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Durable housing alternative for Dharavi



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Summary

This research paper is about a durable housing alternative for the slums in Dharavi. Dharavi is the biggest slum in Asia and it is located in Mumbai, in India. The living conditions are dreadful and so are the houses. Several projects were made up by the corrupt government to improve the living conditions, but all these projects failed. This makes a design which can be built by the inhabitants of Dharavi themselves a very suitable project. The durable housing alternative is designed to improve the living conditions of the inhabitants of Dharavi. Research is done to indicate the preferences and requirements of the inhabitants. This design can be built as a whole, but the different elements of the design, which are; the construction, the foundation, the walls, the water system and the roof can be used separately as well. This makes the design more accessible for all of the inhabitants of Dharavi. Different ideas were made based on the collected research. The different ideas were tested and a process of testing, identifying problems, brainstorming, adapting and then testing again was repeated for several times. Experiments with the construction, facade and the roof were done to test if the design meets the required demands. The construction can hold the minimum required weight. This was tested by people who stand on the construction. The roof creates a better insulation in the houses, this was tested with a heat source, and for the foundation, experiments were done to calculate it required mass. This research paper will provide all the necessary background information for the design, the design itself and a manual for possible organizations in Dharavi which can be approached. It will show that the durable housing alternative is a realistic design which improves the living conditions of the people in Dharavi.

Introduction

A slum is a densely populated area which is most of the time located in or alongside a mega city. In our PWS we will be focussing on one of the biggest slums in the world, Dharavi, located in Mumbai in India. This slum has more than 1 million inhabitants living on an area of 2,1 square kilometres. People imagine slums as a place of despair with workless people and poverty, but Dharavi is much more than that.

"If one looks past the open drains and plastic sheets, one will see that slums are ecosystems buzzing with activity... Creating neat low-income housing estates will not work unless they allow for many of the messy economic and social activities that thrive in slums," - Sanjeev Sanyal.¹

The living conditions in Dharavi could be better. Our PWS focusses on a durable housing alternative in Dharavi which will improve their living conditions, but is nothing like the big housing projects which just put flats and other newly built buildings in Dharavi. We created something that can be built by the inhabitants themselves. Inhabitants of Dharavi can also chose to only uses parts of the design to make the design useful for everyone.

In this report we will show the theory behind the design, the different ideas for the design and the design itself.



Figure 1, Dharavi

¹ W. (n.d.). These are the world's five biggest slums. Retrieved November 12, 2018, from <https://www.weforum.org/agenda/2016/10/these-are-the-worlds-five-biggest-slums/>

Aim

How can we design a durable housing alternative for the current houses in the slum Dharavi?

Sub-aims

- What is the economic situation in Dharavi?
- What is the social situation in Dharavi?
- What is the geographical context of Dharavi?
- What is the political situation in Dharavi?
- What is the cultural situation in Dharavi?
- What does the historical context of Dharavi look like?

- How do current houses in the slum of Dharavi look like?
- How would the construction of an alternative house in Dharavi look like?
- How would a more durable design of a house in Dharavi look like?
- Which materials can we use for our design?
- What are the characteristics of the materials, we are going to use?
- What are the costs of our design?
- How can we make our design available for the people in Dharavi?

Hypothesis

We expect to develop a sustainable alternative to the current houses in Dharavi. We hope to develop a construction and a new method for a foundation and walls which will be more sustainable and can be built by the locals of Dharavi.

We would like to present our research with this report and a we would like to form a manual for the inhabitants of Dharavi. We want to contact local development organisations to spread our manual over the inhabitants in Dharavi.

List of requirements

- The construction of the design should be simple enough to be built by locals without the help of big machines which can't enter a lot of the places in Dharavi.
- The design should consist of available materials in and around Dharavi only.
- The design should have at least three floors including the ground floor.
- The design has to be able to deal with the weather conditions during the monsoon.
- The design should reduce dirty odours in the house itself.
- The design should be strong enough to hold at least ten people per floor.
- The design should not disturb existing patterns of work and living of inhabitants of Dharavi.

Theory

Geographical context

Location

India is a country in South/Central Asia and has an absolute location of 8° - 37° latitude (N) and 68° - 97° longitude (E). India has a total area of 3287263 km² which makes India the seventh largest country in the world. 91% of this total area is land, only 9 % is water.²

Mumbai is the capital city of the district Maharashtra and has an area of 603,4 km². The city has an absolute location of 19° latitude and 72° longitude. The city is located at the mouth of the Ulhas river and in the West it is bounded by the Arabian sea.



Figure 2, location of Mumbai

Mumbai consists of two regions; Mumbai city district and Mumbai suburban district. The city district is located in the south of Mumbai and is also referred to as the island city. The suburban district is located in the North of Mumbai and comprises all of Mumbai's suburbs.³ Dharavi is located in the middle of Mumbai, close to sea and between two important railroads.

In the past, Mumbai consisted of seven islands; Isle of Bombay, Mazagaon, Colaba, Old Woman's Island, Parel, Worli, and Mahim. In the early 1800s a lot of engineering work was done in Mumbai, this led to large island of Mumbai since all the seven islands of Mumbai were merged to one big island in 1845.⁴ The merged islands were later merged with the island of Trombay and Salsette. The seven small islands are now part of the southern part of the city of Mumbai. Most of the city is above sea level and has an average altitude that ranges from 10-15 meters.⁵

Population

In 2017, India had a total population of 1339200000 people and therefore India deals with a population density of 450 people per square km.⁶ The population of Mumbai in 2017 was 23500000 people⁷. According to the UN Habitat data analyses, which was done in 2015, Mumbai had a population density of 31700 people per square kilometre. This is a big difference with the population density of India. It is hard to estimate and calculate the amount of inhabitants in Dharavi, but a calculation which was done in 2015 shows that Dharavi has a density of 250000 people per square kilometre.⁸ These numbers show the big differences in population density.

² India Geography. (2017, April 07). Retrieved September 24, 2018, from <https://www.worldatlas.com/webimage/countrys/asia/india/inland.htm#page>

³ About District. (n.d.). Retrieved September 24, 2018, from <https://mumbaibusurban.gov.in/about-district/>

⁴ Bombay: History of a City. (2006, January 10). Retrieved September 25, 2018, from <http://www.bl.uk/learning/histcitizen/trading/bombay/history.html>

⁵ Mumbai Location. (n.d.). Retrieved September 25, 2018, from <https://www.mumbai.org.uk/geographical-location.html>

⁶ The world bank. (n.d.). Size of the economy. Retrieved September 24, 2018, from <http://wdi.worldbank.org/table/WV.1>

⁷ Population Of Mumbai 2018. (n.d.). Retrieved September 24, 2018, from <http://indiapopulation2018.in/population-of-mumbai-2018.html>

⁸ Now, T. (2017, May 26). Among world's most dense cities, Mumbai stands still at two. Retrieved from <https://www.timesnownews.com/india/article/where-world-most-dense-populated-cities-mumbai/61774>

Climate

The Köppen climate classification is a classification type which looks at the relation of climate and vegetation and is based on multiple variables and their seasonalities. This classification system is ecologically relevant since it makes a distinction in the major climate type, the subtype (based on precipitation) and the temperature. For example you can have a Csa climate, which means a climate with a mild temperature with dry and hot summers. Mumbai has a tropical savannah climate with dry winters (AW).⁹ This can be classified as a wet and dry climate since this climate has a dry and a raining season. The dry- and the raining season are caused by the Monsoon. The monsoon is a seasonal wind of Southern Asia and the Indian ocean which causes changes in precipitation. In the summer it blows from the south west and in the winter from the north east.¹⁰

