- MATERIAL CATALOGUE
- STUDY LOCAL BUILDING METHODS
- THE MAKE-UP OF THE INDONESIAN HOUSE

THE SITE

// BANDUNG CIGONDEWAH

In this project, the aim was to improve the kampung of Indonesia. It proved difficult to find an exact definition of the word kampung. As the kampung are wide, diverse and informal, so is the definition of the word. In my thesis on the kampungimprovementprograms of Indonesia a definition was destilled from similar research by experts on the topic like Colombijn (2010), Benjamin (1985) and Reerink (2011):

The kampung are housing areas which arise without preconceived plan for either infrastructure or the built environment, inhabited by the urban poor of Indonesia. (Remmerswaal, 2014)

In Bandung it was found that while the urban poor dominated these areas, also a higher income-class chose to live in the kampung to profit from the kampungs informality, cheap ground and flexible building codes. According to Ford (1993) four different types of kampung can be distinguished; the inner city-kampung, the industrial kampung, the squatter kampung and the rural kampung. The inner-city kampung transformed from colonial times to highly urbanized areas. In these areas there is not a lot of space available for improvement, and these kampungs have already been upgraded to a large extent by its richer inhabitants.
The squatter kampung are comparable to slums, and while interesting for my research, these areas can be found everywhere in Bandung, including in our chosen location, the industrial kampung. The squatter kampung can be found illigally on municipal land, alongside railway tracks, next to riversides, underneath tollroad overpasses and even in graveyards (Reerink, 2011).
The rural kampungs do not occor in urbanized areas and were therefore less interesting for this research. For the chosen location it was deemed that the industrial kampung was the most interesting subject to study and research. The industrial kampungs still have some room for growth, they are developing areas and offer a lot of opportunities. These industrial kampungs are next to the factories on the outside of the city.

Fig A1. Visualisation kampung Cigondewah (own ill.)


MLD

LOCATION

The chosen location is an urban industrial kampung called 'Cigondewah'. It is situated in the south-west of the city at approximately six kilometres from the centre of Bandung. The site is sandwiched between the big toll road and the main road to the Kahatex factory. The only access to the site is from this main road to the north, both the river and the toll road close off the kampung to the south. The kampung is densely populated, locals mingle with the migrant workers that work in the factories. The river system is running through and around the kampung. The water from this river ends up in one of the most polluted rivers in the world, 4 kilometer downstream, the so called Ciberem. Only the main road into the kampung is accessible by car, the rest of the kampungroads are so small that only scooters, bikes and handcars can be allowed through.

Fig A2. Visualisation location kampung Cigondewah (own ill.)
Fig A3. Visualisation most important urban elements kampung Cigondewah (own ill.)

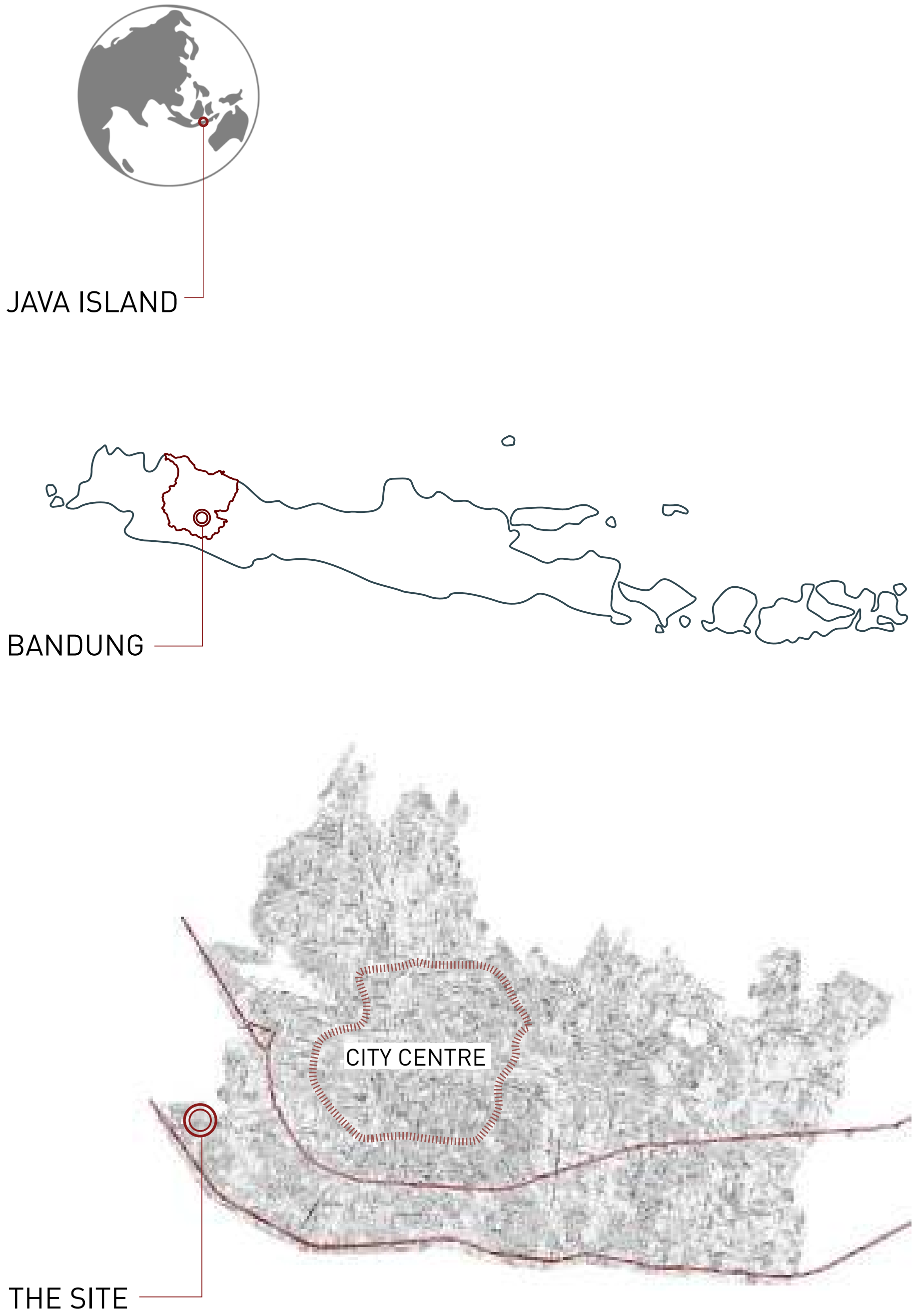


Fig A2.

Fig A3.

FACTORIES

The kahatex factory is situated on the other side of the main road to the north. This factory is the reason the kampung developed on this location. Migration workers work in the factory and live in rented rooms in the kampung. The kampung thrives from the waste of the Kahatex factory. The discarded garments and pieces of cloth are processed and sold in the kampung. The waste is first gathered and organised. It is then either sold or it will be processed into garments or yarn and then sold.

RICE FIELDS

In the kampung housing is interspersed with rice fields, a graveyard and a common area field. The rice fields are fed with water from the river that flows through the kampung. The rice fields are a left over from the time when the kampung was still a rural area. Slowly most of the rice fields had to make place for housing, these fields are one of the few left. These are the only public open spaces the kampung has. The open public square is not developed, it is undeveloped land owned by the factory, they deposit their waste here.

KAMPUNG

The kampung is gradually becoming more urbanized. The migration workers mingle with the original local inhabitants of the kampung. Ground is becoming more sparse and the number of inhabitants per m^2 house is increasing. The housing is mostly self-build and constructed in an incremental way. The kampung leader, is called the RW in Indonesia, for the Cigondewah kampung this is Apek Asep, he was interviewed for the research. This person is the link between the government and the kampung.

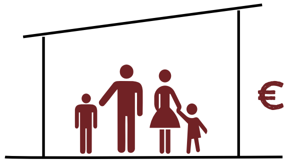
RIVERSYSTEM

The rivers running through Bandung originate from the mountains to the north. Throughout their run in the city the river system is being heavily poluted by both the cities inhabitants and its factories. In the kampung the river is used as both sewage, washing facilities and garbage disposal. Also it is used to grow the crops on the rice fields in our chosen kampung. Due to this pollution the river is not a suitable place to live next to. Only the urban poor choose these areas to build their (often) illegal houses on.

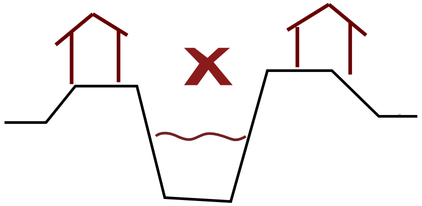
PROBLEMS KAMPUNG

The kampung of Indonesia are known for their versatility, flexibility and informality, there are however known problems too, these problems are visualized in the infographics on the right. Poverty often reigns these areas, indirectly causing problems like a very poor quality housing stock (Guinness, 2009). This is especially the case next to the rivers, the river is not only polluted, but overflows each season during the monsoons. The housing next to the river are considered to be among the poorest quality. This land is owned by the government, and inhabitants of the riverbank often live on these grounds illegally. The river is traditionally used for washing and sewage, which in old times was not a problem. When the kampung were however heavily urbanized more problems arose. There is usually no or a very poor garbage collection systems, so the people will either burn their trash or throw it into the river. The pollution is being further worsened by factories that use the river to get rid of their waste. During interviews in the kampung inhabitants described the river turning blue or red from the dyes being discarded by the factories into the riversystem.
Nowadays the river is so polluted only the very poor live next to this 'sewage' system. In the kampung this is considered a way of life and many inhabitants do not see a problem with the poluted rivers. Many of the poorest kampung, the so called 'squatter kampung', as discussed in the beginning of this chapter, choose the riverside to build their poorly constructed, often illegal dwellings. The riverside can be considered to be of very poor quality everywere Bandung.
These riverside-urban poor can usually not improve their situations on their own, an external force like the government, an NGO or the local factories have to contribute for this situation to change.

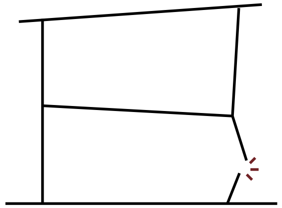
Fig A4. Visualisation problem kampungs Bandung Indonesia (own ill.)



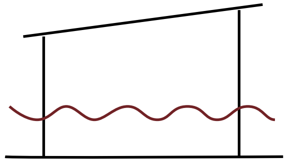
POVERTY



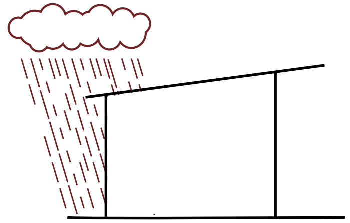
POOR QUALITY RIVERSIDE



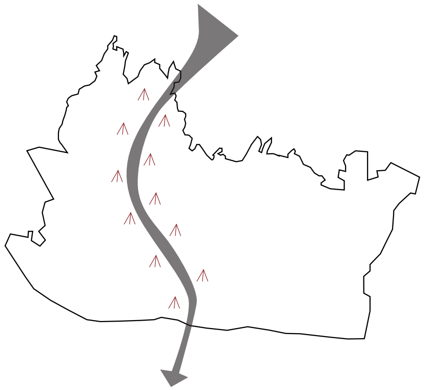
POOR CONSTRUCTION



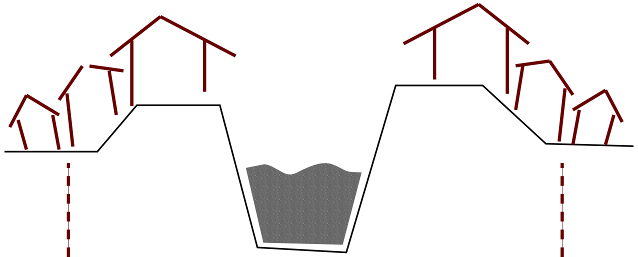
FLOOD CIBAREM



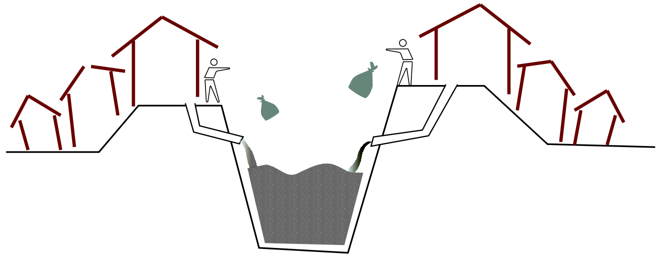
MONSOONS



SQUATTER SETTLEMENTS RIVER



GOVERNMENT OWNED LAND



GARBAGE RIVER

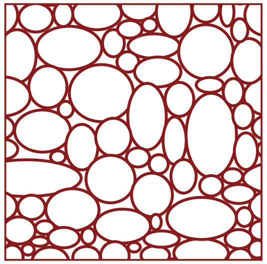
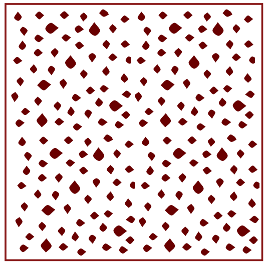
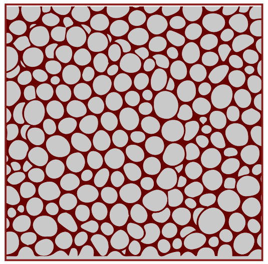
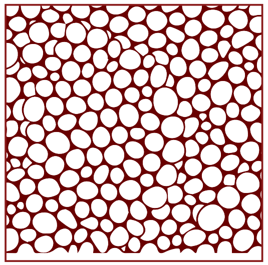
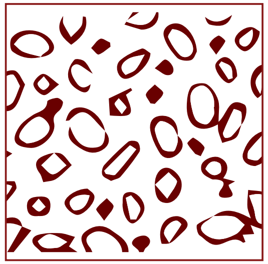
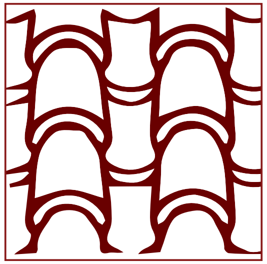
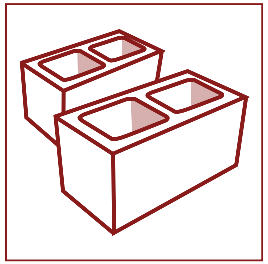
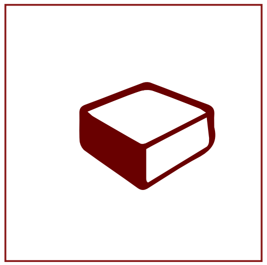
MATERIAL CATALOGUE

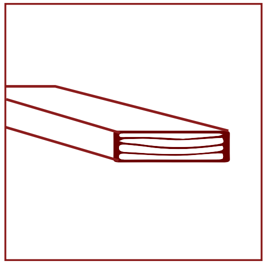
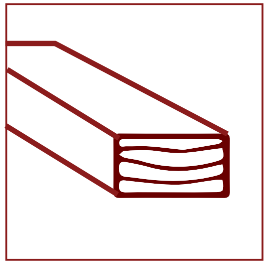
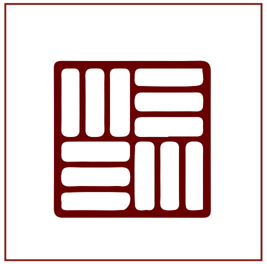
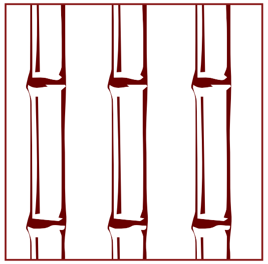
// MATERIALS KAMPUNGS BANDUNG

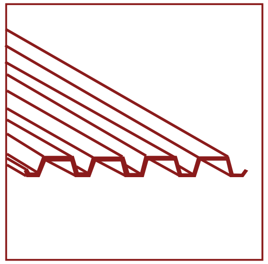
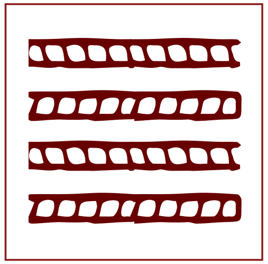
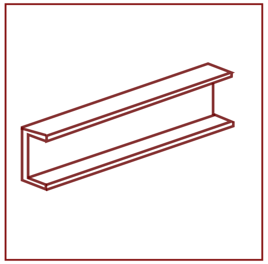
In the kampung of Bandung, often the chosen material fits both the building methods as the budget. More on these building methods is explained in the next paragraph. Usually simple building methods are applied to construct the often one-, or maximum two-storey houses of the kampong.
Materials used are often bricks, cement and corrugated steel for the foundations and wooden construction and tiles for the roof. Wood is also used to construct doors and windows.
In the poorest area's of the kampong, for example next to a riverside as described in the last paragraph, poorer materials are used; such as untreated bamboo, corrogated steel sheets and asbestos sheets. People are often unaware of the dangers of asbestos on their health. Building constructors usually just stand with bare feet into the mixed concrete and protective clothing is not used very often.
The ground floor is usually made up of a concrete slab on which the house is build to prevent the yearly floods from flowing into the house.

