Stone to Stone

Balancing stone demolition waste with the demand of stone materials for new houses in Indonesia

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Martin van Splunter 4009460
Tutors: Mo Smit, Jan Jongert
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Abstract

This research investigates the possibilities an architect has to balance the volume of stone construction and demolition waste with the demand of new stone building materials within the development of a new multi-family housing typology in Indonesian kampungs. The research consists out of two parts, one part to understand the informal building culture and waste management within the Indonesian kampung. This part is build upon a week long field research and interviews conducted within a neighbourhood in Bandung. Literature and data concerning the topic further illustrated these findings. The result of this part is an overview through a material flow analysis and an assessment op the problems and opportunities within the kampung.

The second part is an investigation into eight possibilities to help the balancing of the waste material with the production of new houses. Based on the findings of part 1 criteria were formed. These case studies were tested on these criteria with the help of the material flow analysis.

As a result it can be concluded that several solutions need to be combined in order to achieve a balance between the local volume of waste and the demand of building materials. Furthermore, criteria concerning the housing and sorting programme of the design assignment were found. Lastly, criteria for the building material used within the design assignment were found based on the site analysis.

Keywords: **Informal housing, demolition waste, brick, concrete, Indonesia**

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Introduction

Indonesia is a country in development. It has rapid growing economy and experiences a stable population growth. These give rise to a growing middle class and industry. Another consequence is the rising demand in housing. It is estimated that within the next few years 50 million houses have to be built all over the country to satisfy this demand. The construction of 50 million houses creates an increased demand of stone building materials like concrete, mortar and brick, since most of the houses in Indonesia are built with these materials. In Bandung, for example 98 percent of the houses is made out of the previous listed stone building materials.

There is an other development in Indonesia too: is estimated that there will be an increase of construction and demolition (C&D) waste within Indonesia. In the city of Bandung it is estimated that between 2012 and 2020 49 million tons of C&D waste will be generated (Surahman, Higashi, & Kubota, 2015). In comparison: within 8 years, the total production of household waste (HHW) within the city of Bandung will be around 4.5 million tons (Damanhuri, Wahya, Ramang, & Padmi, 2009). This estimated production of C&D waste is projected to create enourmous problems for the already limited capacity of landfills around Bandung.

This increased demand for stone building materials and the estimated increase of C&D waste in the coming years in Indonesia demands further research into the ways in which the waste can be reduced, re-used and recycled. Most of the Indonesian houses constructed in the next years will be informally constructed. Furthermore, the most of the C&D waste will be produced within the informally constructed neighbourhoods as well. Therefore, there is a demand for housing that helps to balance the demand of construction materials with the stone C&D waste within these neighbourhoods.

This leads to the following **design question:**

How can the systematic transformation of stone building waste material encourage the development of multi-family housing typologies within Cigondewah?

The programme of the design is not only limited to housing, since there is a demand to recycle and re-use stone waste material. It is not known yet what this extra programme could be. Furthermore, there are different ways to reduce, re-use and recycle stone waste within the architectural design. This together with the programme have to be investigated within this research.

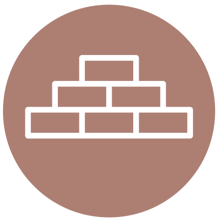
The main **research question** is as follows:

What are design solutions to reduce, re-use and recycle stone construction and demolition waste that can be implemented on the scale of informally constructed neighbourhoods in Indonesia?

The question demands a deep understanding of the informally constructed neighbourhoods, in order to understand these neighbourhoods better and to be able to test the design solutions. The solution to the problem is to analyse the site of the design within the city of Bandung. Therefore, the paper is structured in two parts. In part I is the site analysis that illustrate the literature on the conditions of the building industry and the built environment within informally constructed neighbourhoods. As a conclusion to this site analysis is the establishment of the material flow analysis (MFA) of stone building materials of this particular area. Part II entail the potential of the implementation of case studies that reduce, re-use or recycling of stone C&D waste within these Indonesian neighourhoods.

The different nature of research for the two parts demand a different approach of research. The approach to the research paper as a whole and these different parts is further elaborated in the methodology. The connection with the design assignment of the architecture project demands that after conclusions are reached at the end that a quick overview is given of the design considerations regarding the development of a new housing typology within the informally constructed neighbourhoods.

50 Million extra
houses in Indonesia



98% of the houses in
Bandung are built with
concrete or brick

49 Million ton stone
C&D waste in
Bandung in 8 years

49 Million ton HHW
waste in
Bandung in 8 years

Methodology

The research, as noted earlier, contains two parts, an analysis of the neighbourhood and a comparative analysis of different case studies as can be seen in figure 1. Figure 1 represents an overview how this research is structured and how different elements of the research influence the design process.

Part I Site analysis

The goal of the analytical research of the site is to establish several problems and strengths within the particular area. These local problems and strengths serve as input for the criteria the design need to address. The analysis of the area will address the current social situation, building culture and waste management, in order to find these problems and strengths. Furthermore, a material flow analysis (MFA) of the current situation will illustrate the balance of stone building materials and waste.

The method of research concerning the analysis of the area is a combination of literature, data, interviews and observations during a week long field research in Cigondewah. The literature consists out of research done on Bandung specifically or Indonesia in general. The data concerns the city of Bandung or the particular area as well. The interviews were conducted at the same time of the field research. Local builders and home owners were questioned on the topics of waste management, construction methods and processes. Consultations with students and lecturers of the Institut Technologi Bandung (University of Technology Bandung) were used as well.

The material flow analysis is constructed on the base of the analysis of the area. The data collected from literature and the Bandung Statistics Bureau (BPS) serve as main input for the analysis. The material flow analysis allows for a greater understanding of material use in various stages of the construction and waste processes. Furthermore, the MFA will be used as a tool to test the design on the established criteria.

Part II Case study analysis

The goal of the comparison of different design solutions is to assess the potential of the implementation of different existing solutions to balance building material and waste. Criteria to make these case studies comparable are based on the problems the design needs to solve found in part I. This allows for a quick evaluation of what solutions would work within this particular context and allows for a more in depth development within the design process.

First an overview of three design strategies is given. Within these three design strategies are different example solutions to illustrate different approaches of these strategies. These example solutions are chosen based on the boundary conditions established in part I. These examples need to be projects that have been realised and tested already in order to qualify for this analysis. The sources for these examples consists mostly out of literary works, which are in some cases further elaborated with information from lectures at the TU Delft.

The criteria used to assess these examples are similar to the criteria of the final design itself. To test these criteria the MFA is used to quantify how well the different examples perform on the criteria.

Design considerations

The design considerations list the criteria and local opportunities which have to be considered within the design. These criteria deal with the programme and materialisation of the design. Furthermore, a first step will be made on the decision of implementation of exisisting solutions to further investigate and which solutions to disregard as they are not applicable to the area. These findings will further inform the design on programme and materialisation.

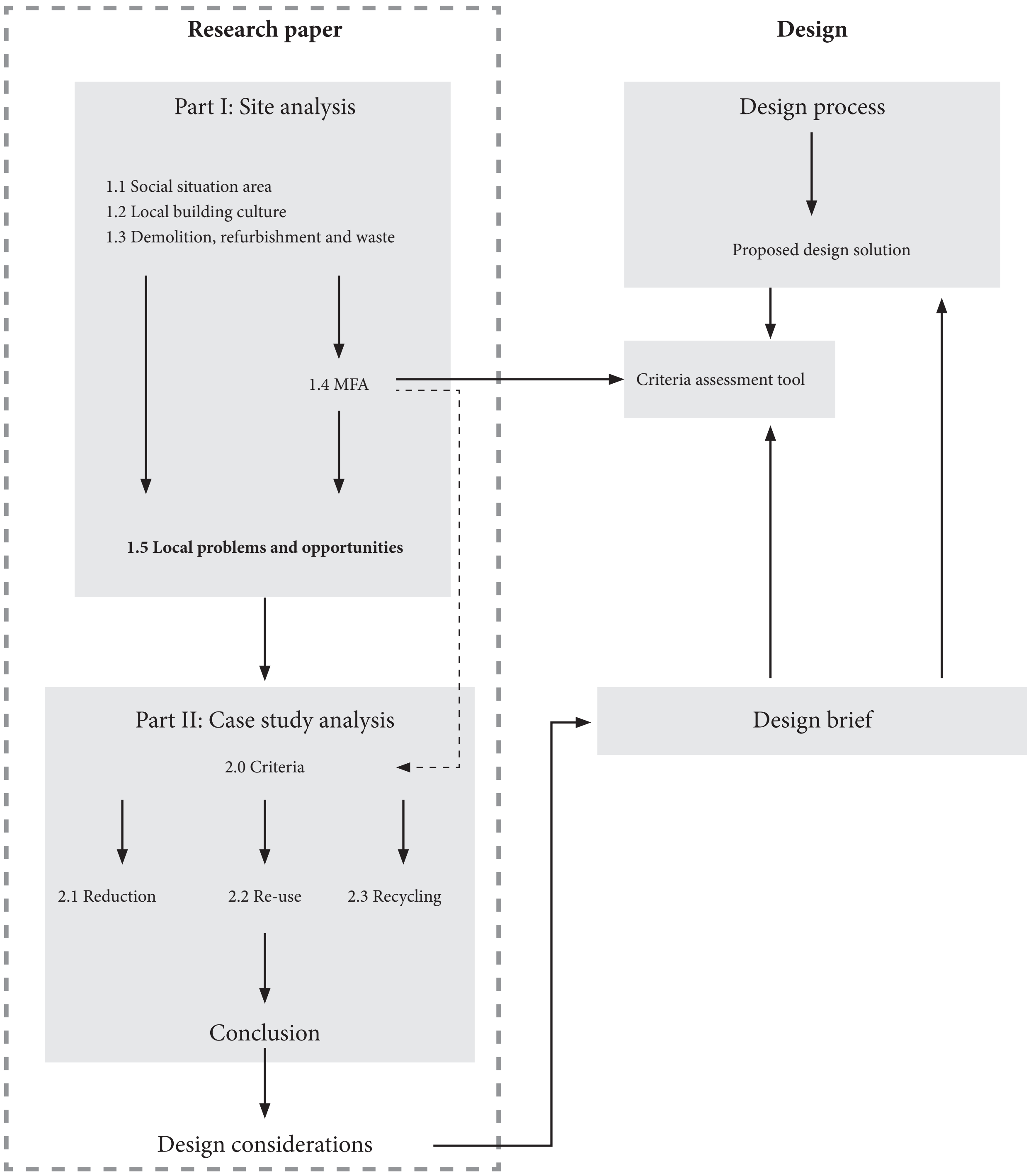


Figure 1: Diagram of relations between different aspects of the research paper and their influence on the design process. Source: own image.

Part I: Site Analysis

The main outline of this chapter is as follows. First an introduction of the site is given. Of particular interest are the demographics of this kampung and its situation within Bandung . Second follows a description of the organisation of construction activities within the area. Actors and the organisation of funds, resources and knowledge are key elements within this overview. Thirdly, an overview is given of refurbishment, demolition and waste management within the site. Complementary to these last two points, the extraction and manufacturing of stone building materials and processing of C&D waste outside of the area will be addressed. This will put the data of the kampung in perspective. Lastly, the constructed flow diagram shows how the building industry within the area functions. From these data, the problems and opportunities within the existing building industry will be extrapolated.

1.1 Cigondewah

Once planned as a garden city, Bandung is currently the mecca of the Indonesian textile and fashion industry. The city of approximately 2,4 million inhabitants lies a three hour drive south-west of Jakarta. The investigated area is part of Cigondewah Kaler a kecematan (district) of Bandung and has a central role within the city's textile industry. The particular area is called a kampung. Which according to Ford (Ford, 1993) is defined as "a mostly unplanned, primarily low-income residential area that has gradually been built and serviced". This particular area has to be categorised as a peri-urban industrial kampung since the definition of kampung can apply to a multitude of areas with different topographical and socio-economic conditions.

Two administrative districts of the kecamatan Cigondewah Kaler make up the area of intervention: rukun warga (RW) 02 and rukun warga 12. These two RWs are located on the border of the city of Bandung and the city of Cimahi. The textile and garment industry have a prominent position within this particular area. These factories have a large influence on the kampung, not only as the main employer but also as the main polluter, main landlord and provider of material for the local textile industry within the RWs (Smit, Loen, Toledo, Yanindraputri, & Ingen-Housz, 2016).

The demographics show the influence of the textile and garment industry on the kampung. Around 3.100 people live within these two RWs out of which 1.500 migrant workers, who work in the different textile and garment factories bordering the kampung (Guratman, 2016; Smit et al., 2016). Based on the population growth rate of Bandung it is estimated that in 2030 the total population of Cigondewah Kaler could be 5.000 people. This would mean that the population density would rise from 25.900 inhabitants per km2 to 42.000 inhabitants per km2. In comparison the average density of the city of Bandung is currently 18.000 inhabitants per km2.

	Bandung (2016)	RWs (2016)	RWs (2030)
Total population	2,3 million	3100	5000
Migrant workers	-	1500	2500
Density [p/km^2]	18.000	29.500	42.000

The textile industry not only influences the demographics but also the housing typologies within the kampung. Housing for the migrant workers make up around 40 to 50 percent of the current housing stock (Smit et al., 2016). This means that migrant housing is prominent within RW 02 and 12. Many of the migrants live in small compounds either owned by the factories or the local families of the kampung. This housing provides an extra income for the local populace. The houses of local families are mostly owned by the families themselves and differ in typology based on the main income of the household. Some of these houses have a garment workshop or shop attached to it.