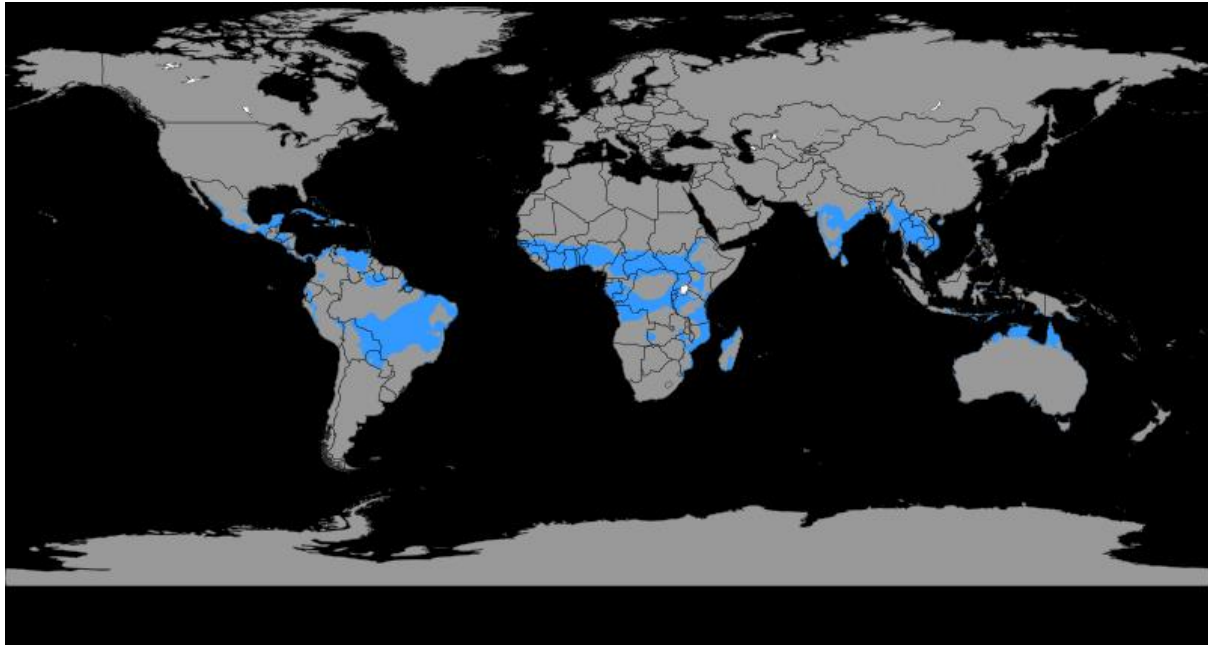


Figure 3, Blue area is AW climate

The monsoon occurs when there is a significant difference in warmth between the ocean and the land. Throughout the year the land and the oceans are heated by the sun, but both the land and the oceans absorb the heat in different ways. The temperature of the land rises more quickly, but cools down more quickly as well, therefore is the land temperature more variable. The temperature of the oceans stay relatively stable. This is because of two reasons. First of all, water has a high heat capacity (3.9×10^3 to $4.2 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$) the heat capacity of land is much lower (0.19×10^3 to $0.35 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$).¹¹ The other reasons why the oceans have a more stable temperature is that in the oceans both conduction and convection happen. Conduction is: "The heat transfer resulting from the energy exchange between molecules, due to molecular contact."¹² The conduction of heat in the oceans occurs because when the molecules increase in temperature, they will vibrate. The vibration causes the molecules to move and because they move, they pass the heat energy to the surrounding molecules.¹³ Convection is: "The process by which heat travels through air, water, and other gases

⁹ Chen, H. (n.d.). Köppen climate classification. Retrieved September 24, 2018, from <http://hanschen.org/koppen/>

¹⁰ Dictionary. (n.d.). Monsoon. Retrieved September 25, 2018, from <https://www.dictionary.com/browse/monsoon?s=t>

¹¹ Libretexts. (2015, March 12). Heat capacity, the ocean, and our weather. Retrieved September 25, 2018, from [https://geo.libretexts.org/Textmaps/Book:_Oceanography_\(Hill\)/04:_Properties_of_Water/4.2:_Heat_capacity_the_ocean_and_our_weather](https://geo.libretexts.org/Textmaps/Book:_Oceanography_(Hill)/04:_Properties_of_Water/4.2:_Heat_capacity_the_ocean_and_our_weather)

¹² Conduction definition and meaning | Collins English Dictionary. (n.d.). Retrieved September 25, 2018, from <https://www.collinsdictionary.com/dictionary/english/conduction>

¹³ What is conduction in science? (n.d.). Retrieved September 25, 2018, from <https://study.com/academy/lesson/what-is-conduction-in-science-definition-examples.html>

and liquids.”¹⁴ This has to do with the physical movement of the water. The heated water in the oceans has a lower density and therefore will rise, but when it rises it cools down and by cooling down it becomes more dense again. This process of the physical movement of water occurs in the oceans and causes the stable temperature.¹⁵ The land can only absorb the heat by conduction.

These differences in the stable temperature of the oceans and the variable temperature of the seas causes the division of the monsoon into two types, the summer monsoon and the winter monsoon.¹⁶ The summer monsoon usually happens between April and September and causes heavy rainfall and a humid climate. During these months the sun makes the temperature of both land and the ocean rise, but the land temperature rises more quickly. The air above the land expands and creates a low pressure. The wind always blows from a high pressure towards a low pressure (from cold to warm), so in the summer months from the high pressured ocean towards the low pressured land. The wind brings a moist air inlands which causes the heavy rainfall. During the winter monsoon, which happens between October and April, the opposite happens. The land cooled down quicker than the ocean does.¹⁷ The low pressure area is above sea which causes the wind to blow away from the land leaving an India with a winter with less than 60 mm of precipitation behind it.¹⁸



Figure 4, Summer monsoon

In Mumbai the Monsoon has positive effects and negative ones. The agriculture needs the rain which falls during the monsoon to make the soil usable and fertile and to fill the shallow aquifers for the rest of the year. Also the industry needs the rain of the monsoon since a lot of electricity is produced by hydroelectric power plant. The plants are driven by the collected water of the monsoon. When the summer monsoon is late or weak the economy suffers. On the other hand the summer monsoon causes a lot of problems. Even though the Monsoon occurs every year, the Inhabitants aren't

¹⁴ Definition of 'convection'. (n.d.). Retrieved September 25, 2018, from <https://www.collinsdictionary.com/dictionary/english/convection>

¹⁵ Convection in Science: Definition, Equation & Examples. (n.d.). Retrieved September 25, 2018, from <https://study.com/academy/lesson/convection-in-science-definition-equation-examples.html>

¹⁶ National Geographic Society. (2012, October 09). Monsoon. Retrieved September 25, 2018, from <https://www.nationalgeographic.org/encyclopedia/monsoon/>

¹⁷ Hendriks, I. G. (n.d.). *De geo Systeem aarde*. ThiemeMeulenhof.

¹⁸ Chen, H. (n.d.). Retrieved September 25, 2018, from <http://hanschen.org/koppen/#classification>

prepared very well. The streets are flooded with half a meter or sometimes a meter of water, but most houses can't handle this amount of rain. When the summer monsoon is stronger than expected whole neighbourhoods in Mumbai can disappear due to heavy floods and mudslides. Especially Dharavi experiences the most problems with this, since lots of their houses are not secure enough.¹⁹