If there is a second floor it is usually made up of a light wooden construction. In the poorer parts of the kampung the materials used are often discarded building materials that can be bought cheap. The walls can be constructed from split bamboo mats which are insulated with newspapers and dyed in bright colours.
We found it striking that while bamboo was always found to be a poor man's construction in the kampong, architecture in richer area's often used treated bamboo combined with modern materials like concrete. So while modern construction are reversing to the usage of traditional materials, working with these materials is still deemed poor in the kampung.
The materials are usually bought in local shops that are either situated inside the kampung, or in close proximity of the kampung. See for an example of such a shop the first image on the next page. The prices which are organised on the next page are taken from a shop in Jakarta, but were found to be similar to Bandung prices.

Fig A5. Right: Visualisation materials kampungs Bandung (own ill.)
Fig A6. Next page: Material catalogue with prices per unit (own ill.)

MATERIAL		UNIT	COST Rp (IDR)	€ (EUR)
	**GRAVEL** BATU SPLIT	per 'Isunhi' +/- 1 m^3	300.000	21.00
	**RIVER SAND**	per 'Isunhi' +/- 1 m3	350.000	24.50
	**BLACK SAND** PASIR HITAM	per 'Isunhi' +/- 1 m3	300.000	21.00
	**WHITE SAND** PASIR PUTIH	per 'Isunhi' +/- 1 m3	350.000	24.50
	**CEMENT**	50 kg 1 kg	70.000 1.400	4.90 0.10
	**ROOF TILES**	Per tile	4.000	0.28
	**HOLLOW CEMENT BLOCKS**	Per m3 Height: 7.5 cm	730.000	51.10
	**DRY WALL** DUROCK	In cm: 120 X 240	60.000	4.20

MATERIAL		UNIT	COST Rp (IDR)	€ (EUR)
	WOOD	Per m3 Jati Borneo Recycled	 15.000.000 5.000.000 2.000.000	 1.050.00 350.00 140.00
	WOODEN BLOCKS	In cm: 4 X 6 X 400 5 X 7 X 400 5 X 10 X 400 6 X 12 X 400 8 X 12 X 400	 30.000 45.000 65.000 85.000 90.000	 2.10 3.15 4.55 5.95 6.30
	WOODEN BOARD PAPAN	In cm 2 X 20 X 4 M 3 X 20 X 4 M	55.000 90.000	3.85 6.30
	BAMBOO	6 m length Untreated Treated	 5.000 - 12.000 60.000	 0.35 - 0.84 4.20

MATERIAL		UNIT	COST Rp (IDR)	€ (EUR)
	ZINC SHEETS CORRUGATED	Per sheet	40.000	2.80
	CORRUGATED STEEL RE-BAR	12 m length Ø 6 mm Ø 8 mm Ø 10 mm Ø 12 mm Ø 13 mm Ø 16 mm	 24.000 40.000 60.000 90.000 98.000 150.000	 1.68 2.80 4.20 6.30 6.86 10.50
	STEEL C-PROFILE 'LIGHT STEEL'	Per 6 m1 Baja Ringan Reng Baja Ringan	 80.000 50.000	 5.60 3.50

The conversion of Indonesian Rupee to euro's have been calculated on 9-12-2014. The original value taken was that of the Rupee.
Missing in this catalogue are the recycled materials, the value of these items differs too much to catalogue.

LOCAL BUILDING METHODS

// THE BANDUNG KAMPUNG

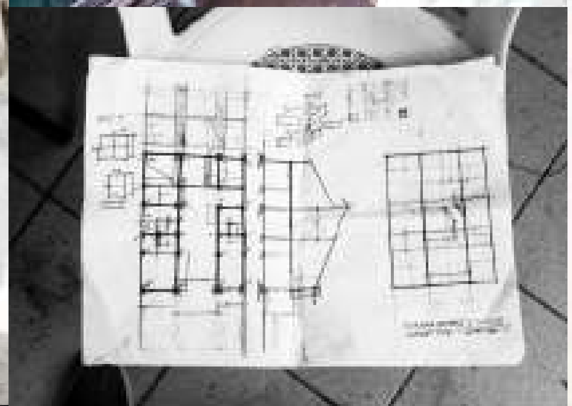
Since informality prevails in the kampung, the study of local building methods was conducted not via literature study but more was to be gained via interviews and observation. In the kampung, interviews were conducted with two construction foreman; Pak Komar and Pak Mardi. A former architect and governmental official, ms. Ramalis Sobandi, was also interviewed, she was refurbishing one of her houses when we were in Bandung, Pak Komar was her appointed foreman. Furthermore we spend three weeks in the kampung observing several building sites and talking to locals. All information discussed in this chapter derives from these sources.
This paragraph investigates several topics; the construction process, the structure of the construction team, the application of specific materials in building elements and safety issues within the building process.

In the kampung a new house is usually initiated by the owner of a plot of land. This person or family hires a subcontractor that is either a relative, or a very good acquaintance of the family. Usually there is one construction team active per area, this could either be a bigger kampung, or several kampungs combined. Ms. Sobandi explained that a construction team is made up of one foreman, the person with the most building knowledge and the subcontractors working under him. These construction workers are trained by this '*mandor*' in a specific trade, like masonry, plastering, or woodworking. There are few to none construction educational centres in Indonesia, knowledge is passed on from uncle to nephew or father to son. In Pak Komars case, he had his nephew and brother working for him, and depending on the size of the job he could ask for different subcontractors to join the team. His nephew had dropped out of school and was learning the construction trade with Pak Komars construction team.
The construction teams are not registered as a company, and no licencing of any kind is needed to build a house. Pak Komar explained that in many kampungs the building code is not strictly followed and regulated.

Fig A6. Right: Visualisation building practices kampungs Bandung (own ill.)





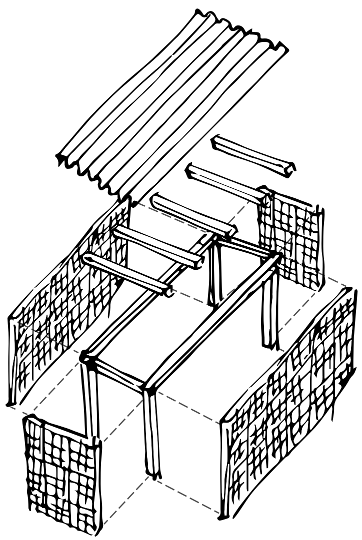




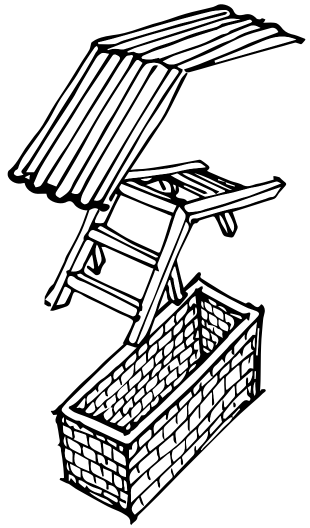
In general, Pak Komar explained, no architect is used for a kampung house, construction drawings are made by hand and discussed with the home owner. Usually the person drawing these plans is also the person who does calculations if needed. This person is hired as an external party and is not a part of the construction team as described. Overall the construction knowledge in the kampung can be described as vernacular, the available building knowledge derives from tradition and experience rather than from education.
In the poorest area of the kampung often there are not enough financial means available to hire these construction teams. Pak Mardi explained that these houses are constructed from waste or cheap materials with the help of family and friends.

On page 23 the most common construction methods and combinations of facade materials are analysed. Figure A7 represents the most basic of dwellings, a wooden construction, often made of non-treated wood or bamboo is closed with bamboo mats that have been lined on the interior with newspapers, painted in a bright colour. These bamboo mats are easy to construct, but when non-treated, a short term solution. Housing in the kampung is incremental, the build environment reflects the current financial means, when new funds are available a more solid construction can be made from brick as seen in figure A8. A slanted roof is constructed to protect against monsoons. The next step could be the build of a second- or third storey, in the kampung these second storeys are often rickety and unsafe. In poorer areas again wood or bamboo is used for the main construction of these two storeys as visualized in figure A9. These constructions often made from untreated, cheap wood are not only unstable but can also become a serious fire threat to the kampung
More often however, a solid base like bricks or cement blocks is used to construct the second storey on in wood as shown in figure A9. These second storeys are almost always cladded with light materials like wood, bamboo mats, corrugated steel sheets or simply lined with a banner for privacy. When the funds allow it, a tiled roof is constructed. This is a clear sign of prosperity, and is often used for the roof above the front facade. We have seen many examples where the back part of the house was still covered with corrugated steel sheets.
There are only a few houses in the kampung with three floors, usually the first two floors are then constructed from cement blocks of which only the first floor is plastered and painted. The top storey is again made from wood. and light facade materials.

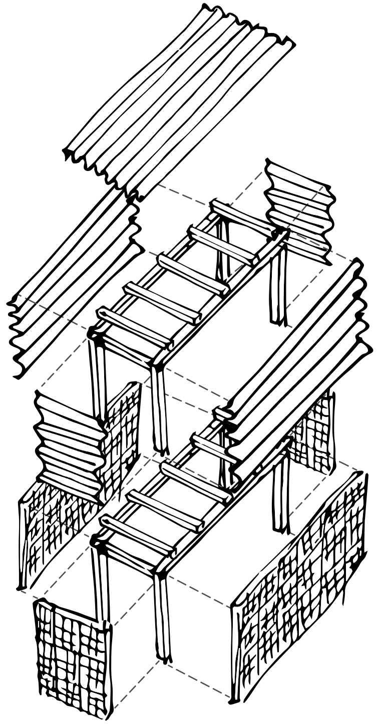
These constructions as described are often build on foundation platforms made from big river stones combined with cement, this prevents the floods from entering the house during monsoon season. Both the floods and the local humid climate affect the building materials, kampung dwellings collapse due to decayed foundations or walls. (Usman Nasrulloh, 2014) The available vernacular knowledge is simply inadequate to cope with these forces of nature.



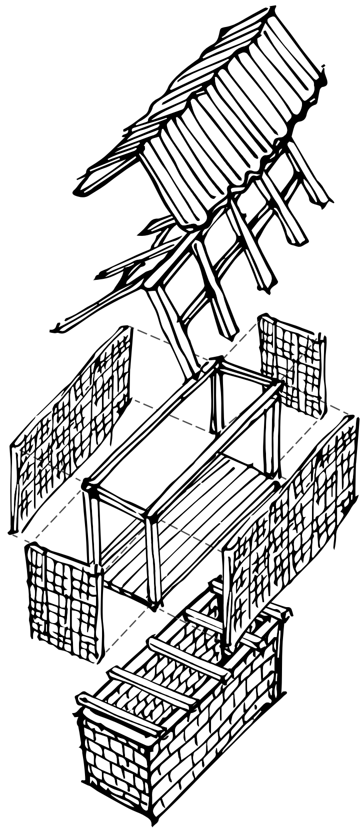
A7. 1 storey
Construction: wood/bamboo
Walls: Bamboo mats
Roof: corrugated steel
(own ill.)



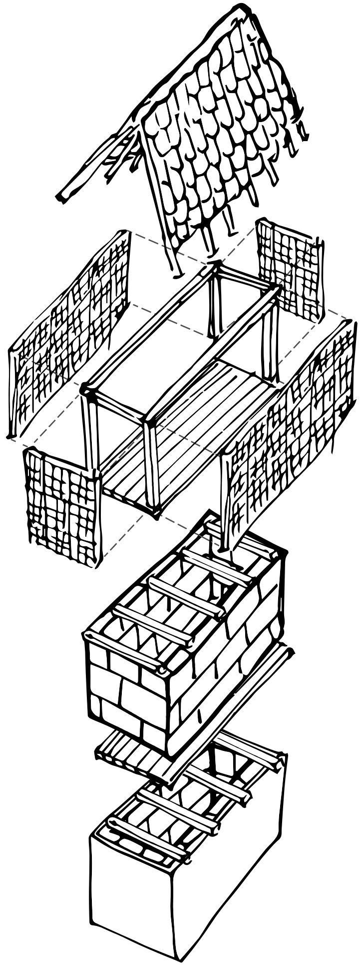
A8. 1 storey
Construction: brick
Walls: Brick
Roof: gable wood structure
slanted corrugated steel
(own ill.)



A9. 2 storeys
Construction: wood
Walls: 1^{st}: Bamboo mats
2^{nd}: corrugated steel sheets
Roof: corrugated steel
(own ill.)



A10. 2 storeys
Construction: 1^{st}: bricks / 2^{nd}: wood
Walls: 1^{st}: bricks / 2^{nd}: Bamboo mats
Roof: gable wood structure / slanted
corrugated steel
(own ill.)



A11. 3 storeys
Construction: 1^{st}& 2^{nd}: cementblocks
3^{rd}: wood
Walls: 1^{st}: plastered cementblocks
2^{nd}: cementblocks 3^{rd}: bamboo mats
Roof: Wooden gable roof structure tiled
(own ill.)

MAKE UP INDONESIAN HOUSE

// EXAMPLE KAMPUNG HOUSE & KAMPUNG FLOORPLANS

In this paragraph the make-up of the Indonesian house is explained through the analysis of a kampung house and the analysis of kampung floorplans. The examined house is that of Nyang Nyang. Pictures of the inhabitants, the exterior and interior can be seen in figure A12. In Figure A13 the interview with the inhabitants is visualised. Nyang Nyang, age 32 is a bird salesman and lives in this 18 m^2 house with his wife and his two children.