The built area of the two RWs consists out of family houses, migrant housing, mosques and factories. Open areas of these two RWs can be classified into three different types: agricultural, communal and fallow areas. The agricultural areas are mostly rice paddies owned by the factories and are used for food production and waste dumping by both locals (HHW) and the factory (textile waste). Communal areas compromise several cemeteries, a badminton square and a football field. These communal areas are multi functional since they serve as spaces where locals sort waste and as general gathering areas as well. The fallow spaces are the areas that are not properly defined by their function. These areas function as a sorting space, temporary agriculture or spaces where the locals dry their laundry.

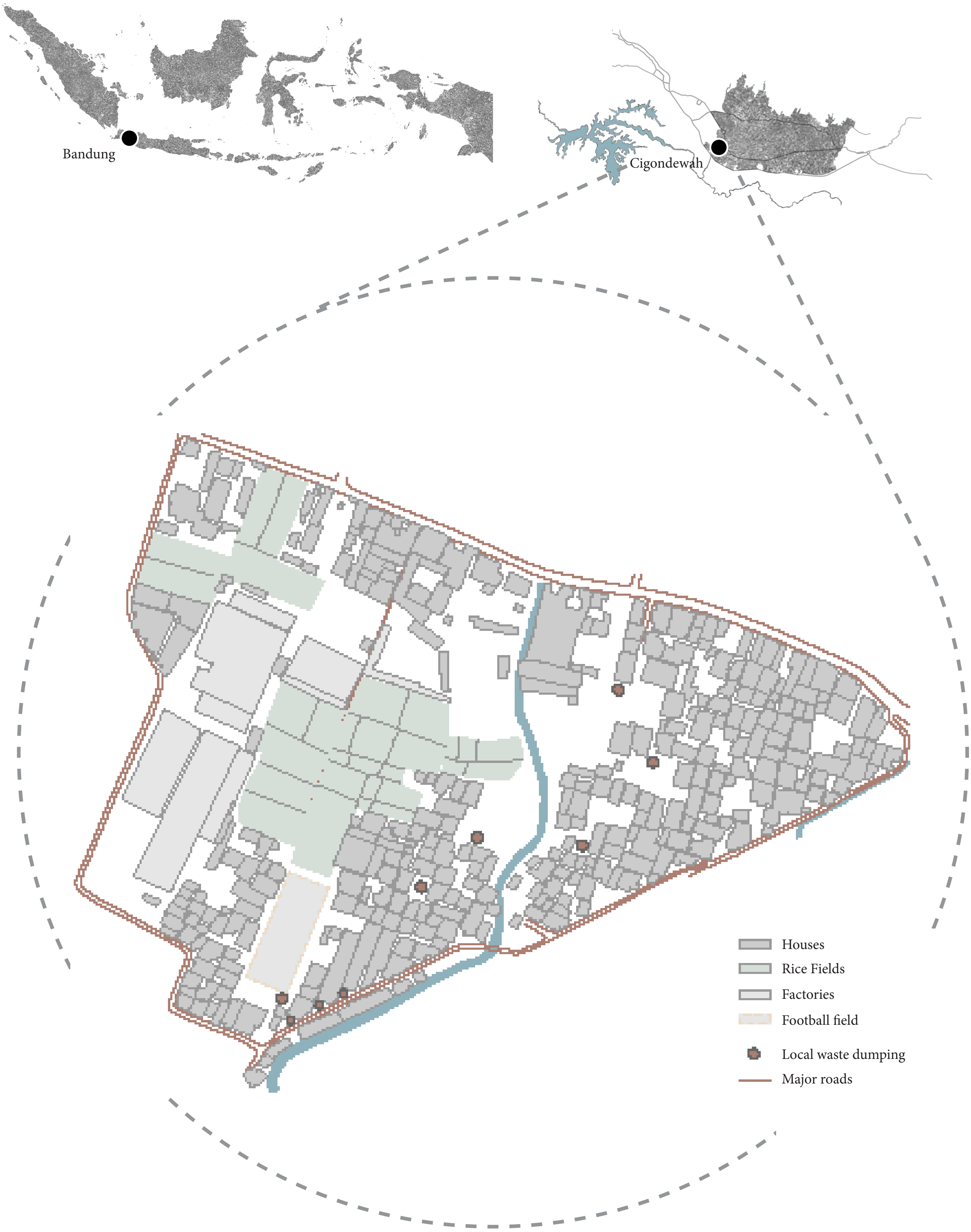


Figure 2: Map of RW 02 and 12 with the various different areas shown. Source: own image

1.2 The local building industry

The local building industry in RW 02 and RW 12 is, like the Indonesian building industry in general, characterised by a large amount of informality (Sannen, 1986). In contrast to the western building industry, the Indonesian building industry is organised on a local scale and consists largely out of a temporary workforce. This is no different in RW 02 and RW 12. During the field research and interviews with the local builders it became clear that there is different way of organisation between private and communal building activities. To illustrate this difference one private shop house and one community building found in RW 02 and 12 have been chosen.

The private building is a shop house found at the edge of the football field in the center of the kampung. This house has been extended over time and is owned by one of the more wealthy households within RW02. The organisation of this building's construction is an example to the construction process of almost all the houses within the kampung. The community building is located in the middle of the kampung and was during the site visit under construction. This communal building houses a religious school for the local children and can serve as a space to get together as a community. This building differs from the private houses in the kampung in ways of organisation, allocation of fund and materiality.

Procurement and organisation of private house construction

Incremental construction is the most common form to build private buildings within the kampungs in Indonesia, this is no different in the observed area (Devisari Tunas & Peresthu, 2010). Another characteristic of these incrementally constructed houses is that they are self-built and owned by the kampung families. This is in line with statistics from the city of Bandung, where around 60 percent of the houses are privately owned (BPS Kota Bandung, 2016). Which in the case of RW 02 and 12 is higher based on the field research. The private house observed as a case study within this research is self-built and incrementally constructed over the years.

The construction of self-built houses is mainly driven by the owner of the building himself, which is the case of the shop house. The owner

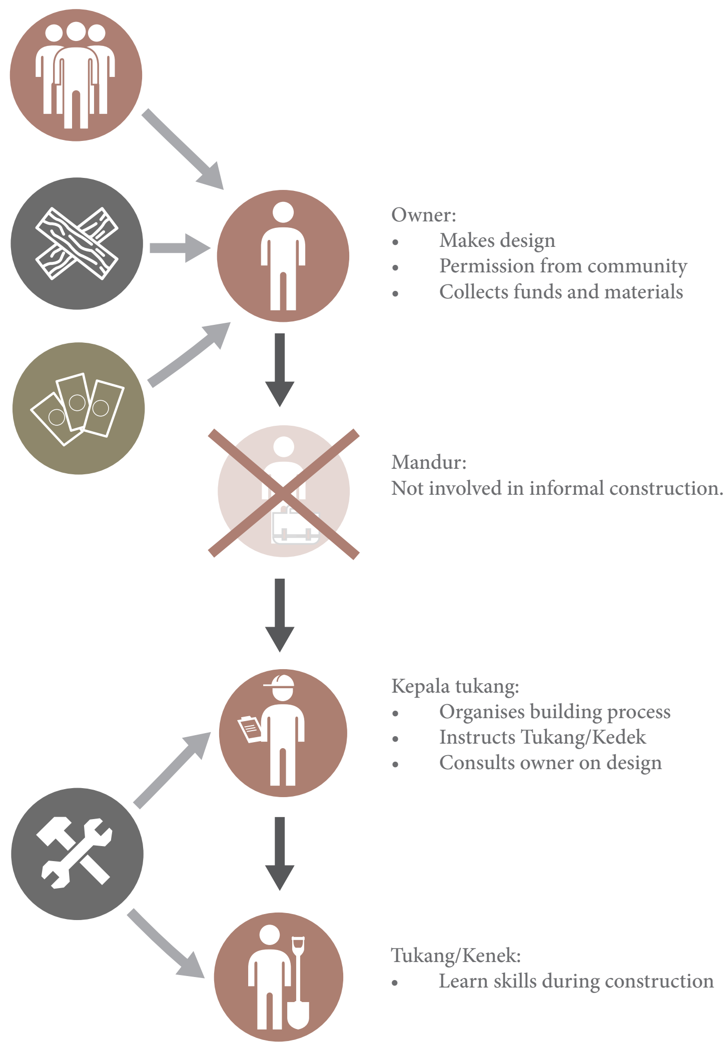


Figure 3: Organisation of private house construction RWs. Source: own image.

is responsible for the allocation of the funds, the proposed design and the organisation of the work force. The design has to be approved by the community in order to be built, since the design may not be too offensive or extravagant. The wealth of the owner is a crucial factor in how much of the design and construction process he is involved in. If local builders are hired, they are chosen based on their skill and connections to the owner's family. The allocation of material and the design of the building is primarily done by the family themselves.

The organisation of local builders within RW 02 and 12 is largely informal and lack therefore a central building firm for which they work. The builders involved in building projects are either local tradesmen, called tukang, or the owners of the building itself. Therefore, a formal contractor, also known as mandur, is not hired, since the mandur are mostly involved in governmental and large private projects (Sannen, 1986).

The local builders can be specified in several skill based categories: the chief skilled worker (Kepala Tukang), the highly skilled worker (Tukang Ahli), the regular skilled worker (Tukang), the semi-skilled worker (Setengah Tukang) and the unskilled workers (Laden or Kenek) (Sannen, 1986). The kepala tukang leads and guides the lower skilled construction labour if a mandur is absent. The tukang, setengah tukang and laden are often involved in multiple trades. Based on their skill they are involved in different parts of the project. The labourers learn their skills while working with more experienced workers on different construction projects. Furthermore, the new builders try to innovate by looking at existing examples on the internet or by observing examples in and around the city. In figure x is an example of innovation with left over plywood material shown.

The allocation of funds for private building projects is largely dependent on the owner itself. Loans are rarely taken when constructing or extending a house in Indonesia (Ellis & Trohanis, 2011). Therefore, the availability of construction funds allowed by the monthly income of a family is an important factor to consider. Shown in table x is the average spending of households of Bandung spend on their house, either by rent, lease or

Figure 4: The shophouse on the soccer field, the plastering and painting shows that the owner is rich. source: own image

Figure 5: The exterior and interior of the community building with the local builders. Source: own images (above) and Chen B. (right)

maintenance. Whenever the family collects enough money, they are able to extend or build their house. This results in an incremental building culture (Devisari Tunas & Peresthu, 2010). When enough funds have been collected by the family they will consider enlarging or building a house, shop or other building. Material price is an important factor considered when deciding what quality and amount of material that will be used in the construction. Often cited by local owners is that they choose the cheapest brick due to the perceived high quality of the brick and the lack of funds to buy more high quality brick.

Shop house

The shop house observed as a case study within this research is self-built and incrementally constructed over the years. The house is a combination of a small convenience store run by the family of the owner and a weekend home for the owner and his family. The owner of the building was considerably wealthy and could, therefore afford to pay local builders to help the family with the construction. The design and allocation of resources was done by the owner himself. As a result he was the main driving force of the construction of the house. Whenever he had the funds he is able to extend his house.

Community building

The design and construction of the community building is organised in a different way from the shop house. Elders from the kampung specify the necessity for a community building. The people within the community can contribute to the project in several ways. If they are able to contribute, they can contribute the land on which it is build, building materials, funds or they participate in the building process. However, participation in the building and design process is dependent on the skill of the builder. The local builders involved in the community building are the same builders involved in private projects. More expert builders make the design, asses the incoming material and where the material can be used. Furthermore, they take the lead during the construction of the building and instruct the junior builders on what to do and how to do it.

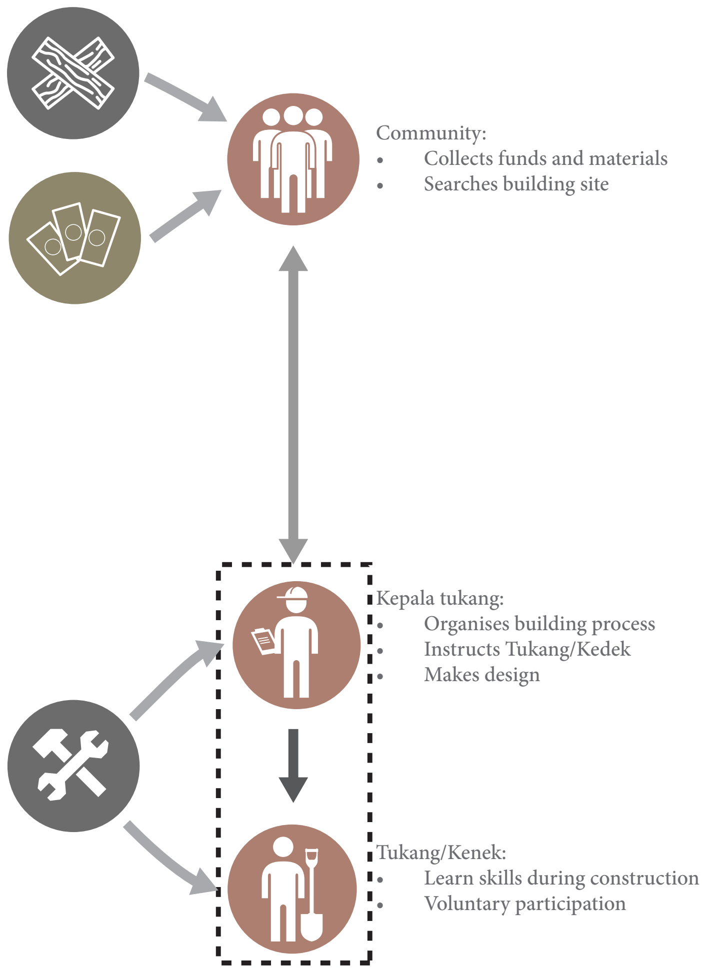


Figure 6: Organisation of community building construction RWs.
Source: own image

Ways of construction

The most common building method used in the kampung is the so called "new" Indonesian construction method (Boen, 2001). This method is the combination of single half brick masonry walls with a (reinforced) concrete column and beam structure. Reinforcement within the concrete is dependent on the funds available for the building project. The roofs are mostly covered with clay rooftiles, although zinc or asbestos corrugated roofplates are found as well. The prominent use of brick and concrete within the kampung can be traced back to a post 1970's movement in Indonesia where brick and concrete are seen as modern, prestigious and structurally safe materials (UNEP, 2008). Furthermore, the half brick thick masonry wall proved to be cheaper than a one brick masonry found in colonial Dutch architecture, due to the high prices for bricks. The use of reinforcement within the concrete columns is highly dependent on the funds.