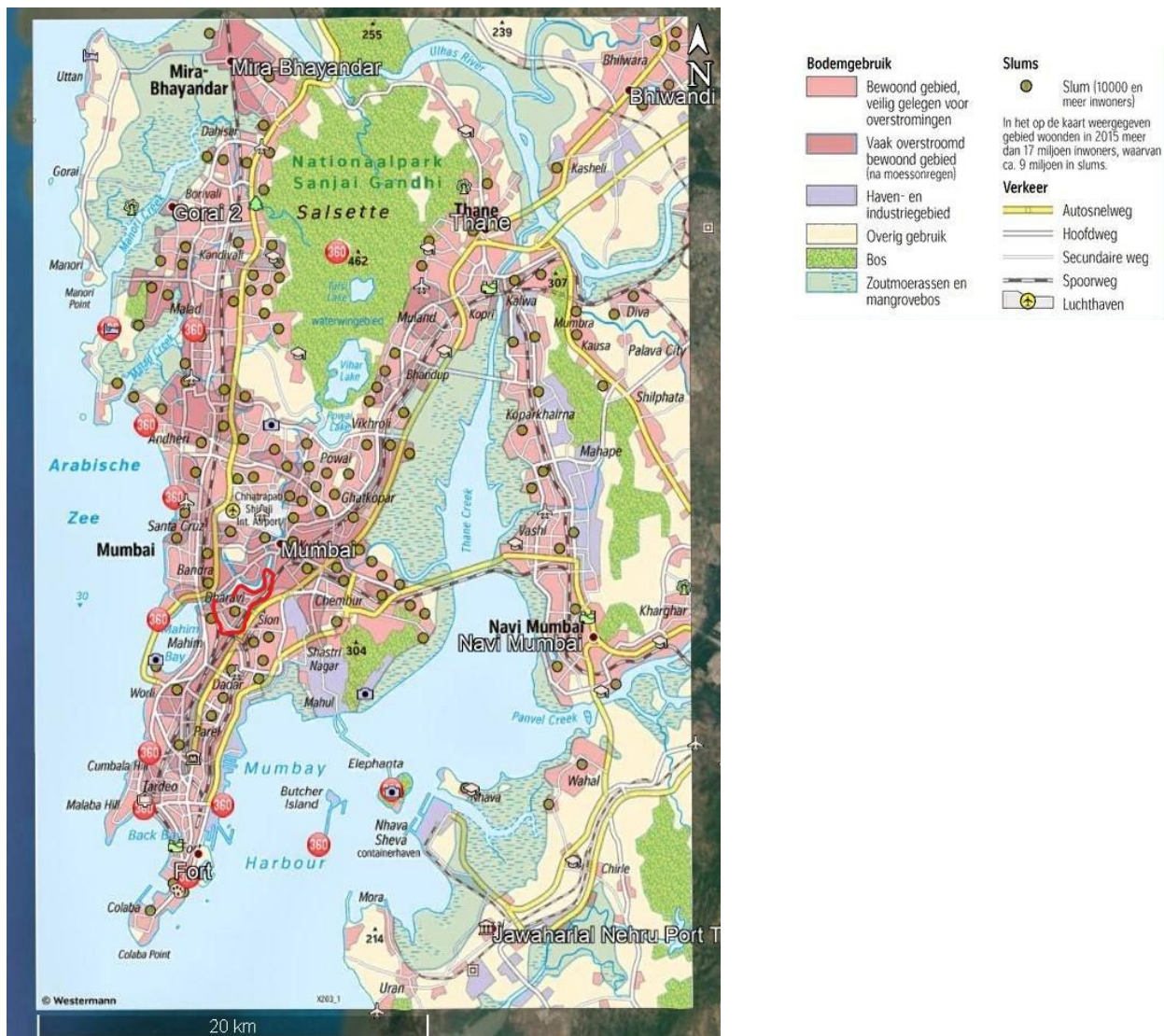


Figure 5, Red area is Dharavi

¹⁹ National Geographic Society. (2012, October 09). Monsoon. Retrieved September 25, 2018, from <https://www.nationalgeographic.org/encyclopedia/monsoon/>

Flooding risks

The location of Mumbai is not very favourable. The land is located in a region which has to deal with the monsoon and it is located alongside the Arabian sea in the West and the mouth of the Ulhas river in the North-East. Dharavi is located alongside the Mithi river.

The ongoing global warming is a big cause for the floods. As the graph below shows, the

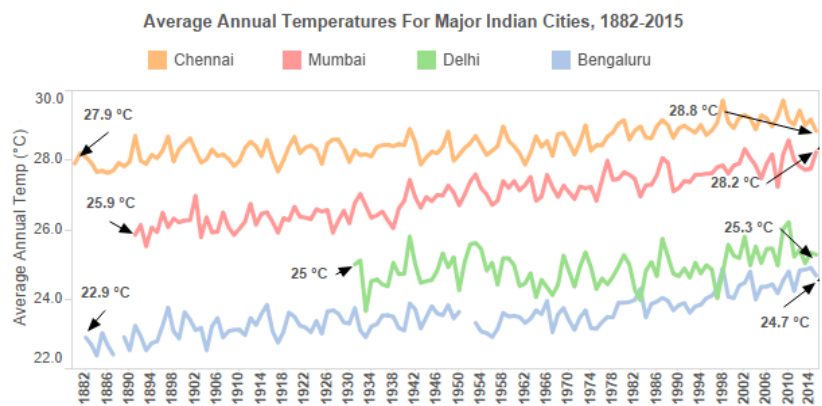


Figure 6

graph below shows, the temperature is rising fast, but according to the Goddard Institute for Space Studies will the annual temperature of Mumbai rise even faster, with 1,2 °C. The global warming will lead to the fact that extreme precipitation situations will occur more often. Situations which happened once in 50 years will in the future happen once in 25 years.

Also the predicted rise of the sea level, which is caused by the melting of the ice, is a big concern for Mumbai. Even though the average altitude in Mumbai rises from 10-15 meters, Mumbai has some risky low areas. Especially the coastal areas alongside the Arabian sea. Since the coastal regions have a low altitude of around 1 m above sea level, the predicted sea level rise is very risky. Only the Northern part of Mumbai is hilly and has an altitude from around 400 m, which can be seen on the map below.

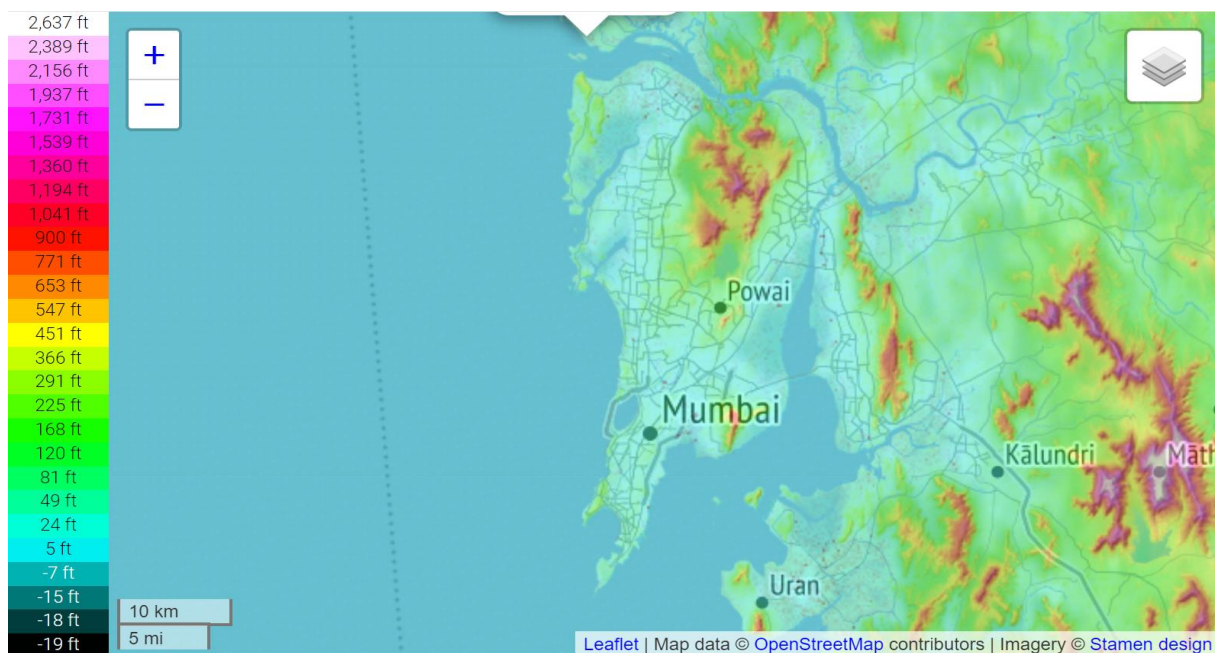


Figure 7, Altitude map of Mumbai

The monsoons strength will increase as well because of the global warming. There will be more rains in Mumbai and the rains will have a higher intensity. The flooding risk is the highest during the monsoon season. The monsoon is effect by the climate changes and global warming. The global warming and the monsoon are natural activities, but man made activities play an important role as well.