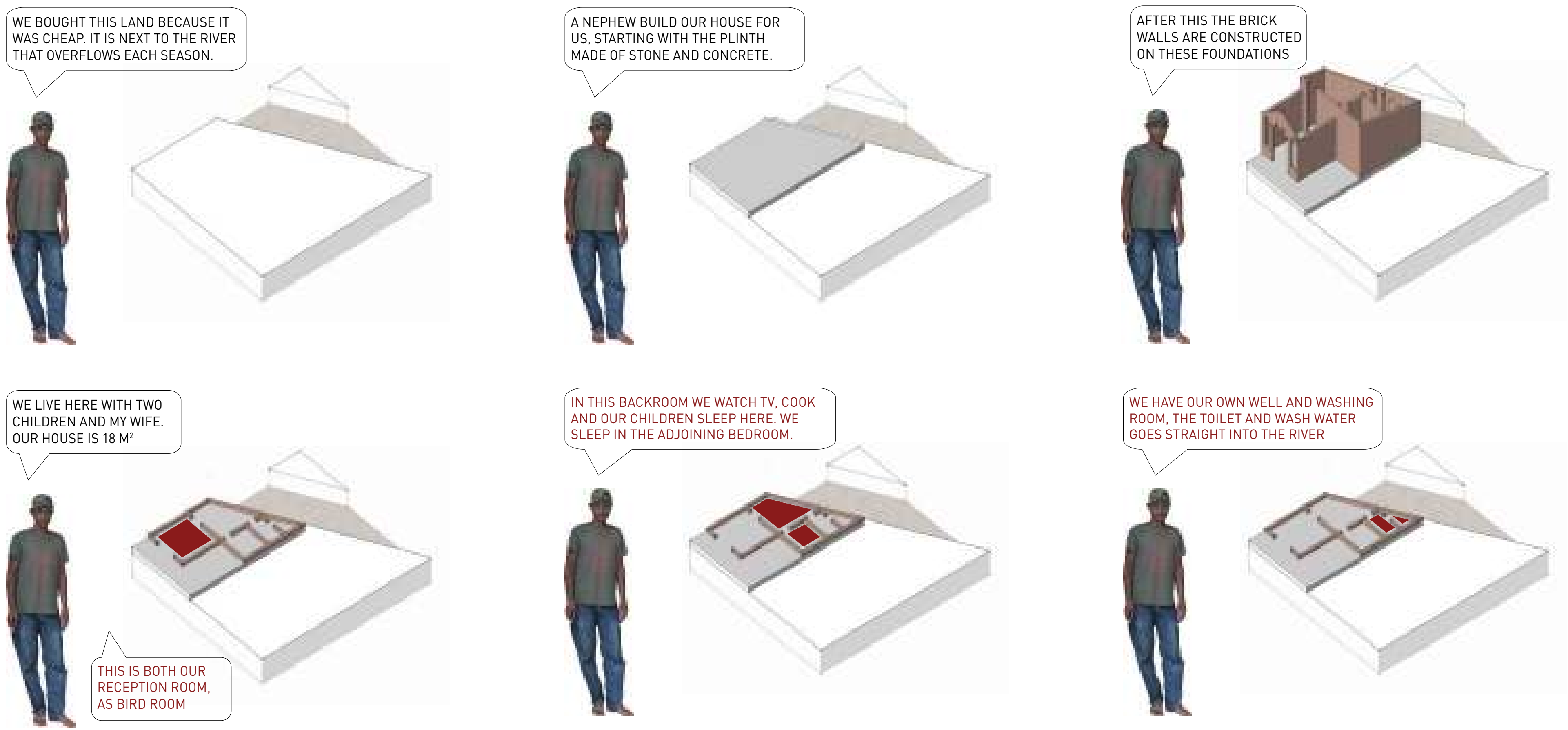
Outward appearances are important to families in the kampung, this is expressed in their architecture. The front of the house is usually decorated with tiles on both the floor, walls and roof. This front room is where guests are received and doubles often as living room. In the sketches made in the kampung (see fig. A14) it is clear that in the kampung houses circularion areas like hallways rare, this is usually due to the limitations of space. Often the bedrooms open directly into this living room. Due to lack of space rooms are often used for multiple purposes. The living rooms doubles as both a parlor, bedroom and sometimes also as a kitchen. Toilets and bathrooms are often not a commodity in the kampung. Sewage systems are not available for all kampungs in Bandung, so often washing facilities and toilets are clustered in strategic places in the kampung. These facilities dispose of their waste in the riversystem of Bandung.

Since the climate allows for outside activities, this is an important part of the Indonesian way of life. Outside areas are important places to meet the community. Despite limited space almost each house had therefore a covered outside area with either a *bale bale,* a wooden or bamboo bed to rest on, or a bench. Often space is taken from the street to build porches, balconies and adjoining small shop-spaces.

Fig A12. House Nyang Nyang, bird salesman: the exterior, interior and inhabitants (own ill.)





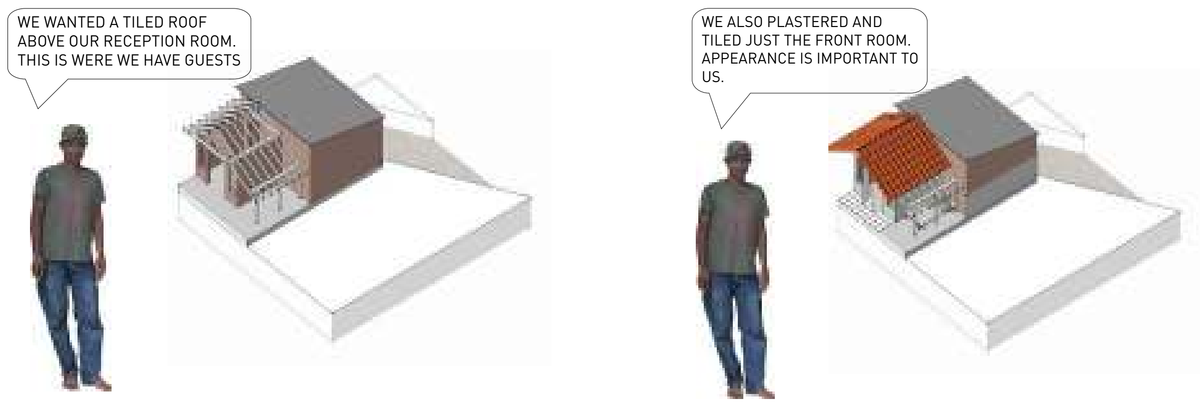
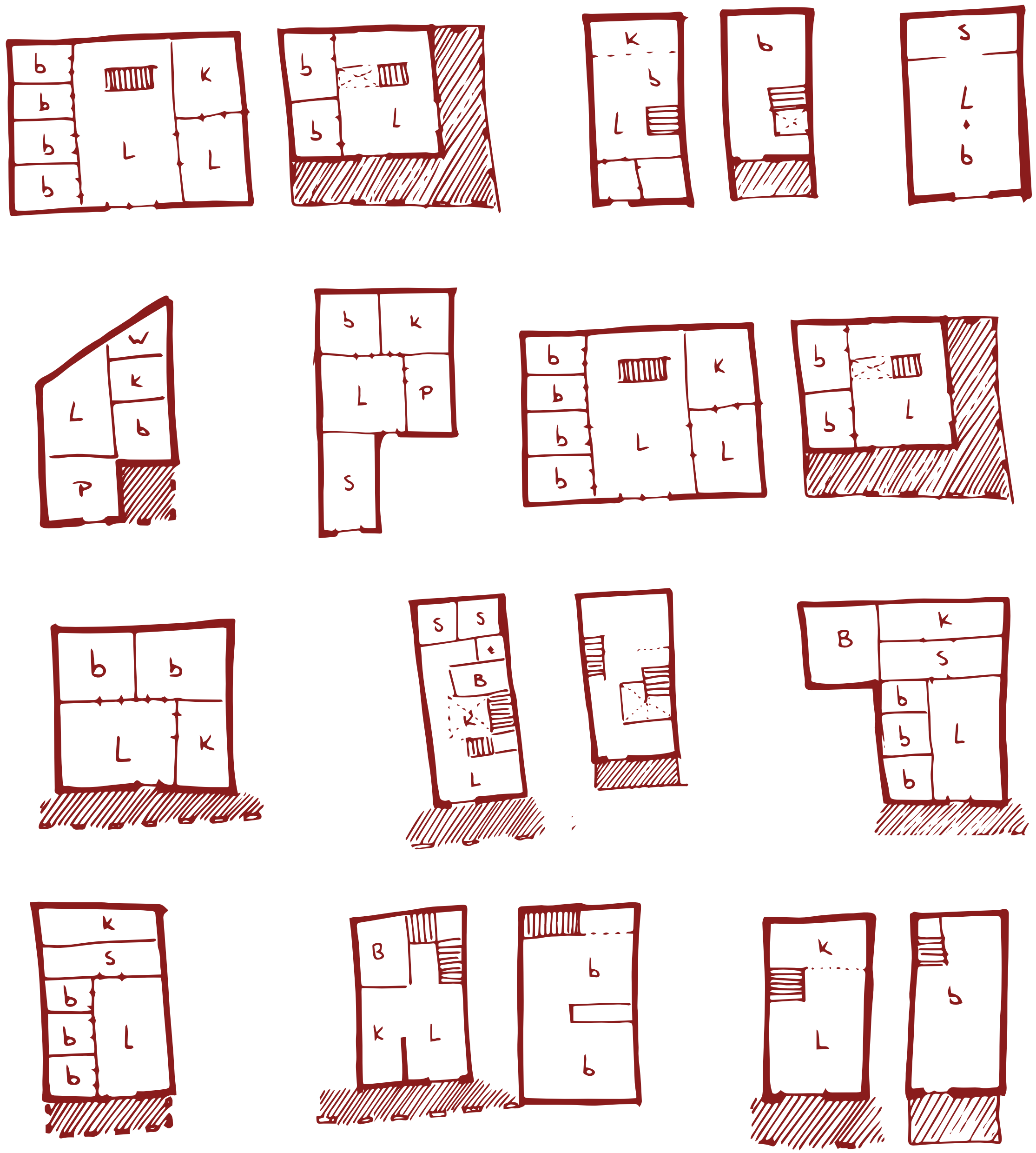


Fig A13. Left page: Example make-up Indonesian house House Nyang Nyang, (own ill.)

Fig A14. Right page: Sketches plans housing kampung (own ill.)
b: Bedroom
B: Bathroom
K: Kitchen
L: Living room
P: Parlor
s: Shop
S: Storage
Hatched: Porch or balcony



B. RESEARCH DIGITAL FABRICATION

+ STRUCTURING RESEARCH DIGITAL FABRICATION
+ DIGITAL FABRICATION METHODS
    - Bricks
    - Steel
    - Wood
    - Concrete
    - Fabric
    - Mud

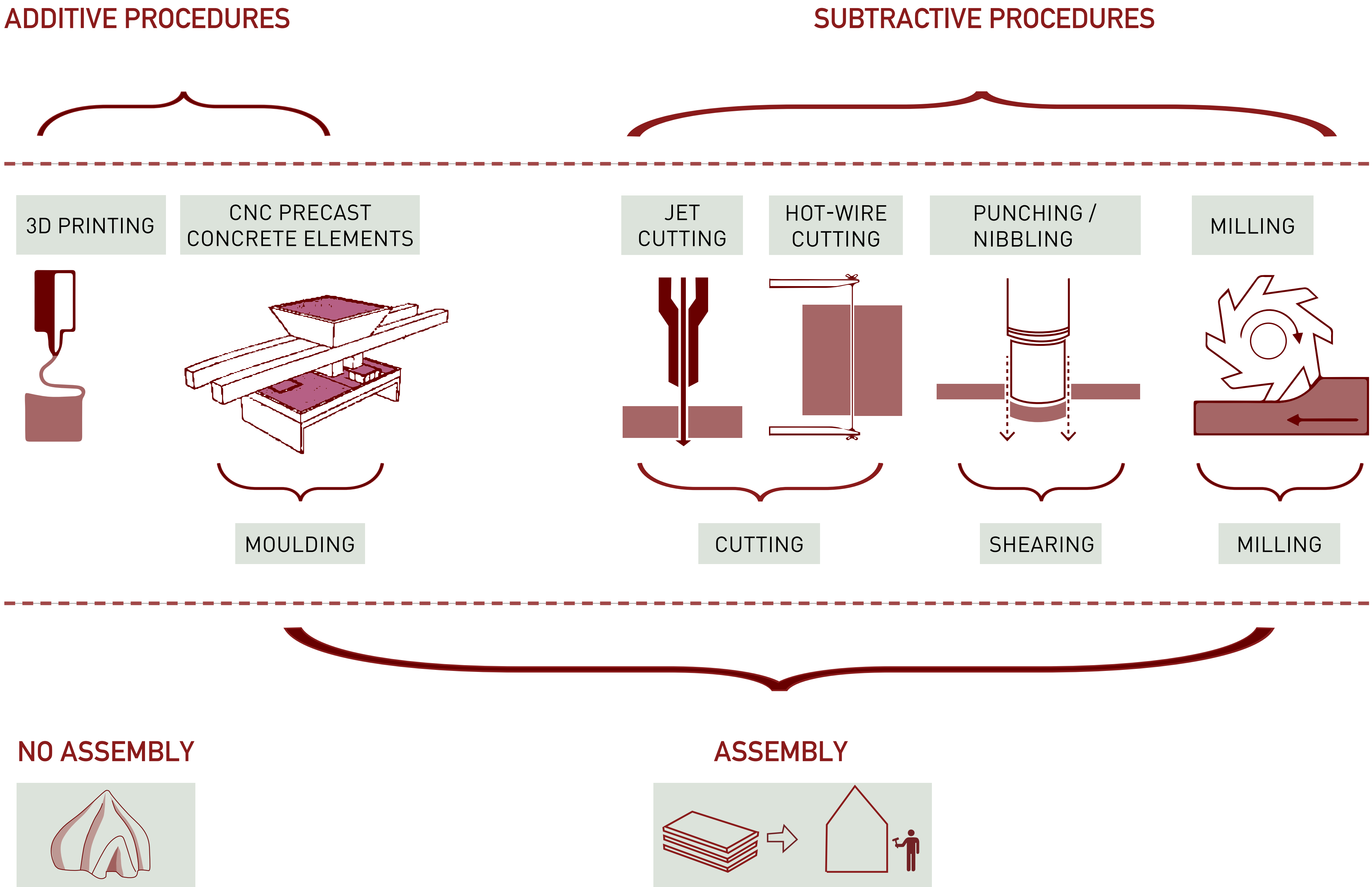
STRUCTURING RESEARCH
DIGITAL FABRICATION

// IWAMOTO, HAUSCHILD, BEOKREM & REMMERSWAAL

When researching digital fabrication methods there is a massive amount of innovative techniques and methods that is only recently being mapped. In her book 'Digital Fabrications', Iwamoto (2009) uses digital fabrication techniques to structure her overview of digital fabrication. These techniques are; sectioning, tessellating, folding, contouring and forming. None of these techniques however are applicable in practical architectural solutions. Most of them are applicable in interior situations and/or used as installations to showcase the particular technique. A more practical overview of digital fabrication techniques is that of Hauschild, Karzel, & Hellstern (2011). In their book 'Digital Processes' they give both an overview of digital production techniques as some project examples. While the production methods are better applicable in practical architectural solutions, many of the project examples are either still in the conceptual phase, or are also used in interior projects. From their research on digital fabrication methods two procedures can be derived, digital fabrication methods are either additive or subtractive. As seen on the right page Hauschild et al. (2011) state that there are two additive procedures; the first being 3-d printing, in which for example concrete or mud is extruded from a 3-D printer to produce an architectural element. The advantage is that this offers great form-freedom so for example double curved structures are easily constructed. In the second additive procedure a CNC controlled moulding robot is used, producing complete building elements like fully assembled walls. These accordingly have to be transported to a building site. This method is called moulding.