The way the "new" construction method is done is shown in figure 7 and follows the following steps:

1. A foundation is layed with found stone material: either river stones or salvaged materials.

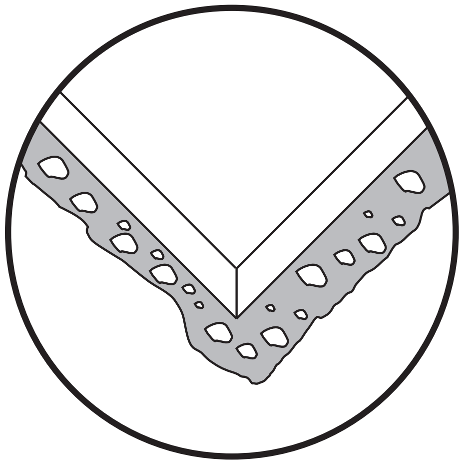
2. A concrete base floor is cast on top of the foundation.

3. Casting for concrete is put on top of the foundation and held into place (with reinforcement). Concrete is poured in to form the column framework of the building.

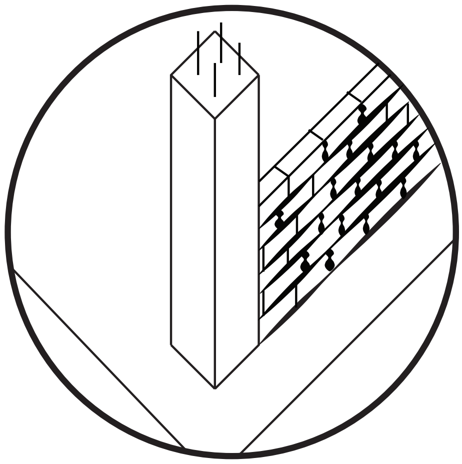
4. In between the columns a half brick wall is laid. Mortar is used generously to cover up height inconsistencies within one layer of brick work. Old and broken bricks are used to fill in gaps.

5. If needed reinforced concrete beams are made on top of the masonry wall. Sometime this is done by pouring the beam directly onto the brick wall.

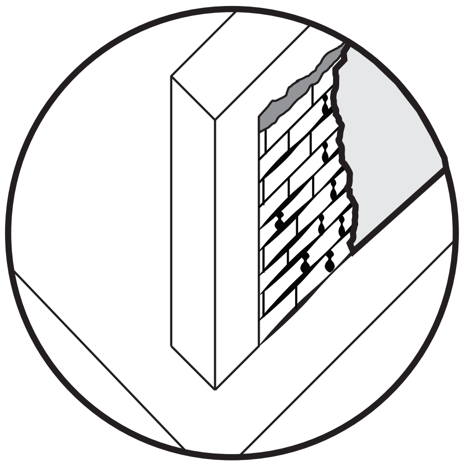
6. If applicable floors are either made from cast concrete on top of the concrete beams or wooden planks.



1 & 2: The concrete floor directly cast onto the stone foundation



3 & 4: The half brick masonry is used as infill between the concrete frame.



5 & 9: Any construction mistakes are filled with mortar and covered with plaster.

Figure 7: Overview of the construction process for the "new" construction method. Source: own image

7. The roof is constructed often with wooden beams and follows traditional ways to construct the roof.

8. Any gaps left between the roof and the rest of the construction is filled up with brickwork.

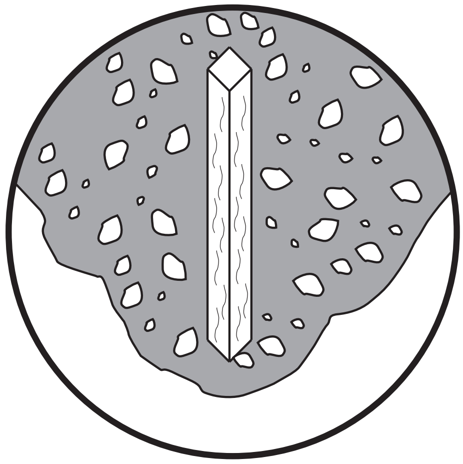
9. The brickwork is covered with a layer of mortar, then a layer of lime plaster and at last a layer of paint. Depending on the availability of funds one or more of these layers are not applied.

The building method of the community building is different from the "new" Indonesian construction method, due to the difference in availability of materials. Bamboo is the most common material used in this building construction, due to the low costs of the material. Therefore, it is the most collected material from the community. The way it is constructed follows mostly how small shacks within the area are constructed, with wooden columns and beams and woven bamboo panels used as infill. The floors are made out of re-purposed wood. The roof is a combination of clay roof tiles in the front and corrugated asbestos sheets in the back. Reason for this is the use of a 'prominent' material like clay roof tiles are used on visible locations of the construction.

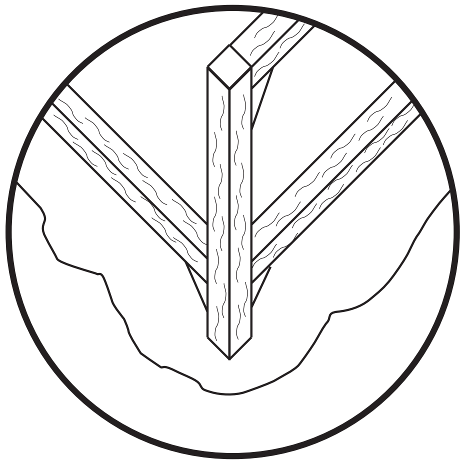
The building was not finished during the field research, this means in that the final use of materials of this building cannot properly assessed. One striking thing that the local builders were working on however, was to embed the bamboo columns in front of the entrance with a layer of brick.

Resulting quality of construction

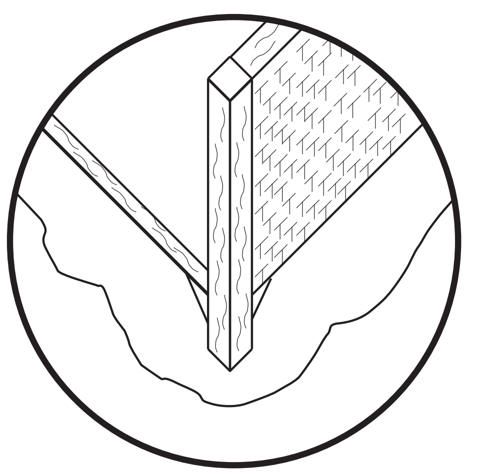
The so called "new" construction method performs from structural point of view in different ways. Earthquakes in Indonesia and Bandung occur often and are a major cause of structural collapse of "new" construction method buildings (Boen, 2001). Causes for the structural failure lie not in the construction method itself but in the poor quality of materials and the poor quality of workmanship. Both can be tied to poverty, with a lack of proper funds for construction and a lack of knowledge of the local builders (Pribadi, Kusumastuti, & Rildova, 2008).



The wooden frame is put directly into the stone foundation.



Construction of the wooden frame.



Application of the woven bamboo panel on the frame.

Figure 8: Overview of the construction process for the community building. Source: own image

The structural quality of traditional vernacular architecture performs often better than this "new" construction method, due to centuries of development of the construction method. The community building reviewed within this research could be classified under traditional vernacular architecture.

Origin of the materials

Building materials are most often bought at local material suppliers. They often have the most used building materials in stock, like brick, construction wood and cement. In table 1 different prices for building materials are shown. Note in particular the low price for bamboo and the difference in exposed and non exposed bricks. The extraction, production and selling of materials happen outside of RW 02 and 12. The extraction and production locations of brick and concrete are found outside of the city of Bandung in rural areas, due to the space needed for these activities. The extraction process of the raw materials often happens in illegal quarries and mines as can be seen in figure 9.

Recycled materials are sometimes used as a cheaper alternative to new materials. It is known that in the formal construction industry stone aggregate is used as such in concrete or as foundation (UNEP, 2008). During the field research several places where found where used bricks where separated from the rest of the building waste. Furthermore, in several brick walls, the use of recycled brick can be traced.

Figure 9: One of the possibly illegal quarries in the rural area near Bandung. The kampung on the top is at at the edge of the quarry. Source: own image.

	unit	cost (Rupiah - IDR)
Stone:		
Gravel	1 m^3	300.000
Cement	1 kg	1.400
Hollow cement blocks	1 m^3	730.000
Red brick (unexposed)	1 piece	350
Red brick (exposed)	1 piece	1.100
Sand:		
River sand	1 m^3	350.000
Black sand	1 m^3	300.000
White sand	1 m^3	350.000
Timber:		
Bamboo - treated	6 m	60.000
Bamboo - untreated	6 m	5.000-12.000
Wood - Teak	1 m^3	15.000.000
Wood - Recycled	1 m^3	2.000.000
Metal:		
Zinc sheet corrugated	1 piece	40.000
Steel Rebar - Size A (ø 6mm)	12 m	24.000
Terracotta:		
Roof Tiles	1 piece	4.000
Internal		
Dry wall (120cm x 240cm)	1 piece	4.000

Table 1: Material prices in the local building material shop. Source: (Remmerswald, 2014; Rossen, 2016; www.hargamaterial.xyz, 2016)

1.3 Refurbishment, demolition and waste management

The act of demolition was not observed during the field research. However, the observed enlargement and refurbishment of houses often contains demolition activity. Refurbishment or enlargement of houses is a common activity within the incrementally growing kampung. Furthermore, it was observed that there were several derelict buildings which had probably collapsed over time, due to insufficient construction quality, insufficient maintenance of the structure or earthquakes. Following is a step by step overview is given on the process of transformation from building material to waste.

Demolition and refurbishment

Demolition activities within Indonesia are often organised with a specific tukang that is familiar with demolition and construction (D. Tunas, 2012). This specialist investigates the parts of the building that need to be demolished and makes a list of salvageable materials. These salvageable materials are often materials that can be sold directly without requiring further processing, for example doors, metal and glass. Notable is that the most valued material is wood, due to the high demand of rare tropical woods.

During the demolition activity, the desired recyclable materials are carefully demounted and the rest broken down with simple hand tools. Both salvaged material and rest material are collected on a nearby available plot of land, the fallow spaces within the kampung. The salvaged materials either remain in possession of the building owner or are sold to special C&D waste scavengers. The left over material is broken into the smallest possible pieces and is either dumped on unofficial waste collection spaces in the kampung or remains on the fallow space.

Local waste management

The local waste management of C&D waste is comparable to the waste management system of household waste as described in the research of K. Rossen and H. Versnel (Rossen, 2016; Versnel, 1986). Scavengers are organised in various layers. There is a 'mobile' scavenger that collects and transports waste within the kampung and is payed by the community. They collect the waste and make sure the waste is transported to landfills outside the area. Recyclable materials are sorted out of the collected waste. The dump site scavenger, scavenges on local dumping sites for sell-able waste materials.

The scavengers sell the found recyclable C&D waste to a middle man specialised in one or several types of material. These middle men are not located within the kampung itself. They resell materials that can be used without any further processing to contractors or house owners in need of building material. The materials that need further processing, like metal, are sold to either factories or workshops.

The C&D waste that is not suitable for further trading ends up on local dumping sites or local waste collection points. From the local collection points, the material is collected by the so called government scavengers who transport the materials to landfills in neighbouring areas.

Local dumping

The local dumping sites are located on fallow spaces around the kampung. On these spaces not only construction and demolition waste gets dumped but also household and/or industrial waste. The different types of waste occurs become mixed on these locations. It is assumed that most of the stone construction and demolition waste remains on the dumping locations throughout the kampung, due to high costs of collection and low selling prices for this waste.

Drawbacks from the local dumping of C&D waste are rooted in the fact that the relative volume of this waste stream is considerably large. This means that when it remains within the kampung, the local dumping sites growexponentially. As a result the fallow grounds grow in height in relation to the existing housing, with flooding problems as a result. Furthermore, both the groundwater and river water become more polluted due to leakage from the dumping locations during rainy periods and the high concentration of Ca^{2+}, Mg^{2+} and SiO_2 in stone C&D waste (Mor, Ravindra, Dahiya, & Chandra, 2006). High concentrations of Ca^{2+}, Mg^{2+} and SiO_2 in the drinking water lead to high hardness of the drinking water and medical conditions like kidney stones.