The ongoing city development in Mumbai is a big cause for the floods during the monsoon. The ideas are not thought out. This is mainly because of the corruption in Mumbai. There is no collaboration between different agencies who all work together on the city planning.²⁰ To create more space for all the people who live in Mumbai, a destruction of natural environments, which can absorb the water, takes place. This leads to the fact that Mumbai consists of only non-absorbing things like buildings and roads and therefore the water which falls during the monsoon cannot be infiltrated in the ground.

The drainage systems in Mumbai is a total fail as well. The system, which was put in place during the early 20th century, can only carry 25mm of water per hour. This is way to less during the monsoon, since during a monsoon the rainfall a day can be 944 mm. The drainage system is also clogged in several places, which leads to an obstacle in the water drain. At last, the drainage system ends directly into the sea. When there is high tide, the sea water will run into the drainage system with the effect that the water cannot be drained.

The sewage system in Mumbai is a negative point as well. The system is very old-fashioned because a lot of pipes are more than a 100 years old. Lots of pipes are clogged with waste. When a lot of rain falls during the monsoon period, the sewer lines will overflow instead of draining the water. This leads to contaminated drinking water and raining water on the streets during the monsoon.²¹

Thus, during the Monsoon season are the flooding risks the highest. During the rest of the year Mumbai is dealing with dry periods. In these periods is the flooding risk very low. The river will not overflow and there is no flooding risk from the sea. However, because of the global warming the extremes will be higher and will happen more often and there will be a threat from the sea. Therefore The location of Mumbai is not very advantageous for the flooding risks.

The effect of the climate on the houses in Dharavi

The summer monsoon season causes high amounts of rainfall during a day. This can lead to floods. During floods high forces, caused by the water, can cause houses to float away. A lot of houses in Dharavi do not survive the floods. Because of the average low incomes in Dharavi, people do not have the money to build strong and well insulated houses. However houses with strong constructions are needed to withstand the monsoon.

The high air humidity in Dharavi causes organic materials to rot faster. This has as an effect that non-treated wood will have a shorter lifespan.

The average warm climate causes high temperatures inside the houses of Dharavi.

²⁰ Indorewala, H., & Wagh, S. (n.d.). Here's Why Mumbai Floods Year After Year. Retrieved December 9, 2018, from <https://thewire.in/urban/mumbai-heavy-rains-floods-reasons>

²¹ Singh, P., & Vijhani, A. (2016). Identification of flood risk on urban road network using Hydrodynamic Model. Retrieved from [https://www.toi.no/getfile.php/1348346/Publikasjoner/Flooding Mumbai.pdf](https://www.toi.no/getfile.php/1348346/Publikasjoner/Flooding%20Mumbai.pdf)

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Economic situation

India belongs to the BRIC countries which is a group of Newly industrialized countries (NICS) A NIC country is a country where lots of labour-intensive industries from the wealthier economies are located due to the big number of inhabitants and low wages.²² BRIC is an acronym for Brazil Russia India and China. These countries are likely to be wealthier in 2050 than most current major economies. The prediction for India is that in 2050 it will be the world's dominant supplier of manufactured services and goods.²³ In India they pay with the currency Rupee, which the reserve Bank of India (located in Mumbai) has full authority of.²⁴ The value of the rupee compared to the euro is very different. 1 rupee is €0,0117.²⁵

Globalization is the process of an worldwide integration in trade, economy, financial and communication. Globalization is a process which is increasing and growing within the years. At this moment the process of globalization will be an important factor for India to become one of the wealthiest economies in 2050. Now a days, Mumbai is the most globalized city in South Asia and an economical hub in the hubs and spokes system of India. This is because Mumbai has the most internationalized economy, is the financial capital of India, has a port and two airports and is the location of the headquarters of NGO's and international institutions.²⁶ The big media and film business of India, called Bollywood is located in Mumbai and is a boost for the economy. Bollywood is the largest film industry in the world which produces the most films in a year. The effect of the big economy of Mumbai is that the income per capita is 3 times as much as the national average.²⁷

Besides the fact that Mumbai has a booming economy, the living conditions aren't good for everyone. This is because Mumbai's business is dominated by the wealthier people in the society and the people from a lower class don't have much to say. This leads to a dual economy. People in Dharavi lack a number of basic services, but they managed to create a micro-economy. Which could be an explanation for the informal economy of Dharavi. Only a few businesses in Dharavi pay taxes, the others are illegal, but this does not mean that Dharavi does not make any money. Dharavi is an example for other slums. Sometimes people visit Dharavi to get inspired and learn new jobs to set up in their own slum. The informal sector in Dharavi is enormous which causes people to work hard. Mohammed Asif, a worker in Dharavi said: "They work hard. They work from 8 in the morning until 11 at the evening because the more they do, the more they will earn to send back to their families. They come here to earn."²⁸ Earning money in Dharavi is not that difficult since there are lots of different jobs being executed for example: Plastic collectors, aluminium smelters, soap recyclers and leather production.²⁹

22 Globalisering in landen. (2017). Retrieved October 4, 2018, from https://media.scholieren.net/public/download/bijlage/1500730178_AK__Wereld_2.pdf

23 Staff, I. (2018, April 04). Brazil, Russia, India and China (BRIC). Retrieved October 16, 2018, from <https://www.investopedia.com/terms/b/bric.asp#ixzz5U5TuyqvM>

24 The rupee. (n.d.). Retrieved October 16, 2018, from <https://www.globalexchange.es/en/currencies-of-the-world/indian-rupee>

25 India Rupees. (n.d.). Retrieved October 16, 2018, from https://www.wisselkoers.nl/india_rupees

26 Clark, G., & Moonen, T. (2014, December). Mumbai: India's global city. Retrieved October 16, 2018, from https://www.jpmorganchase.com/corporate/Corporate-Responsibility/document/gci_mumbai_02.pdf

27 Overzicht van Mumbai. (2008, November 27). Retrieved October 16, 2018, from <http://www.easyexpat.com/nl/guides/india/mumbai/overzicht/economie.htm>

28 Yardley, J. (2011, December 28). In One Slum, Misery, Work, Politics and Hope. Retrieved September 20, 2018, from <https://www.nytimes.com/2011/12/29/world/asia/in-indian-slum-misery-work-politics-and-hope.html>

29 Miller, J. (n.d.). Johnny Miller - The Informal Economy of Dharavi. Retrieved October 16, 2018, from <https://www.lensculture.com/projects/338111-the-informal-economy-of-dharavi>

Social situation

Employment opportunities

Dharavi has a booming micro-economy which is why there is always work to find in Dharavi. People in Dharavi are there to earn money for their family. Therefore, the working opportunities in Dharavi are high. However, in the research paper of Van Krunkelsven a difference between the earnings of men and the earnings of women are different. "Their earnings appear to match their productivity in sorting. Virasj specifies that women can earn up to 150 rupees and men can earn up to 200 rupees. Respectively 1,97 and 2,63 euros."³⁰

Education

Mumbai is the educational and learning centre of India and in many cases is education a very important wealth that Indian parents want to give their child. However the over populated city is the cause of scarcity in the school and universities. There are 1188 primary schools in Mumbai which offer education for 485531 students.³¹ There are three different kinds of schools in India. There are public schools. These schools are under the control of the Maharashtra state board of education, which follows the SSC (Secondary School Certificate) curriculum. The children attend school for 15 years. When they pass the 10th grade, they get an admission to follow junior college for 2 years. After this the students can qualify for senior college. In the senior college they obtain an associate's degree in the direction they choose to do. The public schools offer lessons in English and Marathi. These schools are not very suitable for expats (people who live in another country than where they were born and raised³²) because their way of teaching isn't on the same level. Private schools can be found in Mumbai as well. The way of teaching in these school is more contemporary and it matches the global standards. They teach in English only and therefore are more suitable for expats. The international schools teach according to the IB programme (International Baccalaureate).