The subtractive methods do not add but remove parts of the raw material to split, shear or mill a material. Hauschild et al. (2011) make a distinction between cutting, shearing and milling of a material. The cutting can be done either by jet cutting or thermo-cutting. In jet cutting no cutting edge is used but rather a jet, this jet is either made up of bundled energy (laser jet cutting), gas (plasma cutting) or water (water jet cutting). The very low material loss on the edges make this method suitable for friction lock connections.

Fig B1. Page right: Visualisation production methods Hauschild et al. (2011) (own ill.)



ADDITIVE PROCEDURES
SUBTRACTIVE PROCEDURES
3D PRINTING
CNC PRECAST CONCRETE ELEMENTS
JET CUTTING
HOT-WIRE CUTTING
PUNCHING / NIBBLING
MILLING
MOULDING
CUTTING
SHEARING
MILLING
NO ASSEMBLY
ASSEMBLY

Cutting can also be done by a so called punching-machine, this is called shearing or nibbling. These machines stamp a shape out of the material using a so called die-head. Moving this die-head over a material while repeatedly punching down is called shearing or nibbling. Often metal sheets are used for this method.

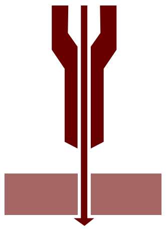
When milling a material, for example wood, a motor head is rotated and moved over the material, scraping off the material in its way. There are now 3-, 5- and even 7- axial machines available that can mill material from multiple angles and can therefore create highly complex geometries. This technique is mainly used for wood and plastics. The milled form can directly be used in a building to form an architectural wooden element, but the shape can also be used as a mould to produce for example concrete elements. In the next chapter more will be explained about this in the example reference of Peinovich (2012).
Thermo cutting is the last of the subtractive methods. An electrical current is send through a metal wire heating it in the process, herewith large blocks of foam can be cut. In architectural applications large scale hot-wire cutting can be used to complete concrete formwork or the construction of light, voluminous construction parts. The Rotterdam based Rapid studio (Beerendonk, 2014) developed a 7m high Styrofoam arch for the 2014 Venice Biënnale using this technique. When the hot wire is mounted on a multi-axes robot all sorts of three-dimensional shapes can be created.

When discussing the aspects of assembly of these subtractive and additive digital fabrication methods only when using full scale 3-D printing there is no further assembly needed. All other digital fabrication methods create building components that need to be assembled on site. In this they are similar to prefabricated building methods. There is however one big difference between prefabricated building methods and digitally fabricated building methods. The advantage of prefabrication is that repetitive construction is possible in an controlled environment. Also, because the building elements are produced on a large scale the costs go down. There is however no customisation of the produced building elements possible. For CNC machines it does not matter if a building element is produced in repetition a hundred times, or if each produced element is unique. In this, digital fabrication has a big advantage over prefabrication methods. Stoutjesdijk (2013) calls this the revolution of 'mass customization'. It could prove the solution for building cheap customized housing on a large scale.

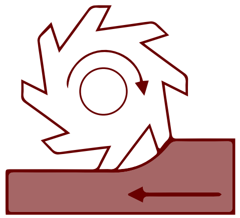
In the table on the right method properties have been given for all methods discussed by Hauschild et al. (2011). It is an adjusted version of the table as presented in the book 'Digital processes'. Useful in this graph is the information on what material to combine with what technique. Also clear from these numbers is that laser cutting is clearly the quickest method for cutting out 2-D shapes, it however also consumes the highest amount of energy.

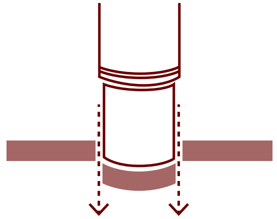
Two sources for structuring research into digital fabrication have been discussed, Iwamoto (2009) and Hauschild et al. (2011). For this research a third useful source was found. Beorkrem (2013) is structuring available digital fabrication methods by material used. Per material chapter a minimum of six references are used to showcase what can be done with this material when digitally fabricated. This is not giving a very clear overview into methods like Hauschild, Karzel, & Hellstern (2011), but it does showcasts many techniques, possibilities and especially relevant references. For this research only certain specific digital fabrication techniques were of interest. The digital fabrication methods had to be **practically applicable** in the building of dwellings, they had to either partially or fully make use of **digital fabrication techniques** and the techniques had to be suitable for small scale building constructions like **dwellings**.
The structuring as used by Beokrem (2013) is employed in this paper to frame the discussion on project references that make up the rest the research.
As explained, there are not enough literary sources to study digital production methods so for each material group one or two references are discussed that are either already build, or hold very practical applications even in its concept phase. The next paragraph will elaborate on these references.

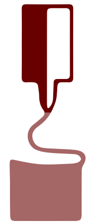
Fig B2. Page right: Properties digital fabrication methods, based on Hauschild et al. (2011)

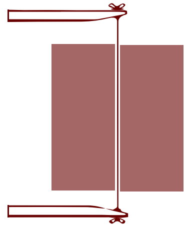


CUTTING









	-LASER	-WATER	-PLASMA	MILLING	NIBBLING	PUNCHING	3-D PRINTING	HOT-WIRE
MATERIALS	Almost all materials	Rubber Plastic Textiles Paper	Conduc-tive & raw materials	Wood Foam Cardboard (aluminium)	Steel Brass Aluminium Copper	Steel Brass Aluminium Copper	'Structural ink' Concrete Mud	Expanded materials: polystyrene Styrodur
MATERIAL THICKNESS	400 mm	Up to 350 mm	3000 mm	Up to approx. 250 mm (with 100 mm drill)	Up to 8 mm	Up to 8 mm	Variable to materials and machinery	Unlimited, only lim-ited by size of the wire
SIZE SEAM	0.1 - 0.5 mm	0.1- 0.25 mm	0.8-1.5 mm	1 mm dependent on the milling head	0 to 5 mm	0 to 3 mm	Not applicable	Depending on thick-ness wire and height electricity
SPEED	300 m/min	35 m/min	6 m/min	Approx. 10 m/min	1200-2800 strokes/min	1400 strokes/min	Variable to both machinery and ma-terials	Variable to both machinery and ma-terials
FINISHING NEEDED?	Depend-ent on material	Depend-ent on material	Yes, grinding	Yes, grinding	Yes, grinding the edges	Yes, grinding the edges	Usually not	No
GEOMETRY OPTIONS	2-D	2-D	2-D	3-D	2-D	2-D	3-D	2-D & 3-D
ENERGY CONSUMPTION	100 kW	37 kW dependent on pump	Approx. 80 A	18 kW	25-50 kW	25-50 kW	Variable to both machinery and ma-terials	Variable to both machinery and ma-terials

DIGITAL FABRICATION METHODS

// REFERENCE RESEARCH STRUCTURED BY MATERIALS

This paragraph will discuss the results of the digital research methods research. Per material one or two references are discussed that were practically applicable on an architectural scale. Each of these references were tested on a number of criteria. These criteria were linked to the chosen context: the kampung of Indonesia as discussed in the first chapter. The chosen criteria;

- How **durable** would this method be compared to local building methods?
- What would be the possibility for constructing **multi-storey**?
- How high would the **material cost** be?
- **Cost** for needed **machinery**?
- Possibility for **local assembly**?
- What is the **difficulty level** of assembly?
- Does the method leave room for **personalization**?
- Usage of **local material**?

These criteria are organised based on priority, with safety being one of the main reasons to improve the current building methods, durability is of the greatest priority. The build of multiple storeys is linked to this, currently there is no safe method for building above one storey, with the increasing densification of the kampung in mind, building height is important. The chosen building method should therefore provide in this. After these two priorities, cost is a very important third priority. The solution should be realizable and therefore cheap, both in used machinery and materials. Since the aim of my research to provide a solution that is self-build, local assembly and ease of assembly will be discussed next. Local assembly represents the way the materials are brought into the kampung, since no car can reach into every kampung this is of importance. Personalization and the usage of local materials are, although important, not of the highest priority in this research.
Each reference plots these criteria's against the technique in a graph. This graph represents the possibilities of the technique when used in the kampung.

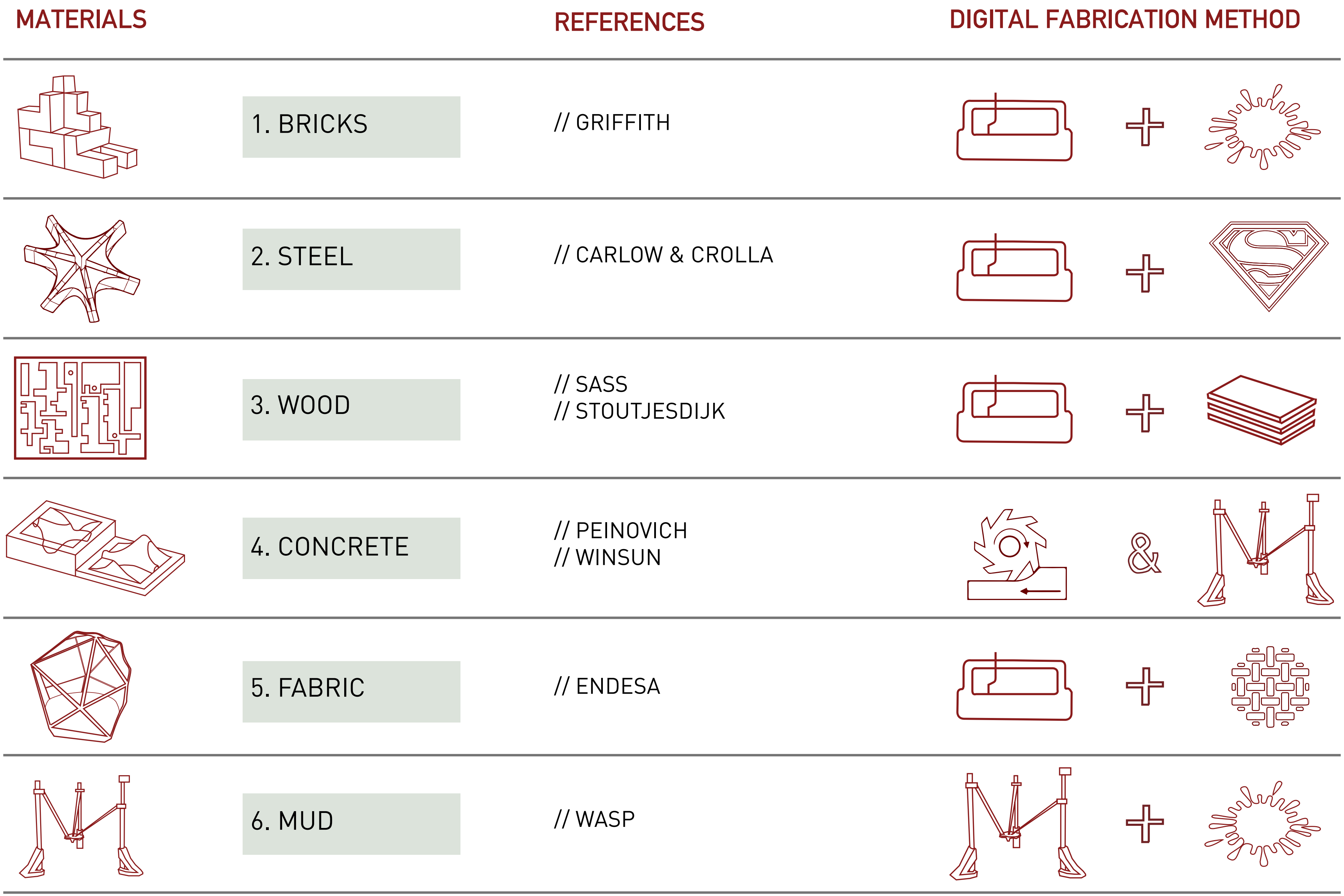
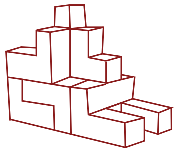


Fig B3. Chosen references sorted by materials, with their given digital fabrication methods (own ill.)

1. BRICKS



// REFERENCE GRIFFITH

Griffith, Williams, Knight, Sass, & Kamath (2012) have developed a method where CAD (Computer Aided Design) and CAM (Computer Aided Manufacturing) have been combined in the manufacturing of building assembly systems. In their method a mouldable composite material like concrete, concrete-mix, adobe, cob or poured earth is combined with a digitally fabricated moulding device to create block assemblies. Griffith et al. (2012) argue that this system offers ways of building infrastructure through repeatable production while using accessible and precision-driven technologies to mitigate the absence of professional labour. They also argue that these precision-driven technologies facilitate the improvement of the build environment, and therefore diminish the need for strict quality control.

As shown on the right page the process for creating the proposed brickwork is quite simple. After development of the digital 3-D model of the moulds, this data is translated into 2-d drawings and send to the CNC laser cutter. In the laser cutter low-grade 13 mm CDX-plywood is used for the outside moulds. Inside these moulds equine recyclable rubber material is used to extract the bricks easily when cured. They form an inner pocket volume to stack the moulding layers in. Usually an agitation mechanism like a vibrator is used to distribute the composite throughout the mould, in this construction a rocking device is designed to facilitate this agitating through human-powered means. After curing, the complete mould can be reused to construct more bricks. The internal rubber pocket volume can change easily to construct different types of bricks. (See also fig. B4)

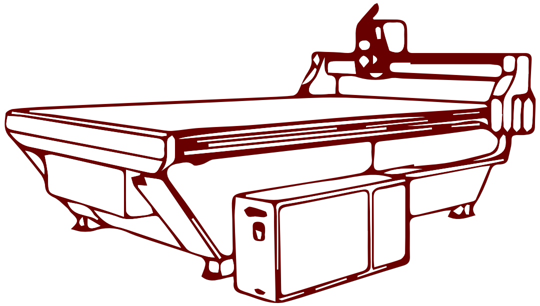
// GRIFFITH VS KAMPUNG

Griffith et al. (2012) designed their bricks for seismic active zones, tests done in their research showed these bricks are suitably safe in usage. They can therefore be deemed durable in use. This method alone does not allow for construction of multiple stories, an external construction like a concrete frame is needed. The material-costs for this method can be considered low. The moulding devices, once printed can be reused, same as the rubber pocket volume. The

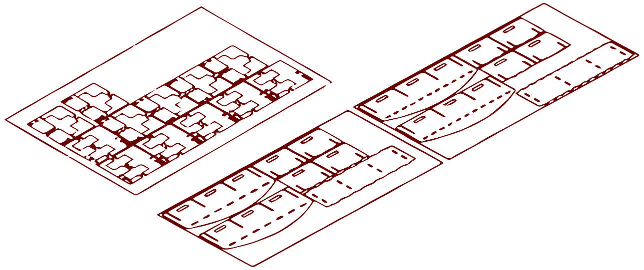
	−	1	2	3	4	5	+
DURABILITY	NO	●	●	●	●	○	YES
MULTI STOREY	NO	●	○	○	○	○	YES
COST MATERIAL	HIGH	●	●	●	●	○	LOW
COST MACHINERY	HIGH	●	●	●	○	○	LOW
LOCAL ASSEMBLY	PREFAB	●	●	●	●	○	IN SITU
DIFFICULTY ASSEMBLY	HARD	●	●	●	●	○	EASY
PERSONALIZATION	NO	●	●	●	○	○	YES
LOCAL MATERIAL	NO	●	●	●	●	○	YES

biggest material cost is the material that makes up the bricks like concrete, concrete-mix, adobe, cob or poured eart, which are, as seen in the Material Catalogue of Bandung, relatively cheap in this region. The machinery is only needed to create the mould once, so again, while using a CNC laser cutter is usually quite expensive, these costs are limited. Once production is executed on larger scale the purchase of a CNC laser cutter might be unavoidable. The estimated cost of such a machine is around € 30.000 (Grant Graphics, n.d.)
Only the moulds are produced off-site, so the assembly is very much on-site. The curing can be done in the kampungs. The assembly of the moulds are very easy, as is the rocking device. Only a rubber mullet needs to be used, the connections are friction locked.
The craft of bricklaying is known in the kampungs and does not need to be tought. Once produced the bricks can be plastered and painted, same as in traditional architecture, allowing for personalization.
All in all this is a very interesting method to use in the kampungs of Bandung Indonesia to improve the self-build structures. However, it will need to be combined with a different method to allow for the build of multiple storeys.