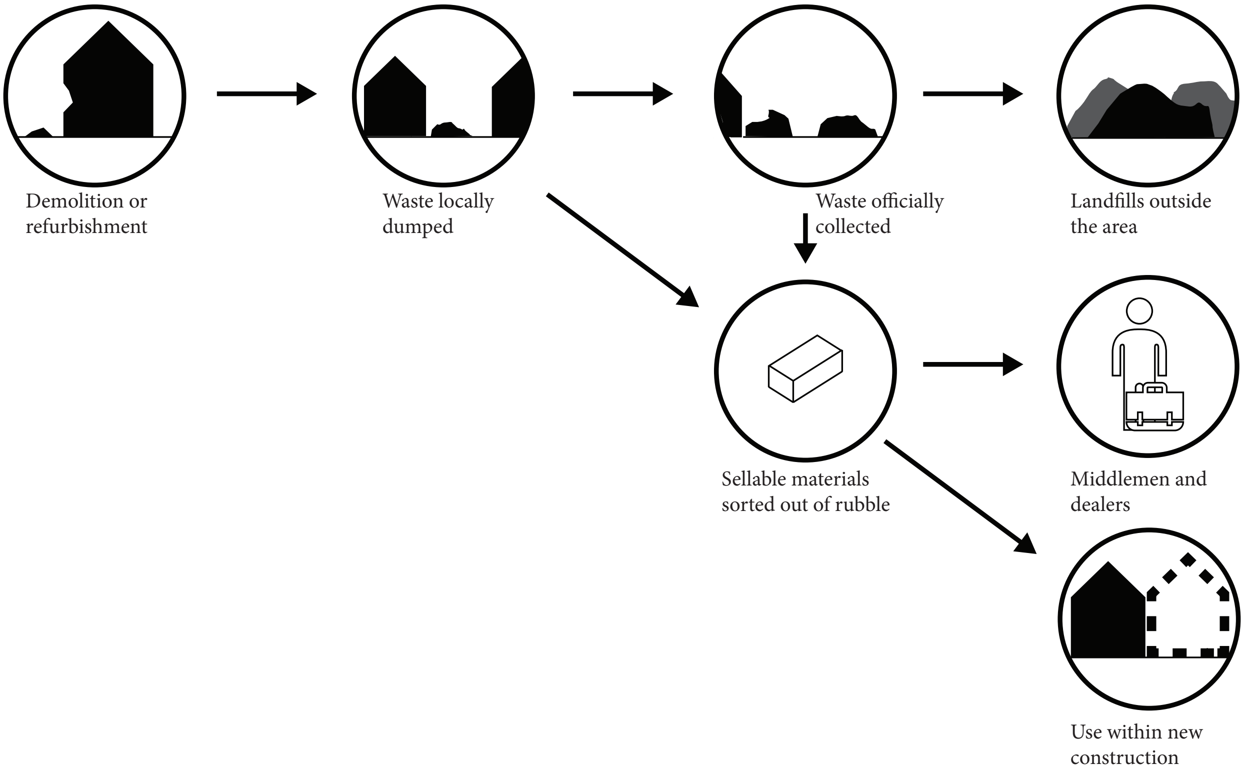


Figure 10: The scheme of stone waste material management within the kampung. Source: own image.

Figure 11: Fallow space with a collapsed building and waste collection Source: own image.

Figure 12: Debris and rubble sorted from the re-usable salvaged bricks. Source: own image

1.4 The material flow diagram of the building industry

In figure 15 the material flow of the main stone material flows and money flows within the researched site per year is given. These are related to construction and demolition. The main stone material flows are based on the building method described earlier: brick, mortar and concrete. The money flow is based on the spending on construction labour and materials of the entirety of the kampung, which is compared with what the whole community earns in a year. The different stages within the material flow diagram are determined by the research done in the previous chapter.

The material flow analysis (MFA) is largely based on the material flow analysis done on the entirety of the informal housing stock of Jakarta and Bandung (Surahman et al., 2015). From several measurements of homes in Bandung they determined per material the input volume in kilogram per square meter floor area between 2012 and 2020. The data was subdivided in three house types: “Simple”, “Medium” and “Luxurious” based on construction quality and size. Based on the floor measurements done in the research it was possible to combine the research data with a site survey of RW 02 and 12. This made it possible to estimate the total in and output (construction and demolition) of the different stone materials within RW 02 and 12. Further input was needed on the amount of houses constructed within a year.

The construction of new houses is based on the growth of households within the area per year(Smit et al., 2016), which lies around 21 new households. Roughly half of those households will consist out of migrant households. They will account for roughly half of the new houses needed. Therefore, it is estimated that around 7 “Simple”, 6 “Medium” and 4 “Luxurious” houses are built in a year within the kampung.

Numbers on management of stone C&D waste are unknown. However, it is estimated that around 60% of the total waste end up on official landfills outside of the kampung (Damanhuri, 2005). Furthermore, based on observations during the field research, it is estimated that around 10% of clay bricks and 60% of roof tiles is re-used in construction.

The costs concerning construction of the houses in a year are split between labour and material costs. Material costs are calculated based on the prices by local material suppliers multiplied by the volume of material needed in a year. Labour costs are calculated based on the costs of bricklayers per day (portalbangunan.com, 2016). Based on the interviews and field research it is assumed that team consisting out of 1 Kepala Tukang, 1 Tukang and 3 Tukang Setengah/Kenek is needed for the construction of a house. They work 55 working days on a house of 110 m2.

Figure 13: MFA assumptions. Source: own image

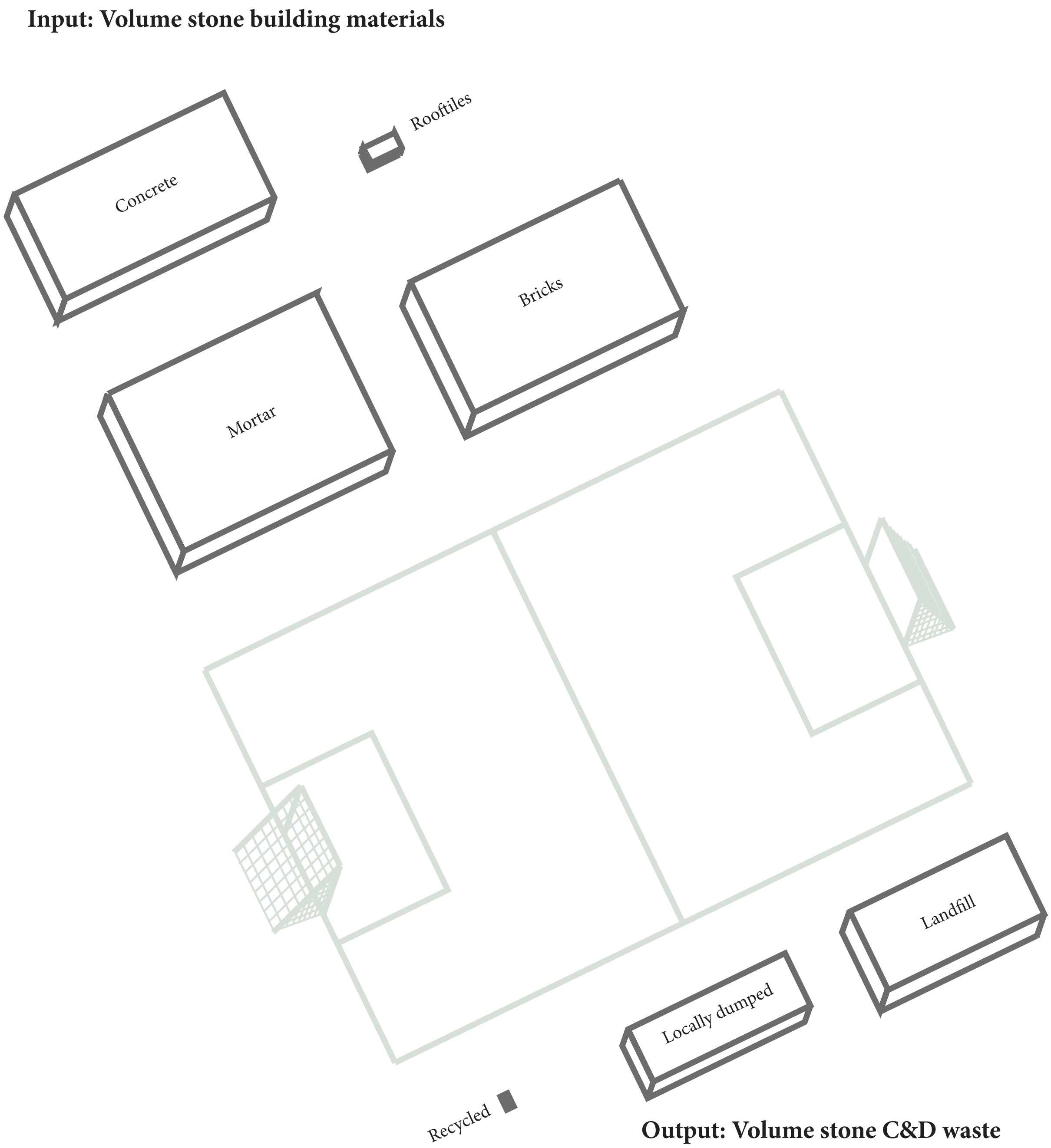


Figure 14: Volumes of building material and waste material compared to an officially size football field. Source: own image.

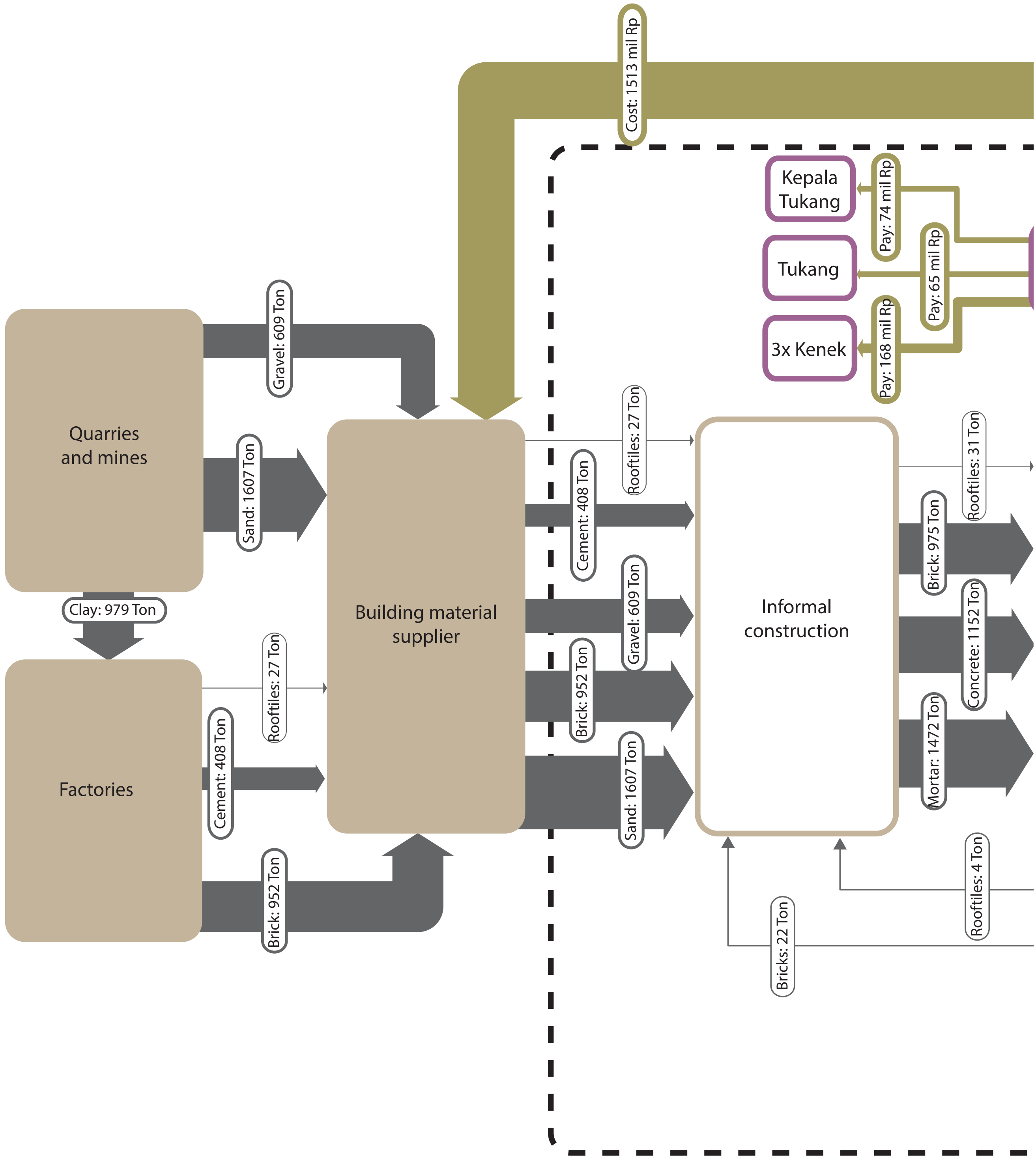
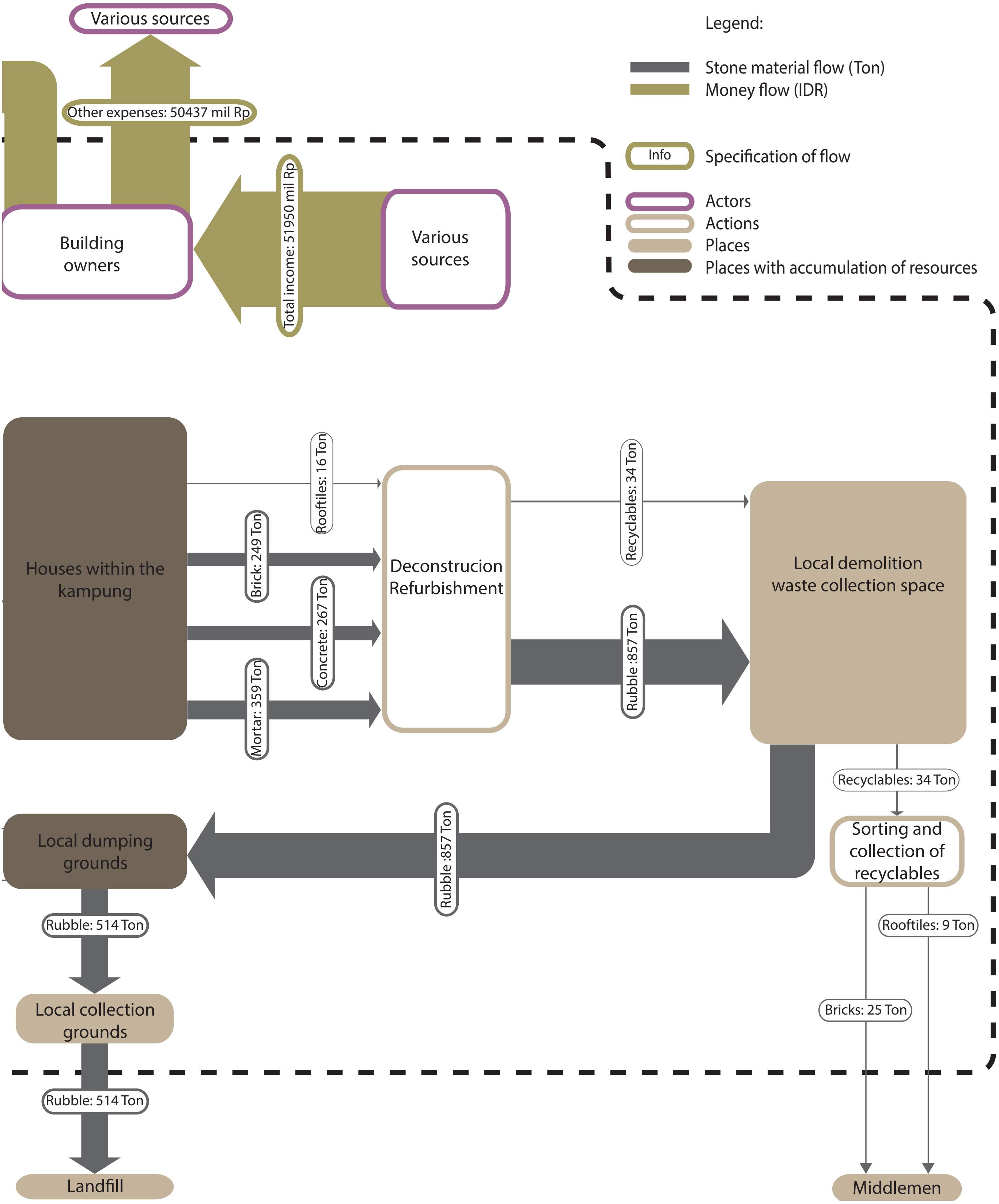