Mumbai has a university as well. This university focuses on the directions which have lots of work opportunities in Mumbai the most. These directions are engineering, fashion and designing and science.³³

³⁰ [Vankrunkelsven, K. (2014-2015). The City Within (p. 8, Rep.).]

³¹PARTICULARS OF ORGANIZATIONAL FUNCTIONS. (n.d.). Retrieved October 3, 2018, from [https://portal.mcgm.gov.in/irj/go/km/docs/documents/MCGM Department List/Education Officer/RTI Manuals/Education_Officer_RT1_E01.pdf](https://portal.mcgm.gov.in/irj/go/km/docs/documents/MCGM%20Department%20List/Education%20Officer/RTI%20Manuals/Education_Officer_RT1_E01.pdf) (8/10)

³² Expat - Dictionary Definition. (n.d.). Retrieved October 3, 2018, from <https://www.vocabulary.com/dictionary/expat>

³³ Education in Mumbai. (2016, February 10). Retrieved October 3, 2018, from <https://www.mapsofindia.com/education/mumbai/>

Education in Dharavi

Dharavi is the working centre of the city, but parents in India find education for their kids very important. However, lots of kids still don't enter a school because of other circumstances. The organization art of living does not only help to educate children, but it also influences the lives of these families in a positive way. The education does not only teach them the standard things you learn in school, like mathematics and reading and writing. It also teaches some important social factors. The teachers of this project lay emphasis on hygiene, health and individual responsibility. The children are encouraged to bring this message home and therefore it affects the families in in positive way. Bringing education to Dharavi is important since Dharavi is a working centre of the city. To get a change in the national and economical market it is important for the children in Dharavi to get a proper education, so their changes are higher. Even Though there is a lot of work in Dharavi, it will enlighten their future when they got proper education.³⁴



Figure 8, Logo of the school in Dharavi



Figure 9, Dharavi school

³⁴ Meri Dilli Meri Yamuna: A massive river cleaning drive. (n.d.). Retrieved October 3, 2018, from <http://projects.artofliving.org/project/bringing-education-to-the-biggest-slum-in-asia-at-dharavi-in-mumbai/>

Cultural situation

The cultural diversity in Mumbai is immense. This is because Mumbai was and still is a city which pulls lots of immigrants towards it due to the work opportunities, for example the informal economy of Dharavi pulls lots of immigrants since most of the businesses do not pay taxes.

Language

The cultural diversity in Mumbai has as an effect that Mumbai is a multi-lingual city. Lots of languages are spoken in Mumbai including the sixteen major languages of India. The lingua franca is Marathi, but English and Hindi are spoken a lot as well. Marathi is often used for communication on the streets among other inhabitants. English is used for professional, national, commercial and political purposes. Hindi is the main language in India and therefore, together with English often spoken in tourist destinations. In Dharavi there are a lot of different nationalities which leads to different languages being spoken. A new language originated in Mumbai, called the Mumbaiiya or Bumbaiya version of Hindi. This language/dialect is a mix of English, Marathi and Hindi and spoken by numerous inhabitants of Mumbai.³⁵

Religion

This cultural diversity leads to a mix of religions including; Hindus, Muslims, Buddhists, Zoroastrians, Jains and Christians. Hindus cover around $\frac{2}{3}$ of the people in Mumbai. The Muslim population is a large population as well. Many parts of Mumbai were Islamic colonies which caused the high Muslim population. The other religions cover a small percentage of the population of Mumbai. All Mumbaikars are passionate about their holy festivals and all the festivals are celebrated by all the people. Unity is very

important on those days and for Mumbaikars throughout the whole year.³⁶

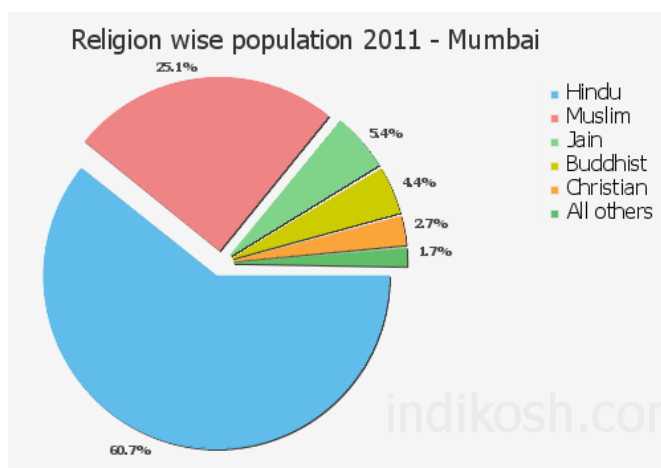


Figure 10, Religion

³⁵ Mumbai Language. (n.d.). Retrieved September 26, 2018, from <https://www.mumbai.org.uk/travel-tips/language.html>

³⁶ Mumbai Religion. (n.d.). Retrieved September 26, 2018, from <https://www.mumbai.org.uk/travel-tips/religion.html>

Historical context Mumbai

History of Mumbai

The History of India can be divided into 4 periods, the early history, the Portuguese period, the British period and the independent period. In the early history of Mumbai were the fishermen communities dominant in Mumbai. The Koli fishermen communities are seen as the first inhabitants of Mumbai.³⁷

In the Portuguese period were the seven island of Mumbai captured by the Portuguese. This happened in 1534. The Portuguese people called the area Bom Bahia (the good bay). The English people pronounced it as Bombay. The trading centre became more and more important and products such as silk, rice, cotton and tobacco were traded.³⁸

In 1661 the British people controlled Mumbai however they were not in a strong positions since the Mughals, Marathas, Portuguese, and Dutch all wanted to control Bombay. In the 19th century Bombay started to grow. This was the effect of external events which led to urbanisation. Bombay was growing even faster and things like being the largest cotton market of India in 1860 and the opening of the Suez canal all had a positive influence on the prosperity of Bombay. While the population increased, living conditions became worse. This led to development of suburban areas.³⁹

In 1947 India achieved independence. It was a very important day and is still celebrated in Mumbai.

Slum development in general

Slums are almost always located near or in a big city. Slums develop because there is not enough living space in the city for all the immigrants and because there are not enough working opportunities. The push and pull factors will be a little different per region, but do look like each other. In many cases in India, people migrate from rural area. Their push factor is the low income in rural areas and the harsh working conditions. The push factor can also be a scarce year with bad harvests. The pull factor is the job opportunities and the envision of earning a lot of money for the family. Because of the push- and pull factors, people migrate from the land towards to city. This process is called urbanization. When normal urbanization takes place, nothing extraordinary is happening and cities are just developing, but when

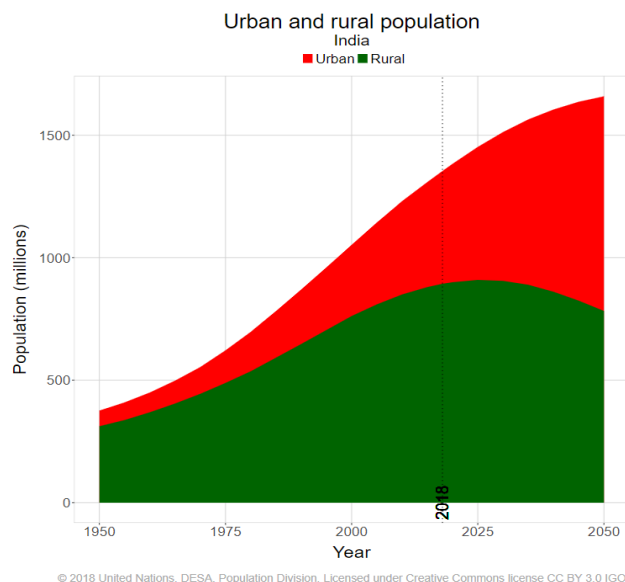


Figure 11, This graph shows the number of inhabitants in urban and rural areas in India.

Note: this is not about Mumbai.