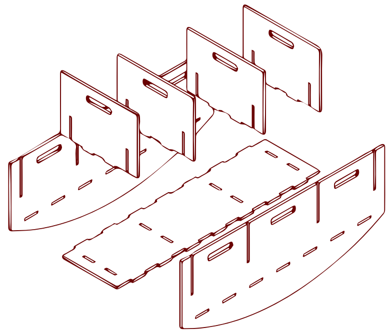
Fig B4. Visualisation production method Griffith, based on visuals from Griffith et al. (2012)



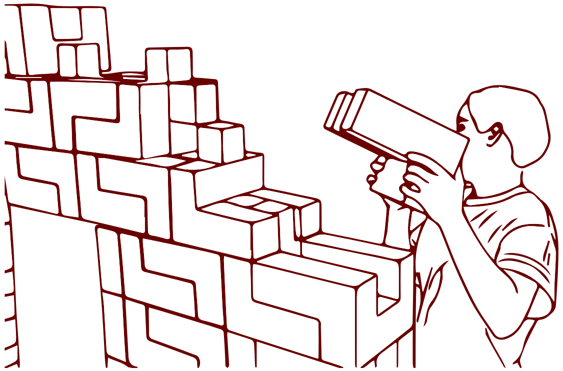
CNC LASERCUTTER



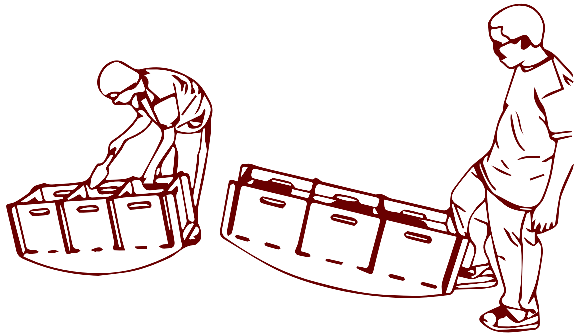
LASERED WOODEN SHEETS



ASSEMBLY MOLDS

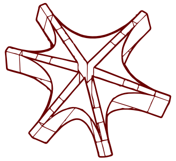


ASSEMBLY COMPONENTS



PREPARATION / CURING

2. STEEL



// REFERENCE CARLOW & CROLLA

Carlow & Crolla (2013) from the University of Hong Kong have designed a method wherein double curved structures can be constructed in remote communities through the use of both a digital model (CAD), and digital printing (CAM). This method focusses on producing the joints in metal and to use mostly locally available materials like wooden beams.
The process starts by creating a digital model in which the curved structure is designed, this model calculates what kind of joints are needed when using specific parameters, like the size of the local materials, or height differences in the site, or the shape and form of the chosen structure. From these calculations 3-D joints are flattened into 2-D drawings that can be lasered from metal sheets. An example of one of these joints can be seen on the right page.
These joints are flat packed and shipped from the design-lab to the remote location. Since a double curved structure has many different joints, each and every piece is unique and needs to be marked so they can be correctly constructed on site. In the design as visualized on the right, 240 pieces need to be printed and shipped to create 49 joints. Each joint also holds information on how long the joining wooden members should be. Carlow & Crolla (2013) state that this method could be suitable for not only wooden profiles, but also steel, aluminium and bamboo. (See also fig. B5)

// CARLOW & CROLLA VS KAMPUNG

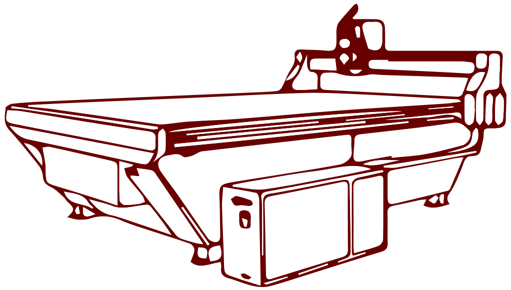
When looking at this system it has a lot of potential. The free-form structures Carlow & Crolla (2013) are trying to make produce for developing countries are however not very suitable for the kampung. The system needs to be considerably simplified to facilitate self-build construction. The graph with the criteria is based on an altered version of the technique, suitable for the kampung.

The durability of this construction is untested in the article of Carlow & Crolla (2013), the assembly and bending of the flat packed joints on location, unless very carefully engineered, could influence the durability of the construction. When properly engineered however the joints, suitable for dome constructions can certainly be used to build up to three storeys high.

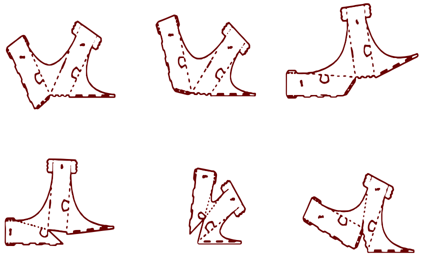
	–	1	2	3	4	5	+
DURABILITY	NO	●	●	●	○	○	YES
MULTI STOREY	NO	●	●	●	○	○	YES
COST MATERIAL	HIGH	○	○	○	○	○	LOW
COST MACHINERY	HIGH	●	○	○	○	○	LOW
LOCAL ASSEMBLY	PREFAB	●	●	●	●	○	IN SITU
DIFFICULTY ASSEMBLY	HARD	●	●	●	○	○	EASY
PERSONALIZATION	NO	●	●	●	●	○	YES
LOCAL MATERIAL	NO	●	●	●	○	○	YES

The production of these flat packed joints could be produced in the country to avoid higher transportation costs. The joints can be used to put together a wooden basic construction on which a secondary structure like walls and doors would be added, this secondary structure can be completely personalized. The machinery costs would be relative low since only the joints would need to be digitally fabricated. The biggest material cost would be the sheet-metal needed for the joints, apart from this only local materials like wood would be used. Metal however is not easily available in the kampung and is considered a more expensive building material that is unknown in the kampung.
This design method definetely has some potential, it can be locally assembled without much effort, the joints can be designed in such a way it takes no effort to put up the wooden structure. It could be deemed circuitous however to construct all joints from an expensive material. And, same as the bricks-method by Griffith, this method will only give you only a wooden structure, not a full house.

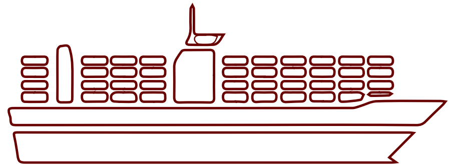
Fig B5. Visualisation production method Carlow & Crolla, based on illustrations from Carlow & Crolla (2013)



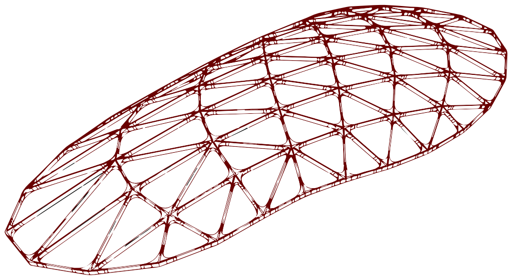
CNC LASERCUTTER



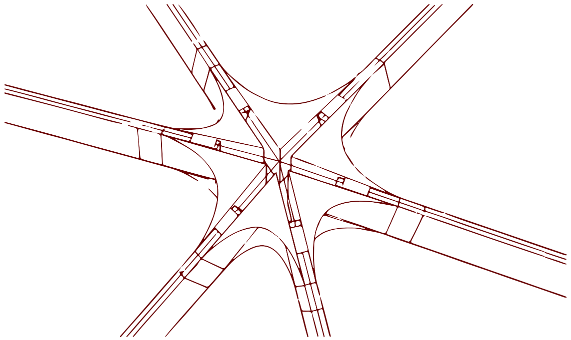
LASERED FLAT PACKED METAL JOINTS



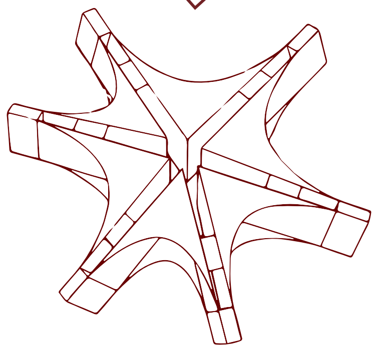
TRANSPORTATION
DEVELOPING COUNTRIES



CONSTRUCT FREE FORM STRUCTURE



ASSEMBLY WOOD AND METAL JOINTS



ASSEMBLY JOINT BY BENDING

3. WOOD

// REFERENCE SASS

Larry Sass of the MIT is one of the first pioneers who started his research on digitally fabricated architecture already from the turn of the century. His research into mass customized housing for emergency and poverty stricken locations led him to construct housing with CAM lasered wood elements.
In 'The Instant House' (Sass & Botha, 2006) Sass argues that this method provides great freedom for personalization, since for this printer it does not matter if a hundred similar houses, or a hundred completely different houses are printed. (See also fig. B6 and B8)

In this method the house is completely constructed from wooden elements. These wooden elements are joined by friction lock joints, so on location only a rubber mallet and crowbar is used to connect the puzzle pieces. The process starts with a 3-D model that is being translated into wooden flat packed elements that can be printed from plywood on a CNC laser printer. These elements are being moved to the location where they are being constructed.

// SASS VS KAMPUNG

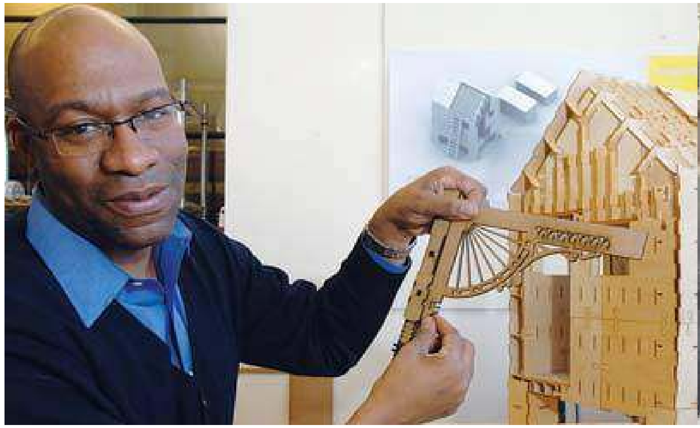
The downside to this method is that the used material is not (yet) waterproof, so once the house is constructed, additional materials are needed in order to make the house waterproof and insulated. When using only materials that are waterproof the material costs rise significantly. Also, the boards that are needed for the CNC printer have to comply with a certain properties, the used wood needs to be treated and reasonably flat and even, so the laser can properly cut out the friction lock joints. These kind of plywood is to our knowledge not readily available in the Kampung nor cheap. Compared to the materials used in the kampung, like concrete, or untreated wood, these treated wooden boards are expensive. The great advantage of this method is that it can be very easily assembled on site, providing a great self-build method that creates safe housing in the kampung. The problem is that this method is most likely too expensive for the kampung. A CNC machine on location is needed to produce all the elements of the house, not only is this expensive, but also the material needed for this machine is relatively expensive in the kampung.

		−	1	2	3	4	5	+
DURABILITY		NO	●	●	○	○	○	YES
MULTI STOREY		NO	●	●	●	○	○	YES
COST MATERIAL		HIGH	●	○	○	○	○	LOW
COST MACHINERY		HIGH	●	●	○	○	○	LOW
LOCAL ASSEMBLY		PREFAB	●	●	○	○	○	IN SITU
DIFFICULTY ASSEMBLY		HARD	●	●	●	●	●	EASY
PERSONALIZATION		NO	●	●	●	○	○	YES
LOCAL MATERIAL		NO	●	○	○	○	○	YES

Also, all the elements of the house need to be transported into the kampung, the infrastructure in the kampung does not allow for transport of large elements, only scooters, handcars and bikes can drive on the small roads of the kampung.

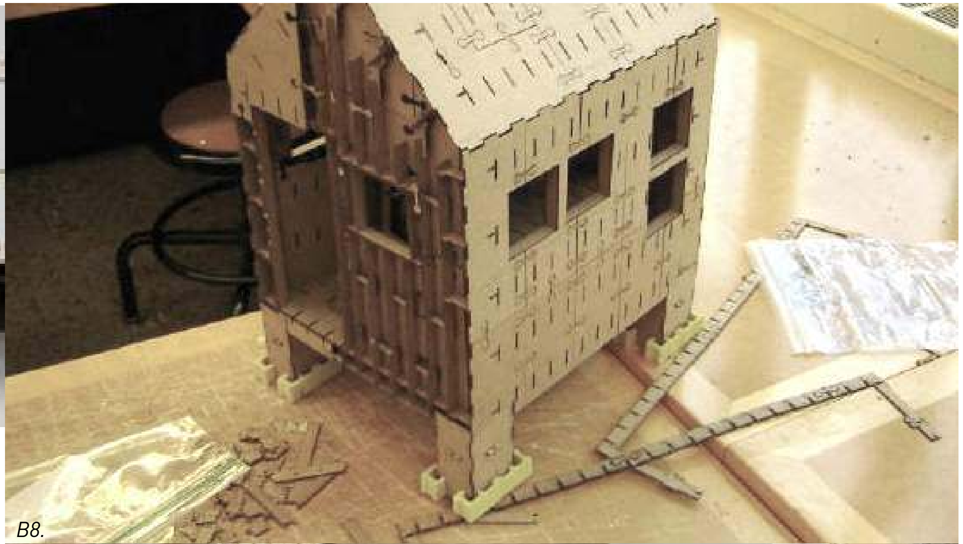
In the kampung there are almost no houses constructed of wood or bamboo, many people find it a status symbol to be living in a concrete structure. Wood and bamboo are usually only found in the poorest areas, where untreated wood and bamboo cause unsafe living conditions. This image problem could prevent people from wanting to live in these all-wooden houses.