Figure 15: The material flow analysis associated with the material flow of brick, clay rooftiles, mortar and concrete within the construction of houses in RW 02 and 12 per year. Further showing the money flow associated with the construction of the houses. (Full page MFA can be found in the Appendix. Source: own image.


Various sources
Other expenses: 50437 mil Rp
Building owners
Total income: 51950 mil Rp
Various sources
Legend:
Stone material flow (Ton)
Money flow (IDR)
Info
Specification of flow
Actors
Actions
Places
Places with accumulation of resources
Houses within the kampung
Rooftiles: 16 Ton
Brick: 249 Ton
Concrete: 267 Ton
Mortar: 359 Ton
Deconstrucion Refurbishment
Recyclables: 34 Ton
Rubble :857 Ton
Local demolition waste collection space
Recyclables: 34 Ton
Sorting and collection of recyclables
Local dumping grounds
Rubble :857 Ton
Rubble: 514 Ton
Local collection grounds
Rubble: 514 Ton
Landfill
Rooftiles: 9 Ton
Bricks: 25 Ton
Middlemen

1.5 Local problems and opportunities

From the site analysis the following problems have to be addressed by the design:

1. The demand for housing continues to grow in the coming years. In an already densely populated kampung means that more and more houses are extended vertically. Which will result in more structural failures within the built houses, due to the poor execution of the construction method. Main reasons for the poor execution of the construction method are:

2. A lack of funds for quality building materials. New building materials for maintenance, construction and refurbishment are expensive for the inhabitants.

3. A lack of knowledge and skill related to the application of the building materials into the preferred building method, due to complicated procedures like casting concrete and proper laying of bricks.

4. The demand in housing also results in a rising demand of stone building materials within the kampung, due to the preferred building method within the kampung. This leads to rising material costs for the inhabitants of the kampung and to a greater environmental impact in the rural areas around Bandung.

5. The amount of stone C&D waste is projected to grow within the next years within the kampung. Around 40% of the volume of waste will end up on several locations within the kampung itself. This results into local health issues for the inhabitants of the kampung.

The following opportunities related to the design have been found:

1. The organisation of the construction related to the community building shows a strong community capable of starting building projects on their own without involvement of the city or state government.

2. Creative use of waste materials in building construction show a possibility of introducing new ways to re-use and recycling of waste within construction of houses.

Figure 16: The pains and opportunities within the kampung. Source: own image.

Figure 17: Typical example of the “new” construction method during construction. source: own image.

Part II: Case study analysis

The case studies discussed within this chapter will be assessed based on criteria formed from the problems found in part I. The case studies are examples already in use in different parts of the world. They are chosen based on a Dutch waste management principle the "Ladder van Lansink". This principle poses a hierarchy when dealing with waste material. The three applicable options for the neighbourhood are:

1. The reduction of material use within the design.

2. The re-use of material within the design.

3. The recycling of material on a local scale within the design

The main distinction between the re-use and recycling of waste material lies in the processing of the waste. For the re-use of waste there is not a processing of the material needed in a factory to use the material in a new building. There is no change in dimensions or characteristics of the waste material from salvage to construction, which is the case with recycling material.

The case studies are a prime example of different approaches to reduction, re-use and recycling stone waste. Furthermore the resulting or used stone building material can be characterised as building elements like brick. Reason for this is the lack of building skill of the local Indonesian builders, therefore simple (stackable) building elements are chosen for further research.

The case studies are assumed to be implemented directly in the construction of houses and the stone C&D waste management within RW 02 and 12, in order to test their effectiveness to resolve the current problems.

Criteria

The following criteria are used to make the case studies comparable:

1. The performance of the case study to reduce the locally dumped stone C&D waste. The reduction of locally dumped waste increases the health situation within the kampung. This will be assessed through the MFA and expressed in a ratio of the volume locally dumped in the new situation versus the old situation.

2. The performance of the case study on recycling/re-using waste in the local construction of houses. The recycling/re-use ratio shows how effective the solution is to reduce the input of new stone building material in the construction of new houses. This will be assessed through the MFA and expressed in a ratio volume material recycled compared to new material input.

3. The space needed for extra programme needed to implement the case study, since land and space is limited within the kampung

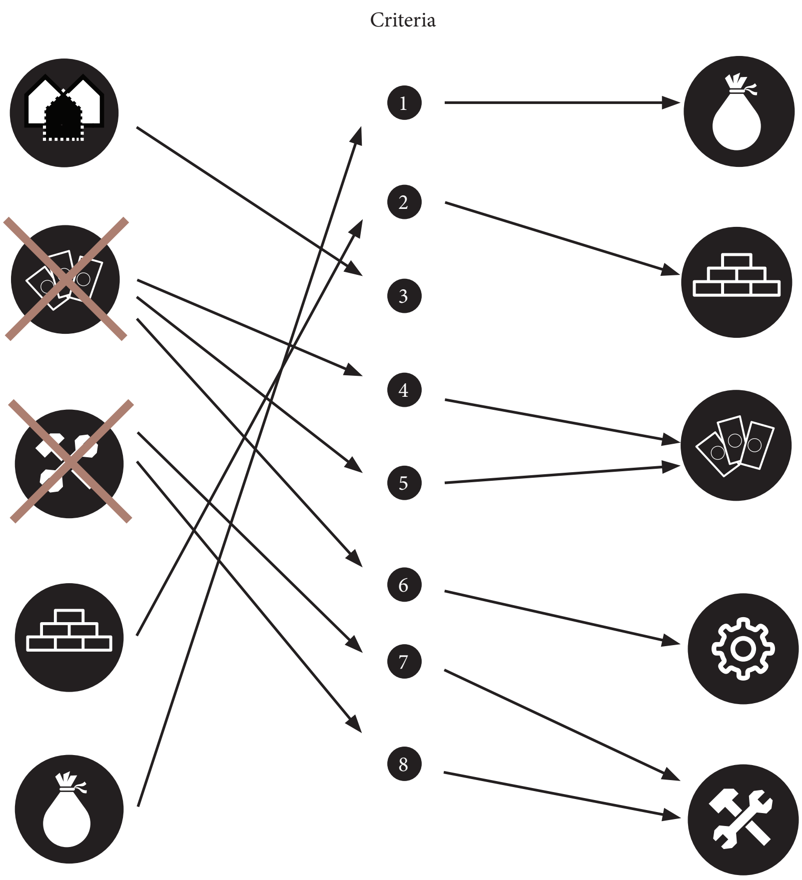
4. The change of the total stone building material costs of the case study versus the new situation, since funds are limited within the local community. The MFA is used to calculate these costs.

5. The costs of new non-stone building materials needed within the case study.

6. The tool and machinery costs needed for implementation of the case study, since funds are limited within the local community.

7. The ease of learning the new building method, since the local builders lack knowledge on other building methods.

8. The ease of learning new tools and machinery, since locals only know the tools and machinery they know.



1	Local dumped waste rate	[%]	Amount of material dumped locally compared to base situation.				
2	Recycle/Re-use rate	[%]	Amount of local recycled material compared to base situation.				
3	Land use	[m2]	Estimated amount of m2 extra space needed for tools, machinery and logistics.				
4	Material cost increase or decrease	[mil IDR]	Amount of material expenses minus material costs base situation.				
	Scale		1	2	3	4	5
5	Extra material cost	[-]	Materials need to be imported	Material scarsely available in Indonesia	Material widely available in Indonesia	Material is available on local markets	No new materials needed
6	Tool cost	[-]	Tools/machin-ery imported	Expensive tools/ machinery in Indonesia	Affordable tools/ machinery in Indonesia	Cheap tools/ machinery in Indonesia	Tools/machinery already available in RW02 and 12
7	Ease of learning new building method	[-]	>3 days train-ing	1-3 days training	1 day training	<1 day training	Almost no training needed
8	Ease of learning new tools	[-]	>3 days train-ing	1-3 days training	1 day training	<1 day training	Almost no training needed

Table 2: Criteria on which the solutions will be assessed.

2.1 Reduction of material use

The reduction of building material use helps the diminishing of waste materials over a long term, due to the long life span of buildings. However, this strategy is not valid to alleviate the current stone C&D waste stock within the kampung. It will affect the amount of locally dumped waste when the houses constructed with this strategy is being refurbished or demolished. There are multiple ways to reduce stone building material. However, the Laurie Baker case study is chosen since the construction method is developed to improve brick constructions in informal neighbourhoods in India.

2.1.1 Laurie Baker cost saving measures: optimisation with known materials and tools

Laurie Baker is an architect who is known for optimisation of the traditional building method common in the southern part of India (Baker, 2000). Like Indonesia, the southern Indian building are mostly build with concrete and brick. Baker poses that instead of concrete use the whole building should be made out of brick by applying a whole brick thick masonry and a preference for brick arches for openings within the facade. The application of the strategies shown in figure 18 would result in the elimination of concrete as building material.

The reduction of concrete and mortar use result in a higher brick use, since the method relies on the effective use of brick in one brick masonry. The reduction of the current inefficient use of mortar results in a reduced local dumping ratio. The elimination of the relative expensive concrete columns and a material efficient one brick masonry result in a decrease of material costs. Furthermore, there is no extra space needed for the implementation of this case study.

Downside of the implementation of this case study within Cigondewah is that the local builders have to be educated on a new building method which they are not familiar with. The lack of mortar and plaster to cover mistakes in the construction of the masonry might be a problem, since it would mean that the local builders need to learn the proper way to lay bricks. However, there is no need to buy new tools or to learn how to use these new tools.