37 Chakrabarty, A. (2016, October 12). The Kolis Of Bombay: The Original Residents Of The City. Retrieved September 13, 2018, from <https://theculturetrip.com/asia/india/articles/the-kolis-of-bombay-the-original-residents-of-the-city/>

38 Bombay: History of a City. (n.d.). Retrieved September 13, 2018, from <http://www.bl.uk/learning/histcitizen/trading/bombay/history.html>

39 Raghavan, C. (2015, September 2). Mumbai. Retrieved September 13, 2018, from <https://www.britannica.com/place/Mumbai>

overurbanization takes place, problems begin to develop. In the first place, the land and house prices will increase, because the city is in great demand. This is the case in Mumbai. Also a fall in wages and unemployment increases. This is because there is a big demand for jobs, which makes it possible to lower the wages, because people will eventually work. The unemployment is because of all the “extra” people in the cities there are not enough jobs for everyone, so the unemployment rate increases.⁴⁰ The result of this is that the difference between the poor people and the rich people will bigger. The poor people, most of them are the immigrants, cannot afford a proper house, so they will develop their own houses, their own little city. Most of the time are the slums located near dangerous places, since these are the places where nothing is built yet. To earn money for their family, people create an own economy with work opportunities, which is the case in Dharavi.

What is notable is that the demographic composition of most slums consists of mainly younger people. This is because at the beginning of the urbanization, the younger people migrate to the city, because for them there is a bigger change that they will find a job and be successful. This causes a brain drain at the rural area, since all the “smarter” people move to the city. There are not enough jobs for these younger people, which leads to them moving to a slum, which leads to more younger people in a slum.

History of the developments in Dharavi

Dharavi developed over the years when more people needed to work and needed a place to live, but in the year 1980 the land was scarce which lead to a big urbanization of migrants from the land. The land could be easily claimed since it was an informal rubbish dump, marsh land and the land was free.⁴¹ Rajiv Gandhi was the prime minister from 1984-1989. He saw Dharavi growing bigger and therefore he reserved one billion rupees (12 million euros) for a program which focused on building affordable houses for the poor people. His plan let to a disaster. A lot of money was used for other purposes and the houses that were build are now dilapidated which led to the growing of the slum. When Dharavi was located on the edge of the city, the city of Mumbai was not affected by Dharavi, but when Mumbai continued to grow northwards Dharavi became the centre of the city. Now lots of politicians and elite people see Dharavi as a problem and a failure for the city of Mumbai. This led to the plan in 2002 to tear Dharavi down and build new apartment blocks. Huge protests against these plans took place. In 2003 the government of Maharashtra decided to redevelop Dharavi and create an integrated planned township.⁴² In 2006 a new plan was introduced. This plan consisted of the construction of



free apartments for the Figure 12, Example of redeveloppment plan

40 Impacts of urbanisation in Mumbai - A-Level Geography - Marked by Teachers.com. (n.d.). Retrieved December 10, 2018, from <http://www.markedbyteachers.com/as-and-a-level/geography/impacts-of-urbanisation-in-mumbai.html>

41 Yardley, J. (2011, December 28). In One Slum, Misery, Work, Politics and Hope. Retrieved September 20, 2018, from <https://www.nytimes.com/2011/12/29/world/asia/in-indian-slum-misery-work-politics-and-hope.html>

42 झोपडपट्टी पुनर्वसन प्राधिकरण, मुंबई. (n.d.). Retrieved October 4, 2018, from <http://sra.gov.in/page/innerpage/about-drp.php>

inhabitants of Dharavi. The additional space could be used for different investors. The plan was supported by the inhabitants of Dharavi and business leaders. Due to bureaucratic infighting and the different perspectives on the problem the plan was cancelled. Afterwards critics said that the plan was basically a giveaway to rich developers.⁴³ In the year 2010 Dharavi was still a problem for the elite people, however the formed solutions are not in favour of the inhabitants of Dharavi anymore, but in favour of private developers. This is because over the years Dharavi's land became worth hundreds of millions of euros. In the eyes of private developers can the land be used for a lot of profit making purposes. This made the interests of the inhabitants of Dharavi even less important.⁴⁴ Now a days lots of redevelopment plans are proposed, but nothing is done.



Figure 13, Example of redevelopment plan

Political situation

India is a democratic republic which consists of several states with a preponderant federal structure. The official name of the country is the republic of India. The president of India is Ram Nath Kovind. The president and the vice president are chosen every five years by a specialized electoral college.⁴⁵

Mumbai is the capital of the state Maharashtra. The government in the state functions according to a parliamentary system. The lower house is the Vidhan Sabha and the upper house is the Vidhan Parishad. The two most popular parties are the NCP and INC. Together they form the coalition.⁴⁶

The township of Mumbai is ruled by the Brihanmumbai Municipal Corporation (BMC). The mayor of Mumbai is Vishwanath Mahadeshwar. The township of Mumbai is divided into two regions, Mumbai city and Mumbai suburban. Mumbai city is the southern part on the peninsula. The rest belongs to Mumbai suburban.⁴⁷

⁴³ Vankrunkelsven, K. (2014-2015). The City Within (p. 10, Rep.). [PDF]

⁴⁴ Yardley, J. (2011, December 28). In One Slum, Misery, Work, Politics and Hope. Retrieved September 20, 2018, from <https://www.nytimes.com/2011/12/29/world/asia/in-indian-slum-misery-work-politics-and-hope.html>

⁴⁵ Cultuur van India. (n.d.). Retrieved September 25, 2018, from <https://www.indiaweb.nl/cultuur-india/>

⁴⁶ Maharashtra. (n.d.). Retrieved September 25, 2018, from <https://nl.wikipedia.org/wiki/Maharashtra>

⁴⁷ Bombay. (n.d.). Retrieved September 25, 2018, from <https://nl.wikipedia.org/wiki/Bombay>

FSI

Mumbai has a very high population density and Dharavi even higher. However there are strict rules in Mumbai over the height of building to create extra space. New buildings should meet the FSI of a city.

FSI stands for the Floor Space Index. FSI is the law that regulates how much floor space a building can have relative to the property size. The FSI can be determined by dividing the total surface of the lot by the total floor surface of a building. So, how higher the FSI, how taller the buildings may be. The FSI calculation is described in the following formula:

$$\text{Total Constructed area} / \text{Total land area} = \text{FSI}^{48}$$

For a long period of time the FSI is kept low so elite people, including people in the governance of Mumbai could earn a lot of money by their owned properties which were only increasing in value, thanks to the high demand of space and low FSI.⁴⁹

In April 2017 the FSI increased. The FSI in the city centre had a maximum of 1,33 across commercial and residential projects. Now it's maximum 3 for residential projects and maximum 5 for commercial projects. The FSI changed in the suburbs as well. For residential projects it changed from max. 2 to max. 2,5 and for commercial projects from max. 2,5 to max. 5. This still are low FSI's compared to other metropolises. New York has a maximum FSI of 15, Singapore a max. FSI of 14 and Dubai has even an unlimited FSI.

The effect of a low FSI is that new building won't be able to be high, to create extra space in the city. This results in extraordinary high rents and high prices which a lot of people can't afford. So they have to go to the suburbs or have to choose for a living in a slums such as Dharavi.⁵⁰ The government's effort to build affordable housing has been poor.⁵¹

48 Bepalen van grondoppervlak voor een FSI-berekening (Publication). (n.d.). Retrieved September 26, 2018, from

file:///C:/Users/flori/AppData/Local/Packages/Microsoft.MicrosoftEdge_8wekyb3d8bbwe/TempState/Downloads/Brittenstein kaders en randvoorwaarden bepalen grondoppervlak voor FSI bijlage 4 (1).pdf

49 Vreeken, R., & Rutting, R. (2006). Bombay, hyperstad. Amsterdam: Meulenhoff.

50 Moch, S. (2017, September 17). Corrupt Space A View of Mumbai's Protest Slum. Retrieved September 26, 2018, from <https://medium.com/age-of-awareness/corrupt-space-d62d35c9b34c>

51 Yardley, J. (2011, December 28). In One Slum, Misery, Work, Politics and Hope. Retrieved September 20, 2018, from <https://www.nytimes.com/2011/12/29/world/asia/in-indian-slum-misery-work-politics-and-hope.html>

Expensive ground

Living in Mumbai is rather expensive. Not all people can afford a proper house, which leads to a lot of slums.⁵²

The location of Dharavi is attractive for the real estate. According to some, Dharavi belongs to the most valuable pieces of real estate in Mumbai. By some people this is seen as a problem since Dharavi is seen as an embarrassment or as a failure. People who know Dharavi know that Dharavi is not a failure.