Fig B6. *Sass, The Instant House (Sass & Botha, 2006)*
Fig B7. *Foundation element 'Home Delivery' exhibition museum of modern art display Sass, 'The Digitally Fabricated House for New Orleans' (Digital Design Fabrication Group, 2008)*
Fig B8. *Model, The Instant House (Sass & Botha, 2006)*
Fig B9. *Exterior 'The Digitally Fabricated House for New Orleans', designed and build by Sass (Digital Design Fabrication Group, 2008)*
Fig B10. *Visualisation production method Sass (own ill.)*

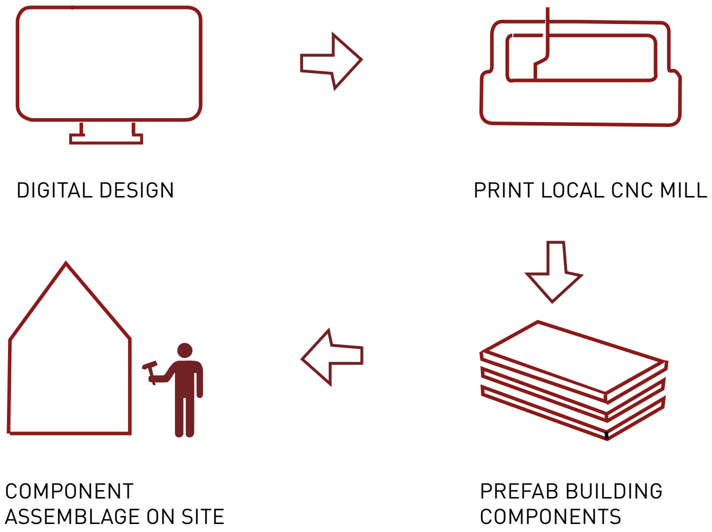


B6.

B7.



B8.



B10.

B9.

3. WOOD

// REFERENCE STOUTJESDIJK

Pieter Stoutjesdijk designed for his graduation project of the TU Delft emergency housing for Haiti using similar techniques. Whereas Sass was building for the people stricken by huricanes in New Orleans, and thus focussing on rebuilding the rich local architecture, Stoutjesdijk focussed on the area of Haiti affected by earthquakes and tropical storms.

The difference between Sass and Stoutjesdijk lies mostly in the chosen context and architecture. Stoutjesdijk (2013) designed a catalogue of printable houses that represent the local architecture of Haiti. (See also fig. B11-13-15 and 17) This shows how the houses are easily personalized. The production method is very similar to that of Larry Sass. From a digital design 2-D flat packed wooden elements are produced that are joined by friction lock joints. Accordingly they are assembled on site using only a mullet. (See also fig. B16)

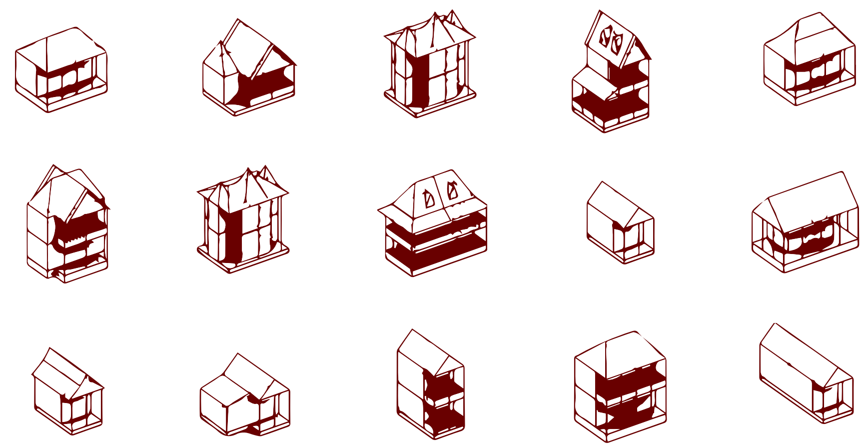
This project was chosen to be build in Africa. Both cost and the image of living in a wooden house created a problem in this area. Instead of building only out of wood the construction is combined with earth bricks which are common in this area.

// STOUTJESDIJK VS KAMPUNG

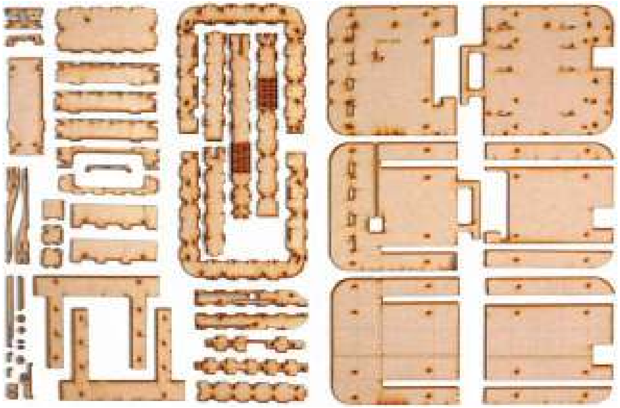
This is a good example of how a hybrid between traditional and modern techniques is the best way to involve the community. Local culture and customs are taken into account. The graph on the right is adjusted to this hybrid variety. The cost of the earth bricks is significantly lower than building solely with lasered wooden elements, not only the material costs are lower, but also the machine costs are lower since less elements have to be lasered.

Fig B11. Catalogue printable houses Stoutjesdijk (Stoutjesdijk, 2013)
Fig B12. Parts CAM printed hot wire lasercutter (Stoutjesdijk, 2014)
Fig B13. Interior graduation project Haiti (Stoutjesdijk, 2013)
Fig B14. Friction lock examples (Stoutjesdijk, 2013)
Fig B15. Exterior graduation project Haiti (Stoutjesdijk, 2013)
Fig B16. Visualisation production method Stoutjesdijk (own ill.)
Fig B17. Architectural elements graduation project Haiti (Stoutjesdijk, 2013)

		−	1	2	3	4	5	+
DURABILITY		NO	●	●	○	○	○	YES
MULTI STOREY		NO	●	●	●	○	○	YES
COST MATERIAL		HIGH	●	●	●	○	○	LOW
COST MACHINERY		HIGH	●	●	●	●	○	LOW
LOCAL ASSEMBLY		PREFAB	●	●	○	○	○	IN SITU
DIFFICULTY ASSEMBLY		HARD	●	●	●	●	●	EASY
PERSONALIZATION		NO	●	●	●	○	○	YES
LOCAL MATERIAL		NO	●	●	●	●	○	YES



B11.

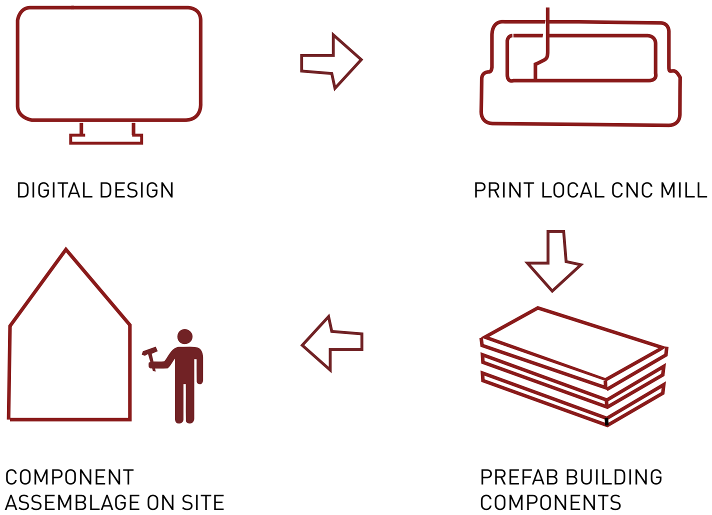


B12.

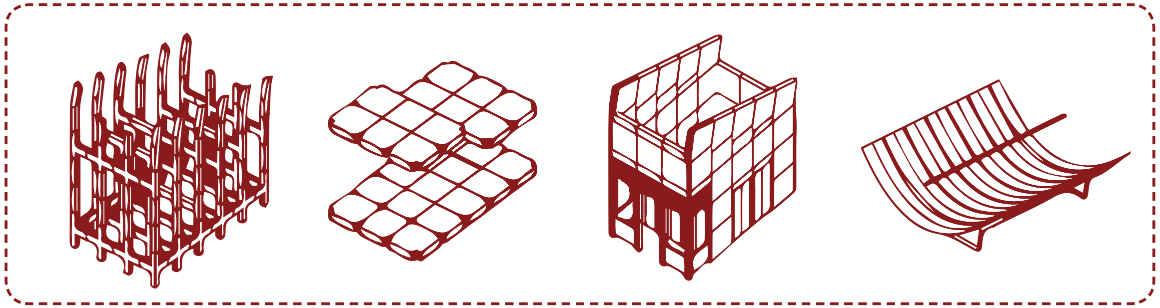
B13.

B14.

B15.

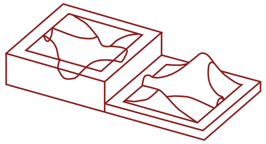


B16.



B17.

4. CONCRETE



// REFERENCE PEINOVICH

In her graduation project Peinovich (2012) designed a project which states a solution for creating culturally sustainable architecture for developing countries. Peinovich promotes localisation of the design-manufacture process to encourage cultural sustainability. This project was focussed on researching the build of reusable. low-cost moulds build from CNC milled parts. This process starts by building a digital 3-d model. Information from this model is used by a CNC machine to mill 2-dimensional elements from wooden boards. These boards are then aligned and laminated with screws, creating the wanted double curved mould. After sanding and plastering of these elements, they are painted and covered with fiberglass. This ensures the mould is reusable more than once. These moulds are then used to pour concrete over a reinforcement, in this case chicken wire, to create the double curved building elements. As seen in figure B18, there are two kind of elements, a wall element, and a 'roof' element. These elements are connected by metal connections at the top, and masonry connections at the bottom, these have to be fabricated on site. As a result an undulating architectural form is fabricated. All construction is to be done by local labourers that have previous knowledge of working with thin-shell structures from ferro-cement.

// PEINOVICH VS KAMPUNG

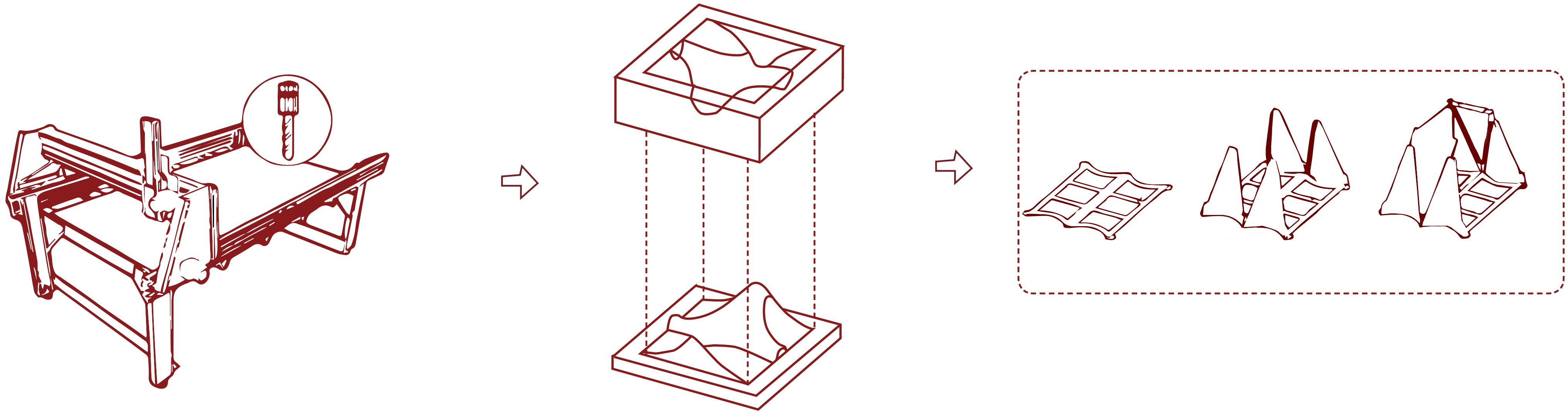
Putting this solution in the perspective of the kampung these double curved structures are not only unnecessarily difficult to produce, but also have no cultural connection to its surroundings. As seen in fig. B18 it is almost as if an alien structure has landed in the slums. It could be applicable in emergency housing, as shown by Woods Baggots 'Folded Home' (Carsen, 2013) who uses the same formwork, but made from fabric. While having a similar impractical interior-space, these structures have the advantage of being light, foldable and temporal, practical for temporary housing. When building long-term housing, this build form is not the right solution.

Fig B18. Render of modules along the road in underdeveloped areas (Peinovich 2012)
Fig B19. Visualisation production method Peinovich - based on illustrations from Peinovich (2012)
Fig B20. Original build form to new build form - based on illustrations from Peinovich (2012)

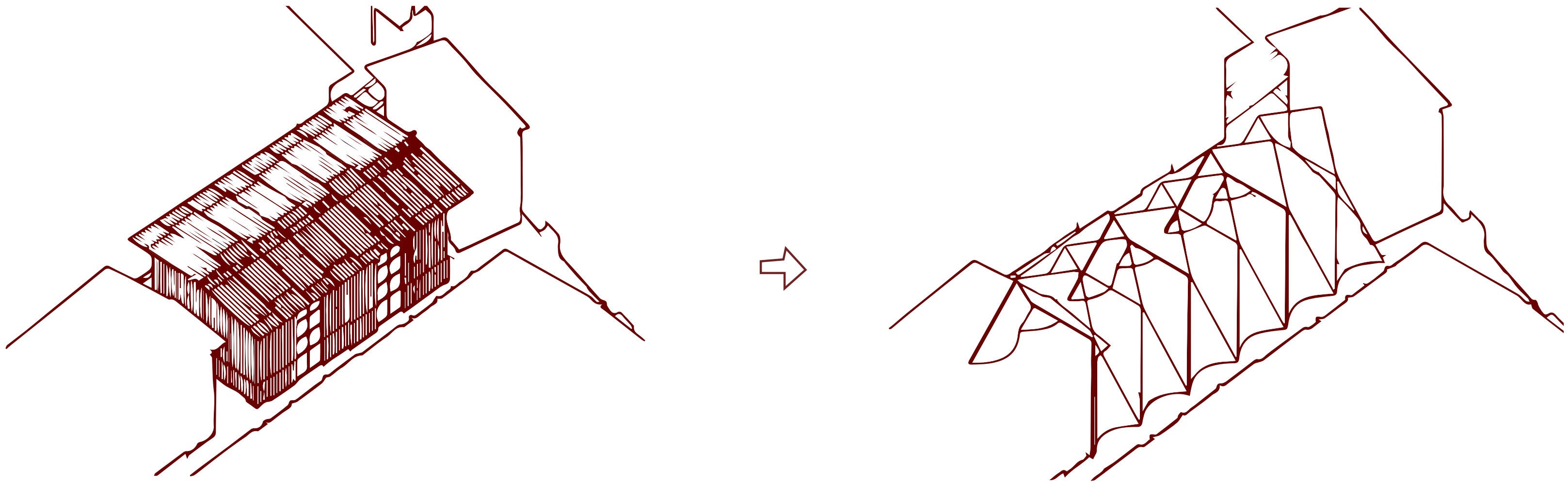
// PEINOVICH VS KAMPUNG

		1	2	3	4	5	
	−						+
DURABILITY	NO	●	●	●	○	○	YES
MULTI STOREY	NO	●	●	●	●	○	YES
COST MATERIAL	HIGH	●	●	●	○	○	LOW
COST MACHINERY	HIGH	●	●	○	○	○	LOW
LOCAL ASSEMBLY	PREFAB	●	●	●	●	○	IN SITU
DIFFICULTY ASSEMBLY	HARD	○	○	○	○	○	EASY
PERSONALIZATION	NO	○	○	○	○	○	YES
LOCAL MATERIAL	NO	●	●	●	○	○	YES

B18.