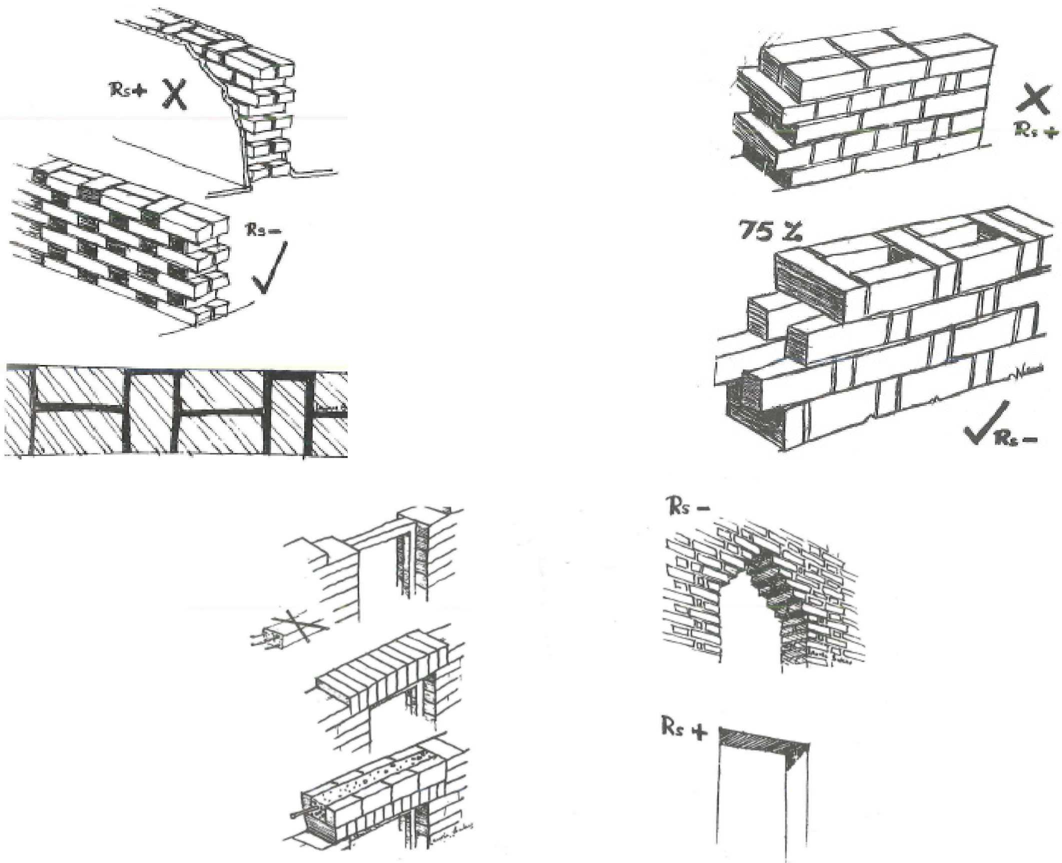


Figure 18: The cost saving methods written down by Laurie Baker. Source: Laurie Baker (Baker, 2000)

Rating Laurie Baker method

● 80% local dumping ratio

0 m^2 extra space needed

● 1% re-use ratio

● ● ● ● ● Costs tools and machinery

● 262 mil Rp saved costs

● ● ● ● ● Costs extra material

● ● ○ ○ ○ Ease of learning new building method

● ● ● ● ● Ease of learning new tools and machinery

Figure 19: The effect of the cost saving methods: arches and a limited use of mortar and plaster. Source: http://www.costford.com/

2.2 Re-use of materials in construction

The re-use of stone waste materials can help with the reduction of material costs during construction and the amount of waste that is dumped locally. There are three solutions to enable the re-use of building materials. First is to use a different method to demolish stone structures by introducing new tools and methods. This solution is short term and can reduce waste almost immediately. Second is the introduction of a new building system which allows for demountability of the existing structure. This solution is longterm, since the re-use of material can only happen after a structure with such a system is demounted. The third and last method is to re-use the rubble from local dumping grounds to construct new houses.

2.2.1 Salvaging brick: A different way of demolition

Within European countries it is already a common practice to salvage bricks from existing masonry. Within this case study only the demolition of brick structures will be observed. Reason is that the careful disassembly of concrete structures requires high-tech solutions that are either not affordable in the Indonesian context or still in prototype development (Addis, 2006). Time and intensive labour is associated with the salvage of bricks from existing masonry. The time intensive process to carefully dismantle the wall and to clean the mortar from the bricks is the factor to consider in this approach. The increased time and labour makes the salvaged bricks more expensive in the western world than in Indonesia.

The implementation of the case study has a marginal effect on the local dumping ratio but greater effect on the re-use ratio. This is due to the fact that only a part of the bricks can be salvaged (60%), due to the difficult cleaning process associated with the use of portland cement in the mortar in the context. The cleaning process also influences the cost of the material and the space it needs.

The low cost of labour allows the salvaged brick to be competitive in price to the new product. It however, requires the locals to be educated how demolition of brick walls and the cleaning of the bricks have to be done. The purchase of new tools or machinery is not needed, since the bricks can be cleaned with tools already available.

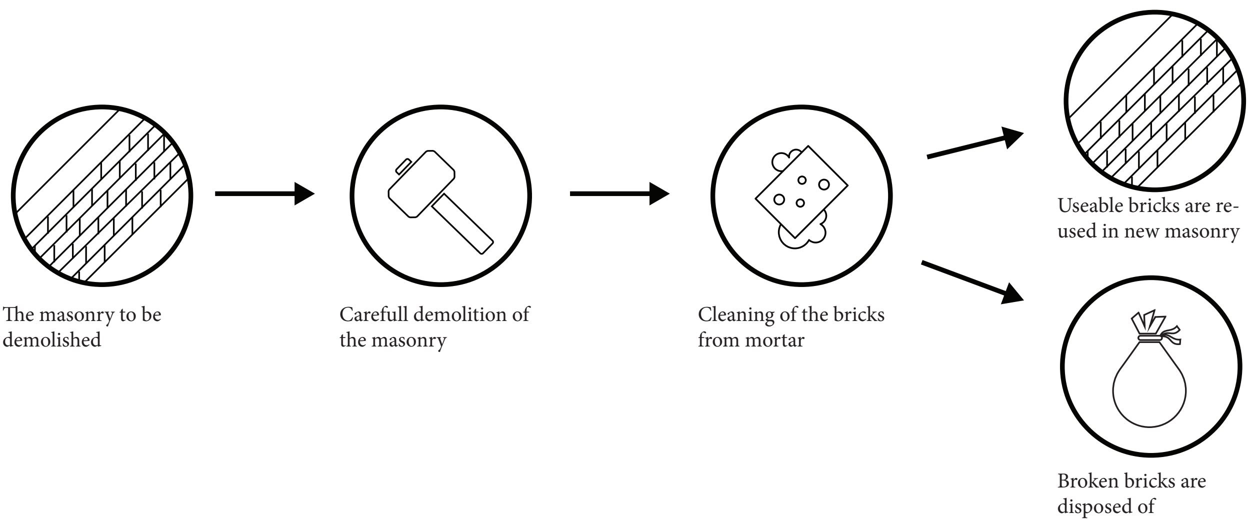


Figure 20: The process needed to salvage bricks. Source: own image

Rating Salvaging bricks

●	87% local dumping ratio	◆	10 m^2 extra space needed
●	4% re-use ratio	● ● ● ● ○	Costs tools and machinery
•	21 mil Rp saved costs	● ● ○ ○ ○	Ease of learning new building method
● ● ● ● ●	Costs extra material	● ● ● ● ●	Ease of learning new tools and machinery

Figure 21: The carefull demolition of the masonryto salvage the bricks. Source: www.homestylechoices.com

2.2.2. ClickBrick: a new construction system

Clickbrick is a brick wall system developed in the Netherlands (Daas Bakstenen, 2016). It is an example of eliminating the use of mortar within the current brick wall constructions. As alternative to regular building methods the system makes use of small stainless steel clips in between bricks to connect them. This results in a brick wall without mortar or a visible joint. This results in facade which requires relatively less maintenance free and allows for fewer mistakes during the construction of the masonry. The use of steel clips instead of mortar allows to re-use the bricks and steel clips after deconstruction.

The implementation of the ClickBrick system would have a great impact on the total waste dumped within the kampung, due to the elimination of mortar and the fact that all bricks theoretically can be re-used. The potential re-use of bricks, reduces the total stone building material costs. However, the use of steel clips will increase the costs of other building materials greatly. To solve this the steel clips could be replaced with a locally found material. Furthermore, the re-use of the bricks on a kampung level would demand a storage space for these bricks in between the deconstruction of old structures and the construction of houses.

The building system would be ideally implemented within the Indonesian kampung, since the system is easy to learn. Furthermore, it allows for less mistakes within the construction of the masonry, which results is better brickwork walls. Lastly there is no need for new machinery or tools to construct with this method.

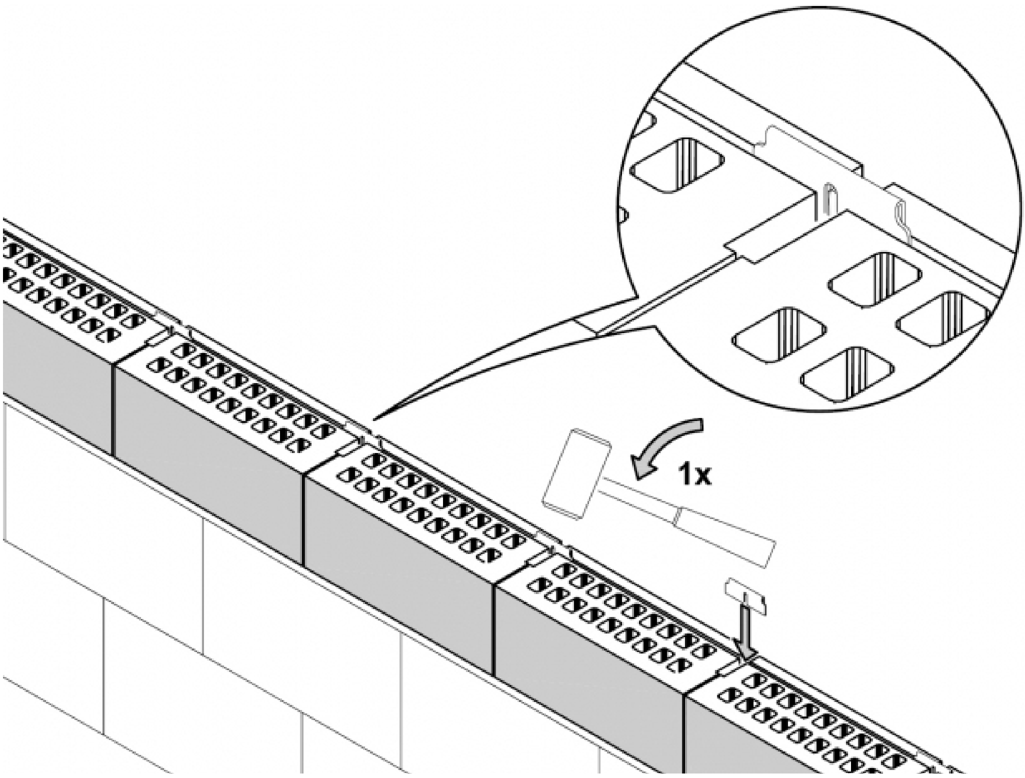


Figure 22: The ease of construction with the ClickBrick system. Source: www.bouwsystemen.nl

Rating ClickBrick

● 32% local dumping ratio

◆ 17 m^2 extra space needed

● 8% re-use ratio

● ● ● ● ○ Costs tools and machinery

● 674 mil Rp saved costs

● ● ○ ○ ○ Costs extra material

● ● ● ● ○ Ease of learning new building method

● ● ● ● ● Ease of learning new tools and machinery

Figure 23: The smooth finishing of a ClickBrick wall due to the lack of mortar. Source: www.Daasbakstenen.nl

2.2.3 The Gabion house: Re-use rubble as construction system

The Gabion house is a primary example of a construction method with the application of rubble within the construction of new houses (Brennan H, Howe C, Mattar-Neri R, & R, 2010). Within this construction method rubble is used to fill gabions, which act as the structure and walls of the house. The gabion walls are covered with plaster in order to protect the structure from the outdoor climate. The estimation of the effect on the local material cycle it needs to be determined how many houses can be made out of the rubble currently available on local dumping sites. Based on the density of stone filled gabion wall with a thickness of 25 cm it is estimated that 8 houses with an average floor size of 110 m2 can be build.

The implementation of the gabion house has a drastic effect on both the local dumping ratio and recycle ratio. It would mean that no stone C&D waste would be found within the Indonesian kampung. Furthermore, it would reduce the cost of the purchase of new stone building material. However, the steel gabions would come with a cost, since gabions are used universally over the world these extra material costs would not be too much.

The introduction of this new system of building would require extensive training of the local builders, since the use of gabions within walls is not known in Indonesia. It also impacts the incremental building method of the kampungs, since the building system is quite rigid. This would mean that extending the house would require the difficult deconstruction of the gabion walls.