A lot of inhabitants and politicians say that Dharavi must be developed. However, a lot of the politicians and developers don't want to develop it for the inhabitants of Dharavi, they want to build office buildings and shopping centres for the elite. Since most of the land in Dharavi belongs to the government they are allowed to do anything they want. By building things for the elite, they do not solve the problem, they make it bigger since the people in Dharavi have nowhere to go when their houses are destroyed for the governments projects. When they have nowhere to go they will find another place to start a new slum.

Political parties and Dharavi

Political parties try to win votes in the slums by delivering things like toilets and adding faucets in the slums. However the biggest part of the politics in Mumbai try to raze Dharavi's economic success.

The thoughts of Mumbai's inhabitants about Dharavi

The inhabitants of Dharavi are sceptic about redeveloping plans, according to an inhabitant. "They are talking about redeveloping Dharavi," said Mohammad Khurshid Sheikh, who owns a leather shop. "But if they do, the whole chain may break down. These businesses can work because Dharavi attracts labour. People can work here and sleep in the workshop. If there is redevelopment, they will not get that room so cheap. They will not come back here."

According to Matias Echanove, an architect and urban planner: redeveloping it, would only push residents into other slums. "They are going to create actual, real slums," he said. "Nobody is saying Dharavi is a paradise. But we need to understand the dynamics, so that when there is an intervention by the government, it doesn't destroy what is there."⁵³

The following quote is the thought of Kishore, a man interviewed by K. Vankrunkelsven: "I think in fact the government encourages them to do what they're doing. The government needs them, because they are the people who vote, the governments never really want people to grow out of their shell. Because then they can become too powerful. So they like to run a country like this, because it is much easier for them. Another thing is that the government is relocating people from other slums in the city to Dharavi. So that they're all concentrated in one area which is run by an organisation called MHADA These people make houses which they feel that the people who live in Dharavi will be able to afford at some stage of their life. But when you look at it from their perspective, they're quite happy being where they are. So there's a reluctance to be relocated into these high-rise buildings."⁵⁴

⁵² Yardley, J. (2011, December 28). In One Slum, Misery, Work, Politics and Hope. Retrieved September 20, 2018, from <https://www.nytimes.com/2011/12/29/world/asia/in-indian-slum-misery-work-politics-and-hope.html>

⁵³ Yardley, J. (2011, December 28). In One Slum, Misery, Work, Politics and Hope. Retrieved September 20, 2018, from <https://www.nytimes.com/2011/12/29/world/asia/in-indian-slum-misery-work-politics-and-hope.html>

⁵⁴ Vankrunkelsven, K. (2014-2015). The City Within (p. 10, Rep.).

Current houses in Dharavi

The current houses in Dharavi are mostly made out of wood, sheets and plastic. Sometimes concrete is used for the floor. There are some houses in Dharavi that are built from bricks, but this is more expensive to make. The houses are made by the inhabitants themselves and with help from construction workers. The houses are small and most of them have 2 floors with only one room on each floor. The houses are shared with many people varying from 5-15. Almost all the houses in Dharavi have electricity and internet due to the illegally draining from the main service lines. In the research paper of Vankrunkelsven an owner from different houses (for rent) said: "So if you can build a strong house with waste that would be very good. More people would be able to afford a house." This is an important aspect for our design. The current houses need constant repairing if this is not done than there is a big change that the whole building will collapse.⁵⁵



Figure 15, Side view of houses in Dharavi



Figure 14, House including inhabitants



Figure 16, Some houses made from bricks and sheets

⁵⁵ Vankrunkelsven, K. (2014-2015). *The City Within* (p. 12, Rep.).

Current living conditions in Dharavi

In Dharavi the main problems concerning living conditions are the privacy, the hygiene and the smell. However, the materials their houses are made of are also important since the different characteristics of materials result in a difference in durability and living comfort of the house.

The hygiene is terrible because of a lack of toilets and the open sewage system. This also causes the terrible smell in Dharavi. The terrible smell also comes from all the waste which is produced in Dharavi and all the air pollution coming from the small workshops. People in Dharavi are living with many people in one house which effects the privacy. Almost all the houses have just one or two small rooms where they sleep with everyone. To improve the privacy, people try to build their houses higher which has as an effect that the houses come closer to each other. This leads to a bad air circulation and less light entering the small alleys. Another factor that decreases the living conditions is the access to water. People in Dharavi have only access to running water 2-3 hours a day. In this amount of time they need to clean themselves, clean clothes, do dishes and they need to save enough water for the rest of the day to drink from and cook with.

At last, the monsoon period leads to heavy rainfalls, which leads to the houses flooding away. This has a negative effect on the living conditions since the water can destroy their house and therefore they lose certainty on a shelter.



Figure 17, A women walking on a pipe next to all the waste

Theory of the design

Construction

Materials

Bamboo is a perfect material for the construction of a building. Bamboo is available in Mumbai. There are several bamboo retailers which sell bamboo for construction. Bamboo in Mumbai is not expensive. A bamboo pole of 4 metres long and with a diameter of approximately 12 cm has an average cost of Rs 70 (€0,82), which is approximately €0,20 per metre. There are several stores in Mumbai where you can buy bamboo poles with a length over 10 metres. These poles have approximately the same price a metre ratio as the poles with a length of 4 metre.⁵⁶

The following bamboo species are recommended for building, in India:⁵⁷

- *Bambusa nutans*
- *Dendrocalamus brandisii*
- *Oxytenanthera stocksii*
- *Melocanna bambusoides*
- *Dendrocalamus strictus*
- *Dendrocalamus hamiltonii*
- *Dendrocalamus giganteus*
- *Bambusa bambos*
- *Bambusa polymorpha*
- *Bambusa balcooa*

Dendrocalamus brandisii, Dendrocalamus strictus and Bambusa bambos are the most suited species because they can grow the closest to Mumbai.

Dendrocalamus brandisii is primarily found in tropical forests. It grows on several places in India, including Karnataka, relatively close to Mumbai. The culm can grow up to 20 metres tall.

Dendrocalamus strictus is found in places with an altitude of up to 1000 metres, in dry, open and deciduous forests. This bamboo specie is widely distributed and is the most common bamboo specie in India. The culm can grow up to 10 metres tall.

Bambusa Bambos grows mostly in deciduous forests as well. It is found in places with an altitude of up to 1000 metres. It prefers warm and moist soils. It grows near perennials rivers and valleys. It is found throughout the whole of India. The culm can grow up to 30 metres tall. This specie is used a lot for roofs of houses.⁵⁸

⁵⁶ Indiamart > bamboo > bamboo in Mumbai, <https://dir.indiamart.com/search.mp?ss=bamboo>

⁵⁷ Ras, D. (2014, July 17). Bamboo species good for construction in india nd as a material [PPT].

⁵⁸ Ras, D. (2014, July 17). Bamboo species good for construction in india nd as a material [PPT].

In the Netherlands it is not possible to buy one of the bamboo species recommended for building, in India (we couldn't find it after a long research). We emailed five Dutch bamboo retailers. We asked which bamboo species grow close to Mumbai and are suited for construction. None of them knew a specie meeting these requirements. However they gave us some species which are suited for construction and are available in the Netherlands. Tonkin bamboo is the specie we are going to use during our tests because it's strong enough for construction and is available in poles with a small diameter, which makes it possible for us to work with a scale of 1:10.