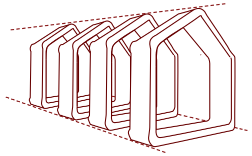


B19.



B20.

4. CONCRETE



// REFERENCE WINSUN

The chinese company Winsun build in 2014 ten houses in one day with the use of a giant 3-d printer. Build from predominantly recycled materials Winsun claims these houses cost less than 5.000 dollar (Winsun, 2014).
The build starts with a threedimensional model wherein not only the design of the building can be changed, but also additions like insulation materials, plumbing, electrical lining and windows can be taken into account.
The data from this digital model is sent to the 3-d printer that uses a special 'ink', made from construction waste, tailings and industrial waste to produce the building elements. The printer is measured 150 x 10 x 6.6 meters and 'spouts' out the recycled cement-mix, building the walls up layer by layer. While the elements are relatively quick to dry, they have to be transported and assembled on site. See also fig. B22 for the building process.

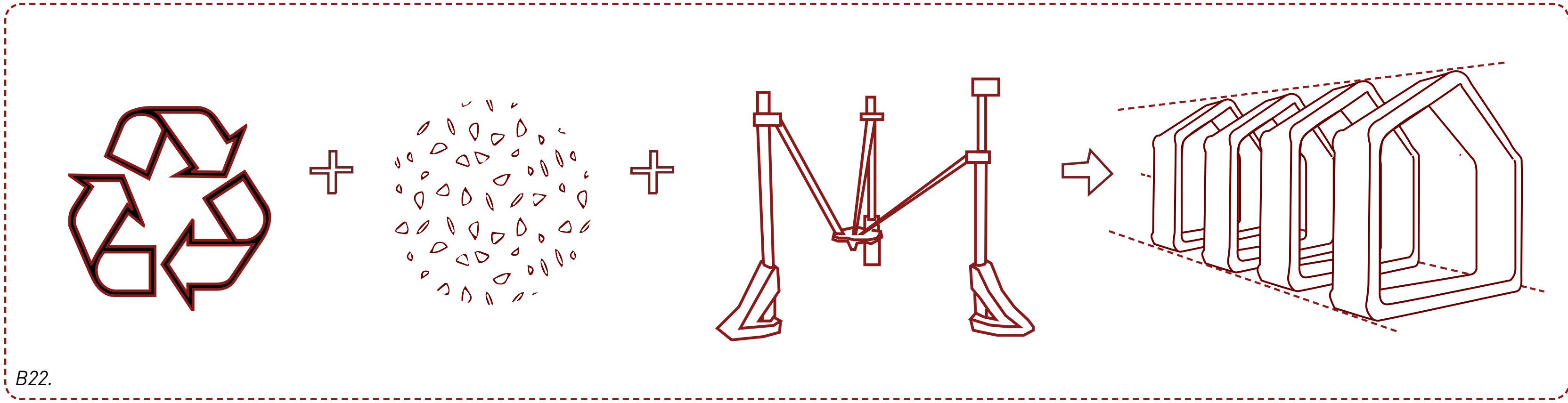
		−	1	2	3	4	5	+
DURABILITY	NO		●	●	●	○	○	YES
MULTI STOREY	NO		●	○	○	○	○	YES
COST MATERIAL	HIGH		●	●	●	○	○	LOW
COST MACHINERY	HIGH		●	●	○	○	○	LOW
LOCAL ASSEMBLY	PREFAB		●	●	●	●	○	IN SITU
DIFFICULTY ASSEMBLY	HARD		○	○	○	○	○	EASY
PERSONALIZATION	NO		○	○	○	○	○	YES
LOCAL MATERIAL	NO		●	●	●	○	○	YES

// WINSUN VS KAMPUNG

There are several problems to this production method when applying this construction method in the kampung of Indonesia. The most important one is the need for transportation of the biggest elements. Since the kampung are only accessible via scooters and handcars this rules out this method for the kampung. The second issue is the ease of assembly, specialized knowledge and machinery is needed to put together these big building elements, none of which is readily available in the kampung. While the solution would be durable and a safe way of building multi-storey housing, there is not a lot of room for personalization. The plots of the kampung are almost never in a square shape, each house needs to be different, in the current form this technique does not provide in this.
Also, the 3-d printed elements need to be affixed with extra elements like windows and roofs.


B21.

Fig B21. House-sized 3-d printer creates corner wall (Winsun, 2014)
Fig B22. Visualisation production method Winsun (own ill.)
Fig B23. Stack of 3-d printed walls (Winsun, 2014)
Fig B24. Assembled dwelling with 3-d printed elements (Winsun, 2014)
Fig B25. Assembly on site of 3-d printed elements (Winsun, 2014)
Fig B26. More complex assembled dwelling using 3-d printed elements (Winsun, 2014)


B22.


B23.


B24.


B25.


B26.

5. FABRIC

// REFERENCE ENDESA

The Endesa pavilion, also known as the 'World Fab Condensor' was designed by the Margen-lab, produced by the IAAC and collaborative designed, build, and customized by the FabLab Network. (Fab10, 2014)
The design of the pavilion was designed, written in code, in two months. After this initial design the parts were manufactured in five days and assembled in four (see also fig. B28)
Only the platform is CNC milled from local materials, in this case wooden boards. The construction of both the wooden frame and the linnen covers are made by traditional machinery (see also fig. B32)

// ENDESA VS KAMPUNG

Since the pavilion was intended to be a temporal exhibition the construction is not durable enough to use in the kampung. While the construction is very lightweight and uses mostly local materials, there is no possibility for multiple storeys. It would be possible to transport the smaller elements via handkart into the kampung, but the milled foundation would already be too big to transport into the kampung. Also, same as Winsun, this structure would need building expertise and machinery that is unavailable in the kampung.
The most interesting thing I took from this reference is that the structure is very lightweight. While not very suited to the local cultural architecture, it is a nice example of a hybrid between digital architecture and more traditional building methods.

	−	1	2	3	4	5	+
DURABILITY	NO	○	○	○	○	○	YES
MULTI STOREY	NO	○	○	○	○	○	YES
COST MATERIAL	HIGH	●	●	●	○	○	LOW
COST MACHINERY	HIGH	●	●	○	○	○	LOW
LOCAL ASSEMBLY	PREFAB	●	●	○	○	○	IN SITU
DIFFICULTY ASSEMBLY	HARD	●	○	○	○	○	EASY
PERSONALIZATION	NO	●	○	○	○	○	YES
LOCAL MATERIAL	NO	●	●	○	○	○	YES

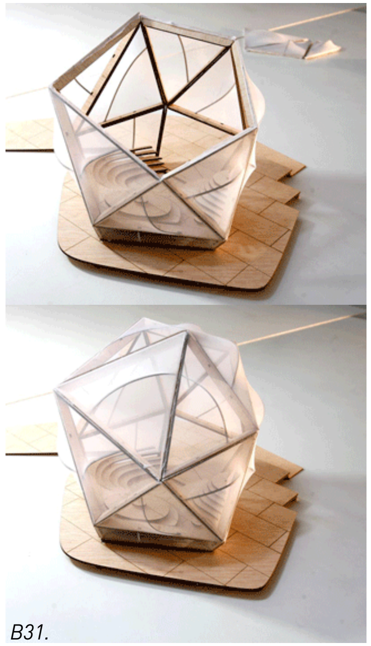

B27.

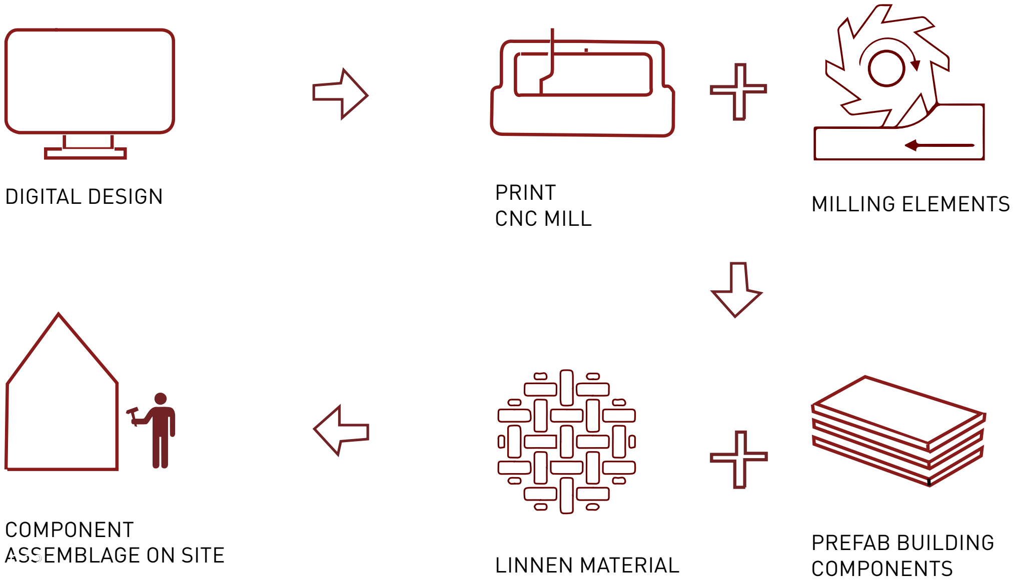
Fig B27. World Fab Condensor exhibition Barcelona (Fab10, 2014)|
Fig B28. Construction Endesa pavilion on site (Fab10, 2014)
Fig B29. Interior Endesa pavilion (Fab10, 2014)
Fig B30. Facade Endesa pavilion (Fab10, 2014)
Fig B31. Assembly of the Endesa pavilion (Fab10, 2014)
Fig B32. Visualisation production method Endesa pavilion (own ill.)


B28.


B29.

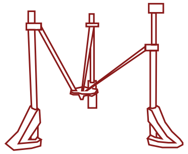

B30.


B31.



B32.

6. MUD



// REFERENCE WASP

Wasproject (World's Advance Saving Project) is developing a 6 meter high portable three-armed delta digital printer. According to the CEO of WASP Massimo Moretti the machine can be assembled on site in two hours.
This method starts, as all methods discussed before, with a digital model. With this printer there is a great deal of form freedom possible in the design. WASP decided to design traditional adobe houses as can be seen in figure B36. When the printer is erected on site, this design can be sent to the printer. When the printer is filled with local materials like mud and fibres it can start printing immediately. The walls are filled with triangular shapes to save on material and to increase the weight bearing capability (see also figure B35). The mud is not fired but sundried, and the current maximum height is 3 meters tall. The printer has not yet printed a full size house, WASP is planning on building the first 3-D printed home in 2015. (Krassenstein)

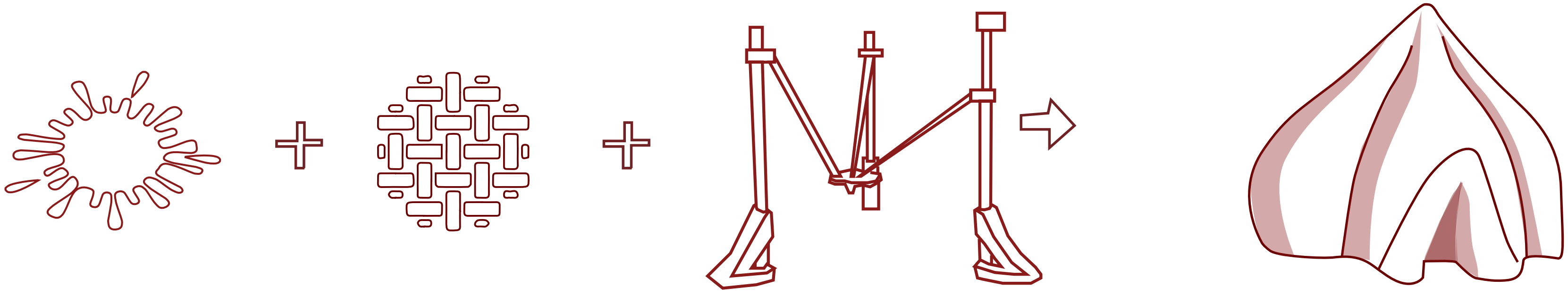
		– 1	2	3	4	5 +	
DURABILITY	NO	●	○	○	○	○	YES
MULTI STOREY	NO	○	○	○	○	○	YES
COST MATERIAL	HIGH	●	●	●	●	●	LOW
COST MACHINERY	HIGH	●	○	○	○	○	LOW
LOCAL ASSEMBLY	PREFAB	●	●	●	●	●	IN SITU
DIFFICULTY ASSEMBLY	HARD	●	●	●	●	●	EASY
PERSONALIZATION	NO	●	●	○	○	○	YES
LOCAL MATERIAL	NO	●	●	●	●	○	YES

// WASP VS KAMPUNG

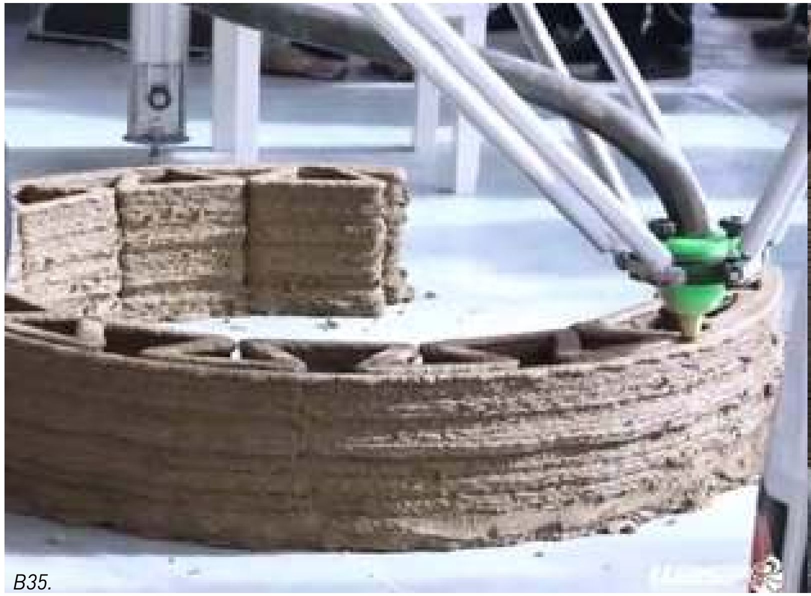
In some ways this is a very interesting option for the kampung of Indonesia, it is very easy to assemble, to produce on site and it makes use of local materials. It would build on the tradition of self-build. The building material however is not yet used in the kampung of Indonesia, and the adobe houses do not fit in the local cultural context. Furthermore, it is an untried concept with a lot of problems still to work out. The building height for example cannot exceed three meters. In this it does not provide a structural solution for the kampungs.

B33.

Fig B33. 6-meter tall 3d printer by WASP project (Krassenstein, 2014)
Fig B34. Visualisation production method WASP (own ill.)
Fig B35. Half scale printed adobe house by WASP (Krassenstein, 2014)
Fig B36. 1/10th scale printed adobe structures by WASP (Krassenstein, 2014)



B34.



B35.

B36.