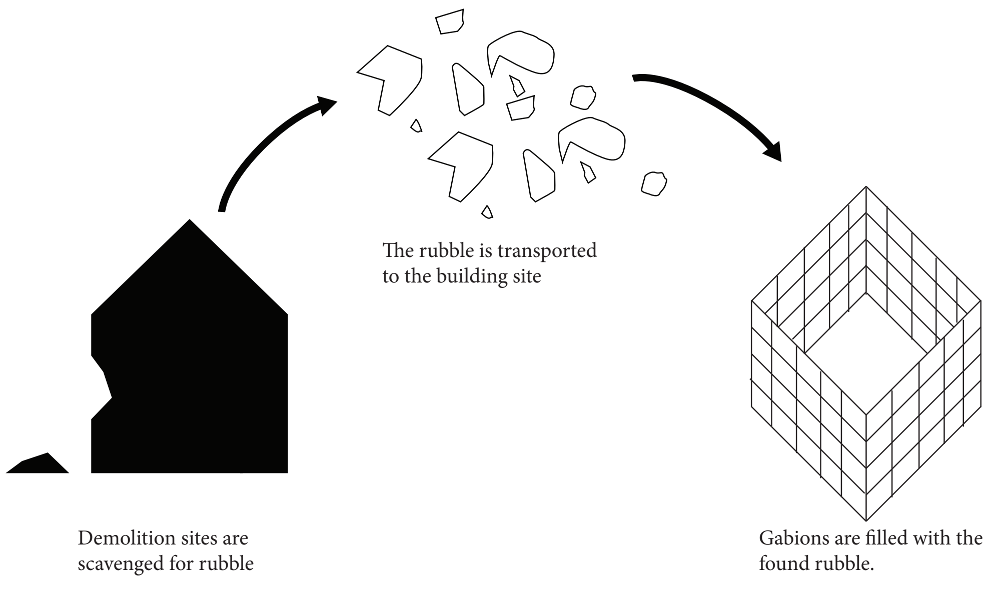


Figure 24: The process of filling the gabions. Source: own image

Rating Gabion house

0% local dumping ratio

0 m^2 extra space needed

42% re-use ratio

● ● ● ● ○ Costs tools and machinery

660 mil Rp saved costs

● ● ● ○ ○ Costs extra material

● ○ ○ ○ ○ Ease of learning new building method

● ● ● ● ○ Ease of learning new tools and machinery

Figure 25: The construction of the walls of the gabion house in Haiti. Source: www.inhabitat.com

2.3 Recycling of stone waste materials on a local scale

The recycling of stone waste materials in Indonesia has been implemented yet (UNEP, 2008). It happens more often on a big scale of a factory, for example with the production of new concrete. The case studies analysed deal with the recycling of stone waste on a local scale. Two methods of recycling stone waste will be discussed. First is the method of the Mobile Factory to produce concrete bricks from rubble. This method is clarified with a case study to produce concrete bricks from rubble in Tanzania, because of the similarities between both processes. The second method discussed is the recycling of stone waste material into new bricks by Stone cycling.

2.3.1 The Mobile Factory: Concrete blocks from rubble

The Qbrixx system developed by the Mobile Factory provides the processing of stone waste material within areas struck by earthquakes, like Haiti (The mobile factory, 2016). The main innovation of the recycling system is that the whole production line fits in several shipping containers. Furthermore it tries to utilise the way the stone waste is processed in developing countries. The recycling of the stone material happens as follows (M.M. Sabaia, M.G.D.M. Cox, R.R. Mato, E.L.C. Egmond, & Lichtenberg, 2013):

1. The rubble from demolition site is crushed manually with hammers.

2. The crushed rubble is filtered on size. Metals are extracted from the crushed rubble waste.

3. A mixture of rubble aggregate of various sizes, water and cement is prepared.

4. The concrete is cast within the mould and a Qbrixx is created.

Within the assessment of the material it is assumed that concrete blocks are only applicable within a different building method than the current building method in the RWs. The total amount of rubble produced can be recycled within these blocks. These blocks make a 15 cm wide wall which result in 8 extra houses with an average floor size of 110 m2. For the material costs of this product it is assumed due to the free availability of the aggregate and low labour costs that it cost around 70% of regular concrete. The size of the production line takes up two shipping containers with some space to sort out the rubble waste.

The implementation of the Qbrixx production line helps in the total reduction of the waste locally dumped. Furthermore due to the relatively cheap concrete blocks made from stone waste the recycling ratio is high and the material costs are saved.

The impact of the production line within the kampung is quite significant, not only space wise but mostly cost wise. The new machinery and tools needed and training to use these machines for the production line are quite expensive considering the fact that this case study is implemented locally.

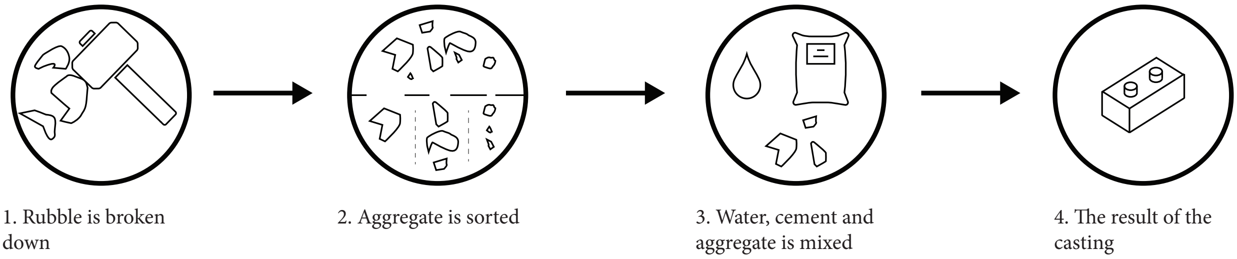


Figure 26: The process of the Mobile Factory. Source: own image

Rating The Mobile Factory

- 0% local dumping ratio
- 46 m^2 extra space needed
- 42% re-use ratio
- ●●○○○ Costs tools and machinery
- 302 mil Rp saved costs
- ●●●●● Costs extra material
- ●●●●● Ease of learning new building method
- ●○○○○ Ease of learning new tools and machinery

Figure 27: The construction of the walls with the Qbrixx blocks in Haiti. Source: The Mobile Factory

2.3.2 StoneCycling: Bricks from stone waste

The StoneCycling method of recycling transforms stone waste material into new bricks (StoneCycling, 2017). The produced bricks have almost the same quality as regular bricks. The bricks are produced as follows:

1. The rubble is sorted on material quality.

2. The rubble of a specific quality is grinded to small particles.

3. The resulting mixture is combined with fresh clay, at the ratio 1:4.

4. The bricks go through the conventional way of producing bricks by hand forming and firing.

5. The aesthetic quality of the produced brick is dependent on the used waste material.

The assessment of this method of recycling is done that at least 80% of the rubble can be manually sorted, since the rest of the rubble cannot be seperated. The cost of the new brick is mostly dependent on the labour costs of the sorting, grinding and handforming the bricks. The result is a product that costs 90% of the price of a new brick. Lastly the space needed is assumed to be similar to a Indonesian brick factory, since the extra storage for the rubble material is similar to the storage of clay in the factory and the grinder only takes up a bit of the overall space.

The implementation of Stone Cycling greatly reduces the locally dumped C&D waste and increases the recycling ratio. However, the case study has a limited impact on the costs saved, due to the labour intensive process. Furthermore, space needed for the solution is in comparison to other solutions quite large. It would therefore, be difficult to make this solution fit on the local scale of the kampung, since space is limited.

The building method does not change with the implementation of the recycled bricks into the local building culture. The Stone Cycling process demands the purchase of new tools and machinery, that are quite well known within Indonesia but not within the local kampung. Therefore, extra training and funds are needed for implementation.

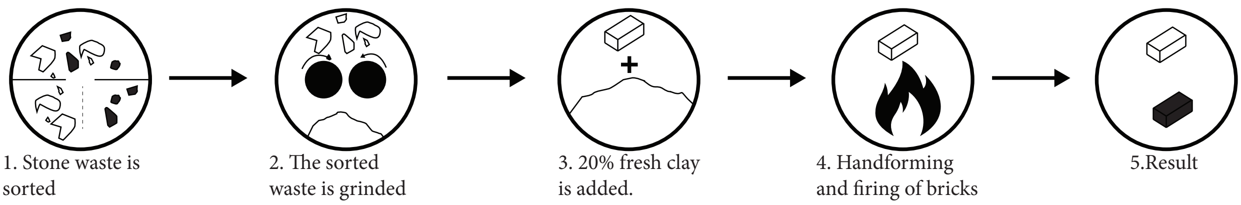


Figure 28: The process of Stonecycling. Source: own image

Rating StoneCycling

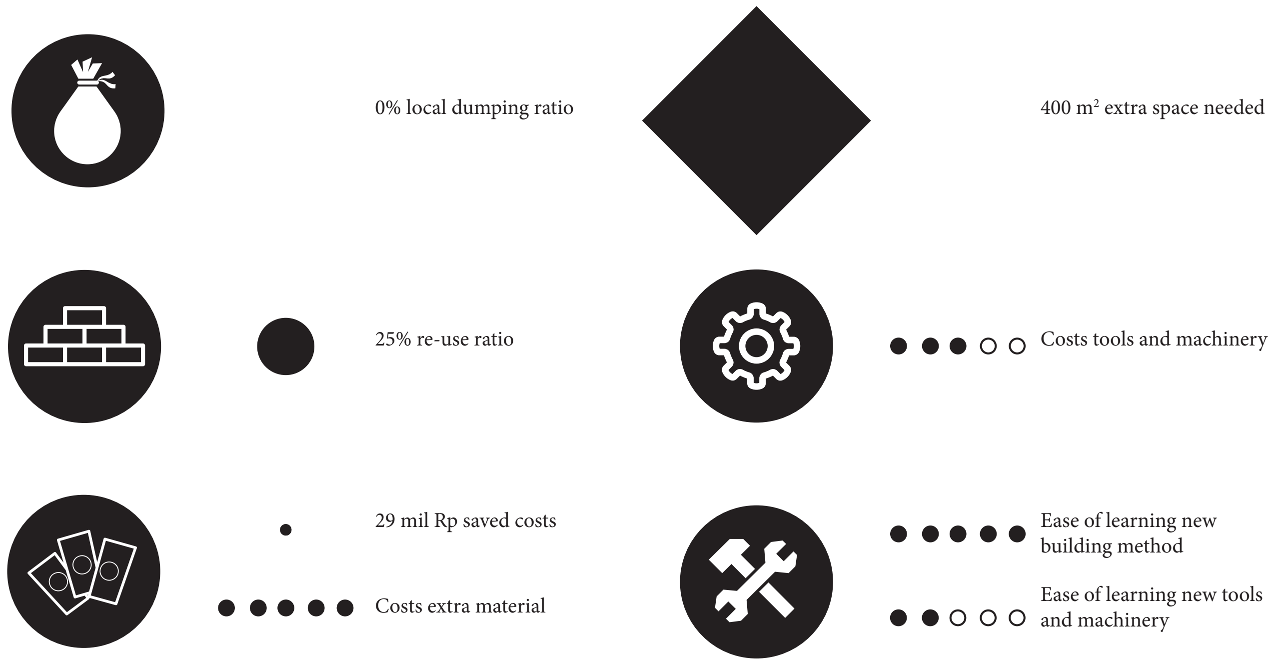


Figure 29: The results of using different quality waste material on the aesthics of the produced bricks. Source: StoneCycling

Conclusion

The research paper started with the question what the design possibilities are to reduce, re-use and recycle stone construction an demolition waste within Indonesian informally constructed neighbourhood or kampungs.

The site analysis was done in order to understand the limitations of the kampung environment on the design possibilities. The growing population of the investigated kampung demand that 17 houses each year have to be constructed to meet the demand in housing. This means that space becomes a highly valued commodity. Therefore, solutions that require a large space are less efficient. Furthermore, the low structural quality of the kampung houses is due to a lack of funds for quality materials and a lack of skill of the local builders to construct according to their preferred construction method. Lastly, the local dumped C&D waste poses a health threat to the kampung inhabitants and demands a solution to minimise the local dumping.

The case study analysis showed a variety of solutions to use C&D waste on a neighbourhood scale. Most cost, material and space effective case studies were methods that re-used stone waste into new products. The most effective method however, the Gabion house limits the way houses are incrementally constructed over time. In order to solve the question most efficiently is a combination of two different methods. One method which allows for the re-use of the stone building material in the future, since these methods are effective in lowering the stone material costs of the kampung. The other method has to solve the problem of the processing of the locally dumped C&D waste, in order to eliminate the locally dumped C&D waste.

Design considerations

The design question addresses the need of the systematic transformation of stone building waste material in order to develop a multi-family housing typology for the Indonesian kampung. There is a need for 17 new built houses per year, due to population growth. However, in the most applicable method only 8 new houses per year can be built with the produced C&D waste.

The combination of two different methods to impact the locally dumped C&D waste the programme of the multi-family housing needs to adress the need to transform the locally dumped waste. The amount transformable locally produced stone waste does not justify the need for a whole production line within the kampung itself. The transformation process will happen on a central location, so that several kampungs can deliver their stone C&D waste. This means however, that within RW 02 and 12 space has to be made to collect and sort the stone C&D waste from the whole neighbourhood. This space has to be easily accessible by one of the main roads at the edge of the area.

The developers of the project will be (a part) of the local community, since they are able to organise building activities and development as a group, as is shown in the construction of the community building. Furthermore, they have the most to gain financially and socially from re-using and recycling stone waste.

The main material demand on the design project is that the used material needs to be either re-used or transformed stone C&D waste. Furthermore, the proposed elements need to be easy in assembly due to lack of skill of the local builders. The elements also need to be easily taken apart to address the fact that most of the houses within the kampung are incremental in nature. The locals change the spaces within their houses to make space for new business activities or demands on housing.

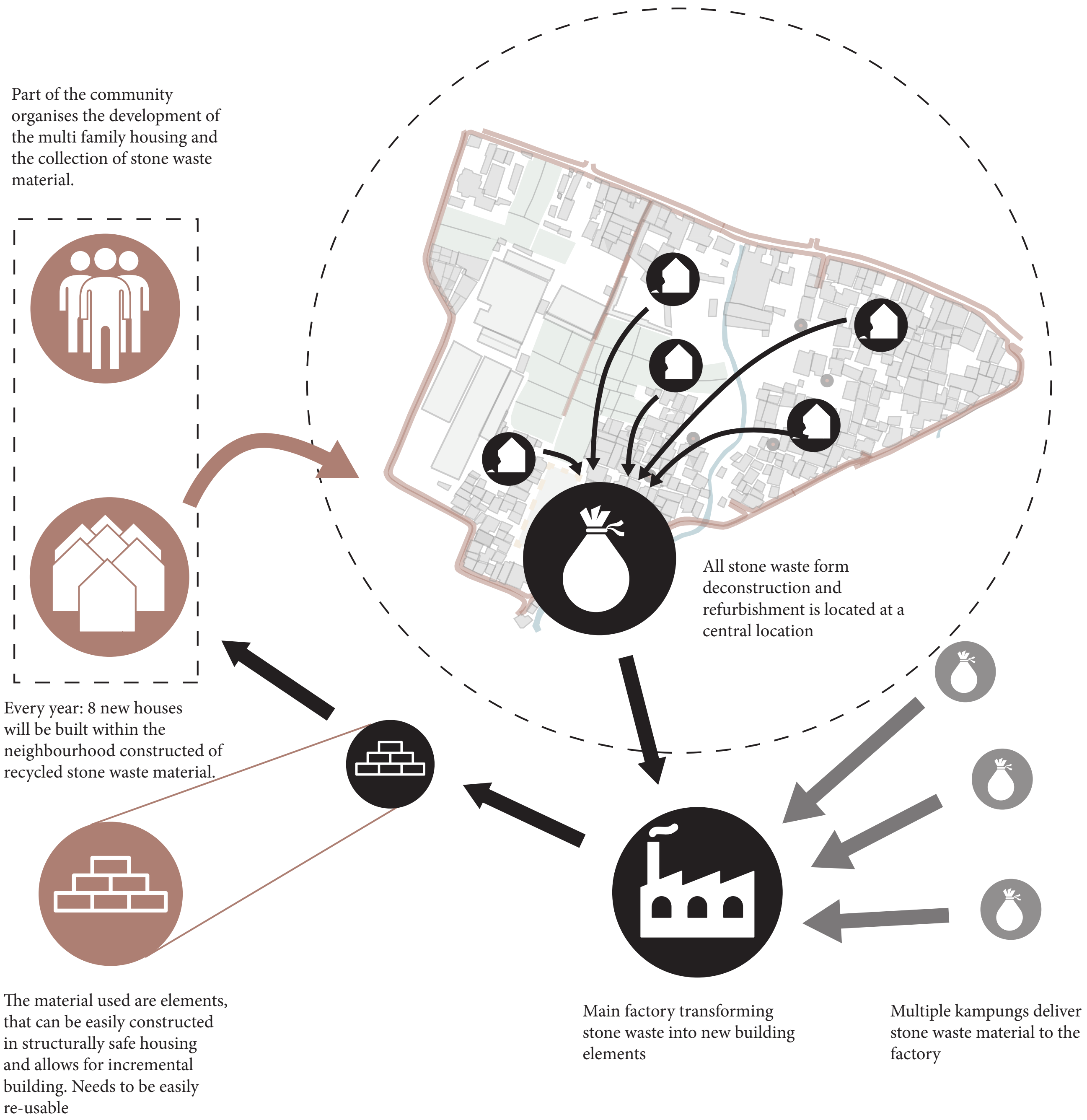


Figure 30: The diagram illustrating the design considerations. Source: own image

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Appendix A - Material Flow Analysis data

Material	Density (kg/m^3)
Mortar	2100
Cement	1506
Sand	1400
Soil	2000
Stone (foundation)	1450
Concrete	2200
Cement	1506
Sand	1400
Stone (gravel)	1450
Clay brick	950
Wood	705
Ceramic tile	2500
Steel	7750
Clay roof	2300
Asbestos roof	2200
Paint	700
Zinc roof	3330
Clear glass	2579
Concrete roof	2500
Gypsum	1100
Concrete brick	2300

Appendix 1 figure 1: The three types of houses. From top to bottom: Simple, Medium and Luxurious. Source: Surahman, 2016

Appendix 1 table 1: Material densities used within the material flow analysis. Source: Surahman, 2016

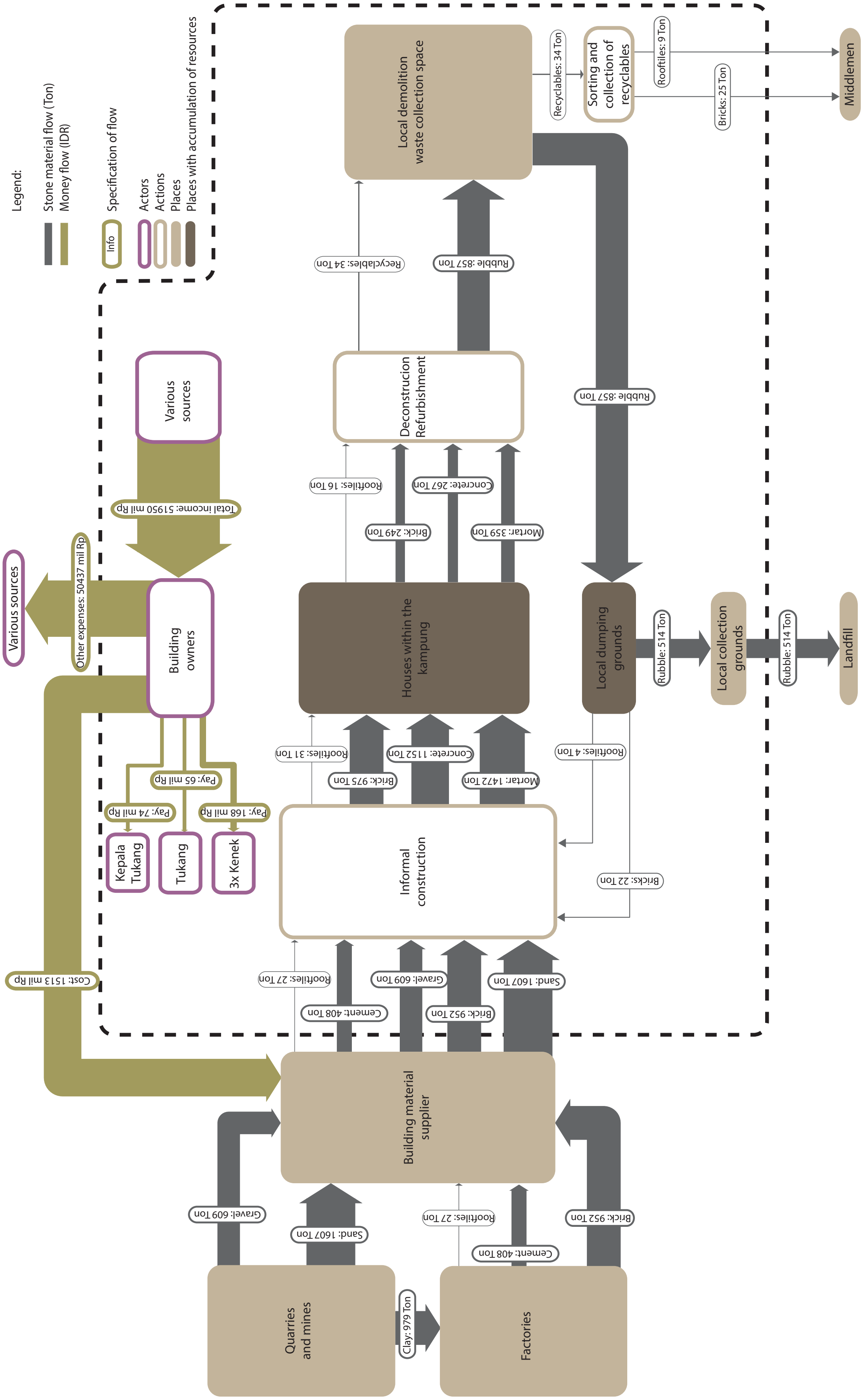
	Jakarta				Bandung			
	Simple	Medium	Luxurious	Whole	Simple	Medium	Luxurious	Whole
Sample size (unplanned/planned)	125 (125/0)	115 (75/40)	57 (29/28)	297 (229/68)	120 (120/0)	99 (99/0)	28 (28/0)	247 (247/0)
Household size (persons)	4.3	4.5	5.3	4.5	4.7	4.7	5.6	4.8
Household income (%)								
<500	81.6	60.8	21.0	61.9	85.8	58.6	7.1	66.0
500–1000	16.8	31.3	38.6	26.6	14.2	38.4	57.2	28.7
>1000	1.6	7.9	40.4	11.5	0.0	3.0	35.7	5.3
Average (USD)	353.9	553.1	1047.9	572.3	330.5	550.8	1105.2	518.1
Total floor area (%)								
<50 (m^2)	71.2	9.6	0	33.7	50.8	6.1	0	25.9
50–99	20.0	51.3	0	28.3	39.2	34.3	3.6	32.4
100–300	8.8	36.5	84.2	34.0	10.0	58.6	64.3	37.7
>300	0	2.6	15.8	4.0	0.0	1.0	32.1	4.0
Average (m^2)	44.2	107.2	213.6	101.1	59.6	124.3	283.1	110.9
Age of house (%)								
<10 (years old)	22.4	25.2	17.5	22.6	13.3	26.3	57.1	23.5
10–20	40.0	17.4	21.0	27.6	14.2	28.3	28.6	21.5
21–30	17.6	29.6	31.6	24.9	21.7	15.1	14.3	18.2
31–40	12.8	15.6	21.1	15.5	8.3	9.1	0	7.7
>40	7.2	12.2	8.8	9.4	42.5	21.2	0	29.1
Average (years old)	19.6	24.1	24.6	22.0	34.5	23.8	10.0	27.5

Appendix 1 table 2: Floor areas and sample sizes used within the MFA. Source: Surahman, 2016

Material	Jakarta: brick and concrete detached houses					Bandung: brick and concrete detached houses					Japan (n = 103) [48]: wooden detached houses		Seville, Spain (n = 10) [36]: urban houses (concrete structure)	
	S	M	L	Total		S	M	L	Total					
	kg/m^2	kg/m^2	kg/m^2	kg/m^2	%	kg/m^2	kg/m^2	kg/m^2	kg/m^2	%	kg/m^2	%	kg/m^2	%
Mortar	733.3	528.1	545.8	617.8	23.2	548.1	580.5	716.3	580.3	22.9	0.0	0.0	93.4	4.6
Cement	102.5	80.7	108.3	95.2	3.6	77.0	87.1	139.1	88.1	3.5				
Sand	630.8	447.4	437.5	522.6	19.6	471.1	493.4	577.2	492.9	19.4				
Soil	667.4	459.1	323.8	520.8	19.5	535.2	428.9	377.2	474.7	18.7	–	–	–	–
Stone (foundation)/ aggregate	580.6	399.3	281.7	453.1	17.0	468.7	376.4	328.2	415.9	16.4	0.0	0.0	467.1	22.9
Concrete	276.3	567.9	472.7	426.9	16.0	286.1	585.1	526.8	432.9	17.0	201.4	47.0	1087.4	53.2
Cement	40.4	95.0	79.1	69.0	2.6	41.8	97.9	88.2	69.4	2.7				
Sand	86.7	175.7	146.3	132.6	5.0	89.9	181.0	163.0	134.6	5.3				
Stone (gravel)	149.2	297.2	247.3	225.3	8.5	154.4	306.2	275.6	228.9	9.0				
Clay brick	494.9	309.2	413.3	407.4	15.3	371.7	414.0	451.2	397.7	15.7	0.0	0.0	0.0	0.0
Wood	105.0	131.0	159.8	125.6	4.7	143.1	161.5	43.2	139.2	5.5	129.3	30.2	0.0	0.0
Ceramic tile	30.8	33.9	59.5	37.5	1.4	15.5	34.2	77.4	30.0	1.2	0.0	0.0	132.6	6.5
Steel	16.6	36.6	30.5	27.0	1.0	17.3	37.7	34.0	27.4	1.1	10.4	2.4	30.9	1.5
Clay roof	16.6	40.9	0.0	22.8	0.9	20.7	30.2	0.0	22.2	0.9	40.8	9.5	43.3	2.1
Asbestos roof	5.6	2.1	0.3	3.2	0.1	0.6	0.3	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Paint/plaster	2.0	5.4	10.0	4.9	0.2	1.6	4.4	12.4	4.0	0.2	1.05	0.2	20.4	1.0
Zinc roof	1.2	0.1	0.0	0.5	0.0	0.8	0.1	0.0	0.4	0.0	0.0	0.0	0.0	0.0
Clear glass	0.8	0.8	1.3	0.9	0.0	1.2	1.3	6.2	1.8	0.0	2.6	0.6	–	–
Concrete roof	0.0	0.0	49.9	9.6	0.4	0.0	0.0	39.2	4.4	0.2	0.0	0.0	0.0	0.0
Gypsum	0.0	7.0	23.0	7.1	0.3	0.3	1.3	24.4	3.4	0.1	10.3	2.4	22.5	1.1
Concrete brick	0.0	0.0	0.0	0.0	0.0	7.5	0.0	0.0	3.6	0.1	0.0	0.0	0.0	0.0
Others	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.6	7.6	146.13	7.2
Total	2931.1	2521.4	2371.6	2665.1	100	2418.4	2655.9	2636.5	2538.3	100	428.4	100	2043.6	100

Appendix 1 table 3: Input materials per square meter of the three different types of houses used within the MFA. Source: Surahman, 2016

Appendix B -Material Flow Analysis



Appendix 2 figure 2: The material flow analysis of RW 02 and 12. Source: Surahman, 2016