C. CONCLUSION

CONCLUSION

// COMPARISON DIGITAL FABRICATION METHODS

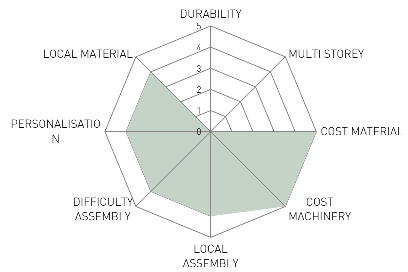
Since the topic of digital fabrication is relatively new, existing literature on this topic is sparse. Therefore it was chosen to focus the research on the study of reference projects to find inspiration for a digitally fabricated solution for the kampung of Indonesia. Of importance was, if this research would not result in a solution that had enough potential; technically, financially and contextually, this graduation project would be continued without making use of these methods.
What became clear in the early research was that there was no perfect solution that could be imediately implemented in the kampung. There was however a lot of potential in each of the chosen reference projects.

A summary of the biggest potential per project is concluded in the spider diagrams on the right. In the first graph the local building methods are analysed, this graph serves as baseline. It is clear from this graph that the local building methods score well on all criteria except safety, durability and the construction of multi-storey buildings. In this research it was essential that a building method was found that could both compete with the local building methods, it had to therefore score well on all criteria. The aim of the research was to find a hybrid method that both used what was available in the kampung and what could be used from the digital fabrication methods.

When analysing the reference projects, two projects had a lot of potential for designing such a hybrid. The first being the brick technology developed by Griffith and the second the reusable moulding systems as researched by Peinovich. Since the bricks, designed by Griffith, would not be suited for building multi-storey height buildings, a combination with a second digital fabrication method had to be found. For me the method developed by Peinovich had a lot of potential to produce reusable moulds for building safe, multiple-storey height structures.

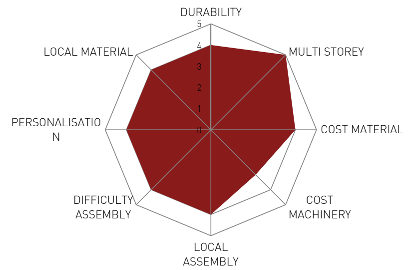
The bricks, designed with the 'Griffith-method', could be used in this building system as facade material and the needed CNC router could not only produce the moulds, but also tricky building elements like stairs, windows and doors. These digital poduction methods hold enough potential to conduct more research for the graduation project. Further research needs to be done on how to construct the reusable mould and how to provide clear instructions for the kampung inhabitants. So in short: how to apply this chosen hybrid building method in the kampung.

LOCAL BUILDING METHODS



The local building methods excel in all criteria with the exception of safety, durability and the possibility for multi-storey height. This graph shows the exactly why research discussed in this paper was conducted. This graph serves as baseline to enable a comparison to researched building methods.

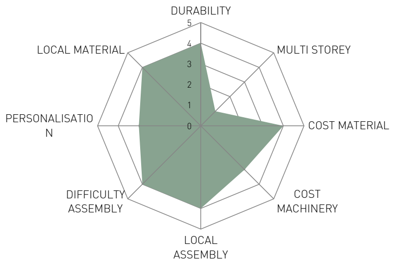
HYBRID BUILDING METHOD



The proposed building method as explained in the conclusion text has the potential to excel in all needed criteria. Further research is needed to check if the costs are not too high for the chosen location.

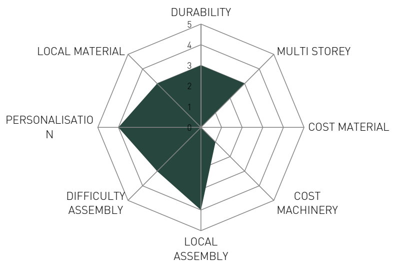
Fig C1. Spiderdiagrams visualizing the biggest potentials per reference project (own ill.)

GRIFFITH



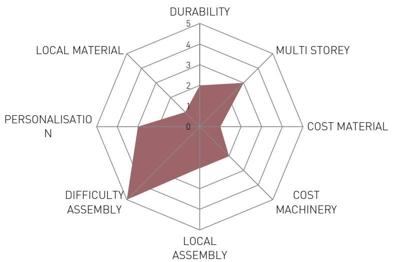
Griffith is one of the most promising reference projects. Excellent in almost all kampung criteria it unfortunately does not imediately offers a possibility for multi-storey height. This building method therefore always has to be combined with either local building methods or another digital fabrication method.

CARLOW & CROLLA



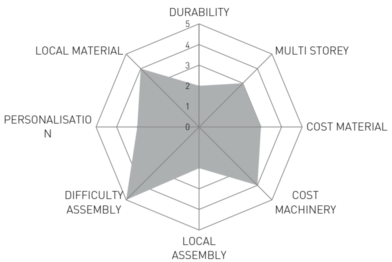
While Carlow and Crolla have developed a very interesting technique, it is less applicable in the kampung for the price of the metal joints. Also, since this technique is used by Carlow and Crolla to produce double curved structures it makes sense to use digital fabrication since each joint is different. When simplified for the kampung this might not be the case.

SASS



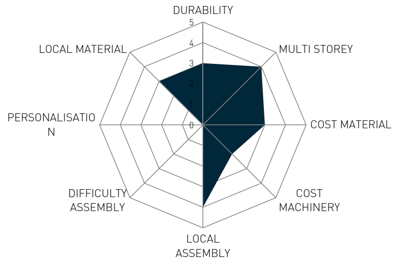
The building method Sass applies is, as seen in the graph, very good in one aspect; the ease of assembly on site. It however scores less well on material and machinery costs. This is a building method well applicable in richer countries to provide for disaster struck areas in America. In the kampung of Indonesia however this method is too expensive.

STOUTJESDIJK



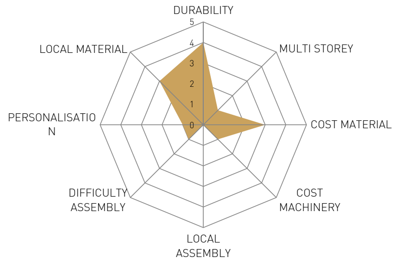
Stoutjesdijk has taken the technique developed by Sass and applied it in developing countries in Afrika. Building with solely wood was not only too expensive, it also did not fit the local context. Therefore a hybrid of both wooden elements and baked earth bricks are used to construct cheap and safe housing for the poor. As seen in the graph this hybrid scores well.

PEINOVICH



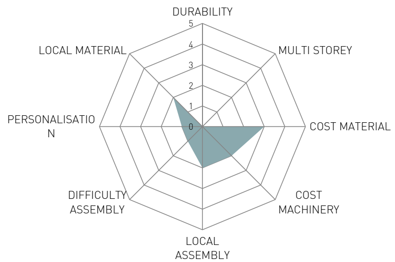
The building method as proposed by Peinovich does not score well on the kampung criteria. When adjusted to the kampung it could however provide a sollution for the build of multi-storey housing. The reusable moulding systems could be used to construct concrete frame-work. There is therefore great potential in this reference project.

WINSUN



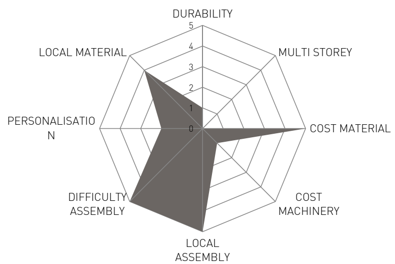
The building method developed by Winsun excells in both durability and the usage of local materials. Unfortunately this method could never be used in the kampung since the transportation of building elements into the kampung is impossible.

ENDESA



While the building method developed for the Endesa pavilion was never intended for the build of dwellings, nor for underdeveloped countries. This results in a bad score as seen in the graph. Of all reference projects presented this project is the least relevant.

WASP



The developers of the 6 meter high 3-d printer have found a very interesting building method. While it would be very easy to construct with local materials, the resulting architecture is like nothing ever build before in a kampung. Also, the technique does not provide (yet) in building in multiple storeys.

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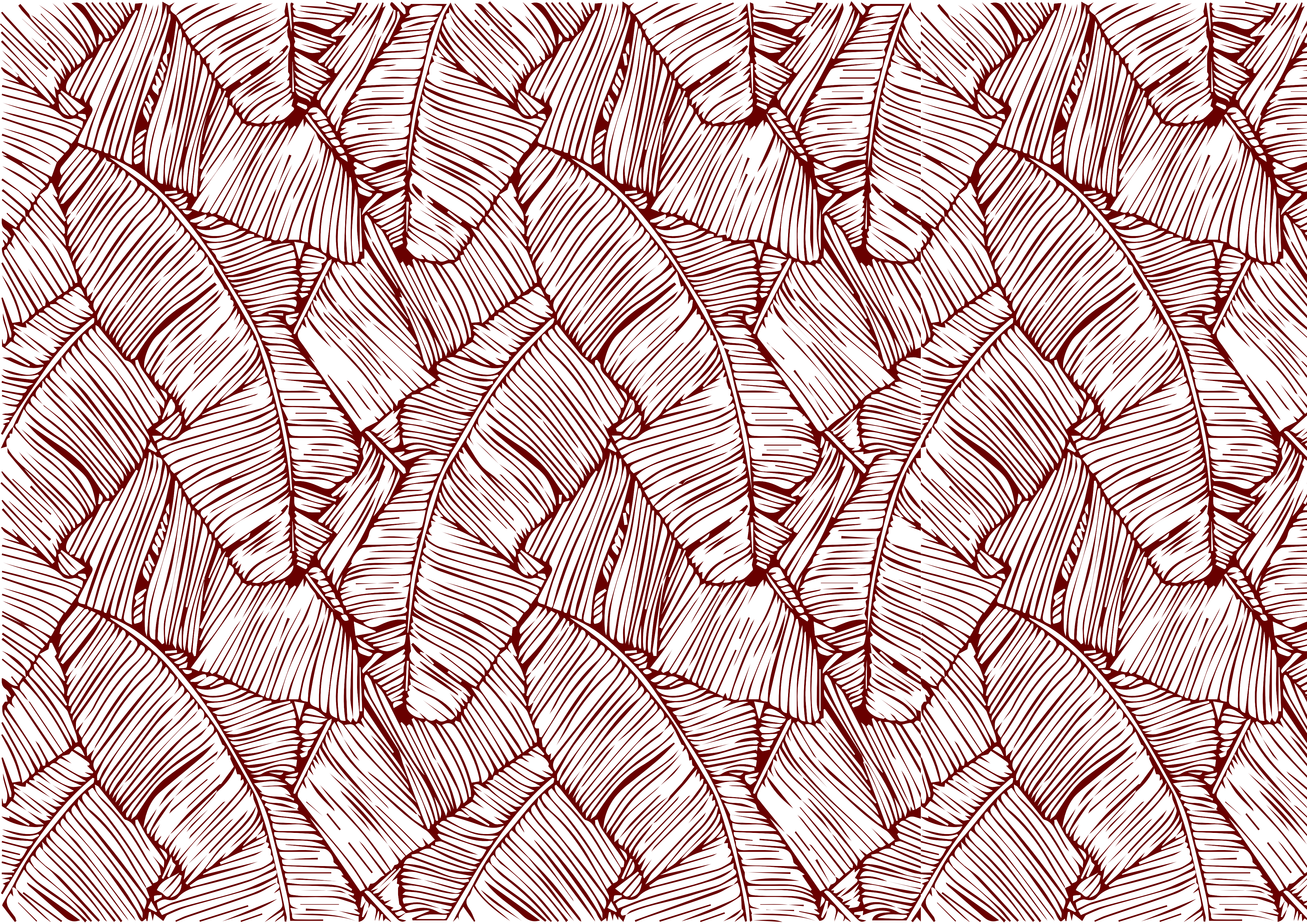

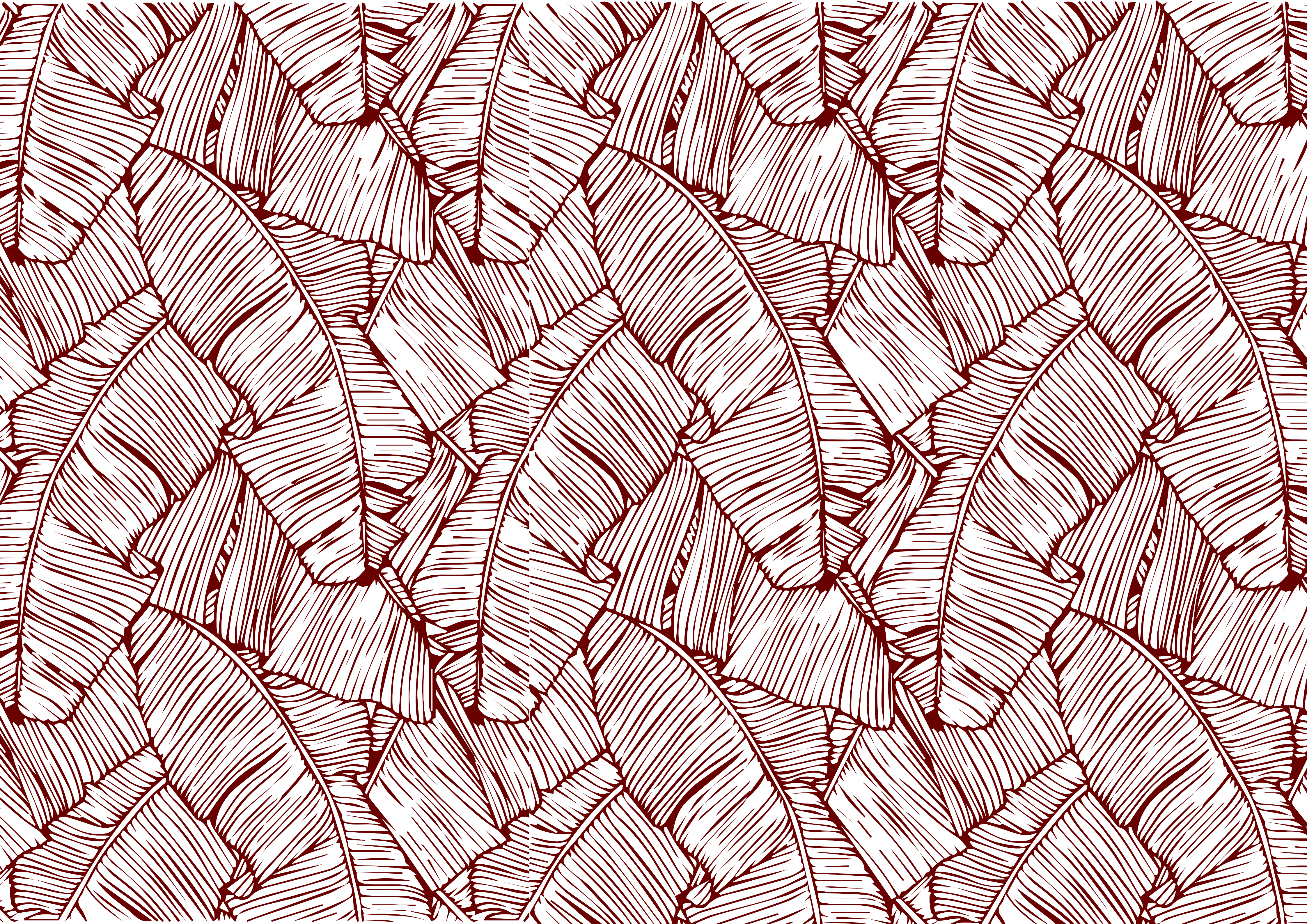

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