The Latin name of Tonkin bamboo is *Pseudosasa amabilis*. It grows in China, Japan, Korea and Vietnam.⁵⁹

There are over 1450 different species of Bamboo. Not all are suitable for construction. Bamboo is popular because of its combination between strength and flexibility.⁶⁰ It also provides earthquake proof constructions.⁶¹ Bamboo is relatively light weighted and cost effective, especially in regions where it can grow. Untreated bamboo has an average life span from 1-3 years when exposed to soil and atmosphere.⁶² However if the bamboo is treated properly, designed carefully and maintained, a bamboo house can last a lifetime.⁶³

Bamboo is often used as a more durable alternative to timber or other building materials. Bamboo can grow much faster than timber. It also has a low or even negative carbon footprint. It reduces pressure on forests, in which the wood is meant for construction. Because of the round and hollow form of bamboo, it can replace cement and plastic in drainage pipes, and other parts of a house. Thanks to the resilient structure of bamboo, bamboo constructions can withstand earthquakes.⁶⁴

When bamboo is used as an alternative of steel in concrete a thin layer of epoxy with a coating of sand is used to protect the concrete from breaking because of the slight expansion of bamboo when it gets wet. Using the right method, a concrete foundation can be used for a bamboo construction.⁶⁵

*Bamboo is a difficult material to bend, however there are several methods. The first method is sawing pieces out of the bamboo so it can be bend. The second method is to heat the bamboo and then bend it and when it's bend cool it down with water. These two methods should work with relatively green bamboo. Dried up bamboo has the characteristic to go back in its original shape, to prevent this from happening dried bamboo should be heated with a butane torch under tension when it's bend.*⁶⁶

⁵⁹ Bamboe Bouw Nederland, <https://www.bamboebouwnederland.nl/>

⁶⁰ Ras, D. (2014, July 17). Bamboo species good for construction in india nd as a material [PPT]

⁶¹ Schröder, S. (2010, August 21). The Reality about Building with Bamboo. Retrieved September 26, 2018, from <https://www.guadabamboo.com/construction/the-reality-about-building-with-bamboo>

⁶² Ras, D. (2014, July 17). Bamboo species good for construction in india nd as a material [PPT]

⁶³ Frequently Asked Questions. (n.d.). Retrieved October 4, 2018, from <http://ibuku.com/resources/faq/>

⁶⁴ SDG11-Sustainable Cities & Communities. (n.d.). Retrieved October 8, 2018, from <https://www.inbar.int/programmes/sdg11-sustainable-cities/#1>

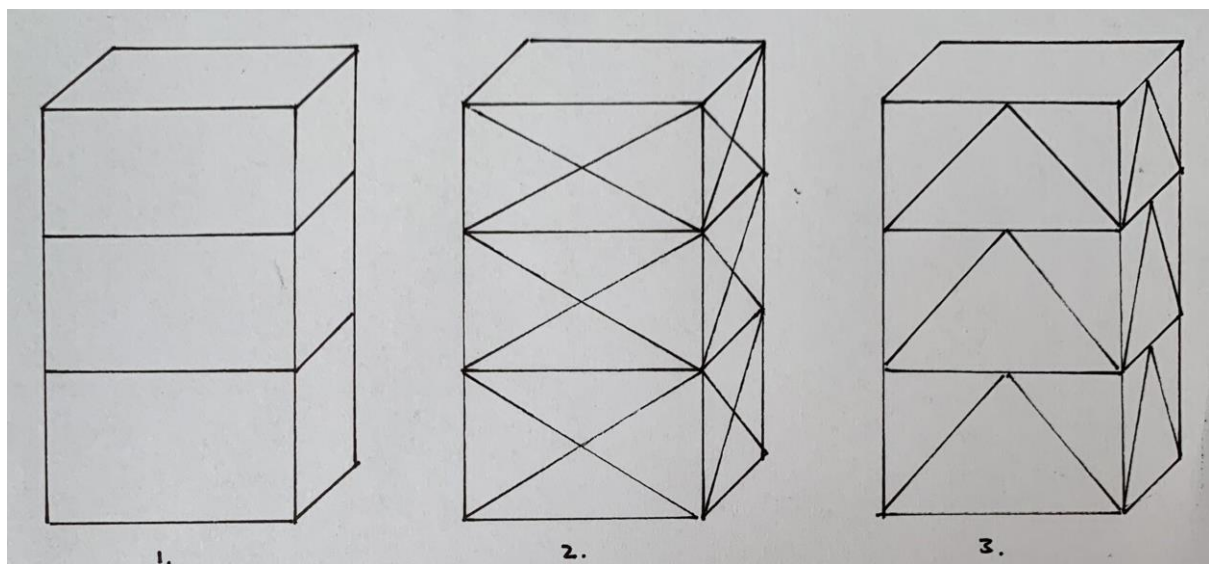
⁶⁵ Ras, D. (2014, July 17). Bamboo species good for construction in india nd as a material [PPT]

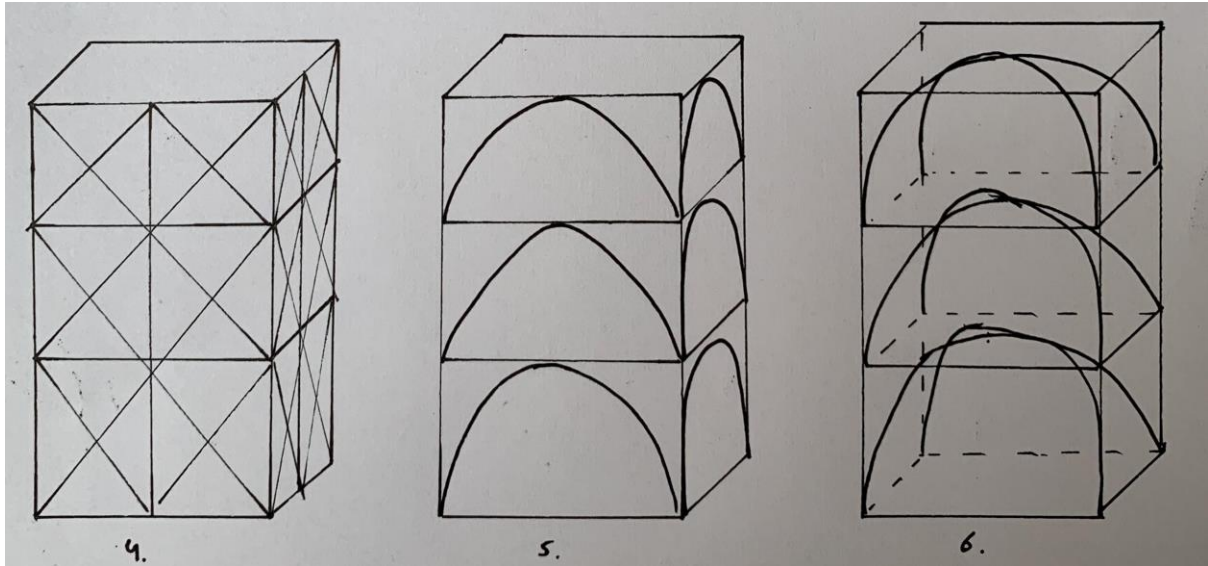
⁶⁶ Schröder, S. (2013, September 24). How to Bend Bamboo. Retrieved October 8, 2018, from <https://www.guadabamboo.com/working-with-bamboo/bending-bamboo>

Design

To attach the bamboo poles to each other, rope will be used. We did research on different types of rope. Meshing was the first rope we thought of. It's produced on a durable way and it's quite strong. However, meshing isn't water resistant and in an outside climate it won't last for a long period of time. After some more research we ended up with rope made out of polyester. It's not produced with durable sources however it's very strong, it is water resistant and does last for a long period of time, even outside. It is used for boats and climbing, which suggests it's resistance to extreme circumstances. Polyester rope costs approximately €0,10 per metre.

For the construction we first thought of possible designs. We made sketches of them. We thought of several approaches. We made one design as simple as possible to take as a starting point (drawing 1). In the designs of drawing 2, 3 and 4 we added diagonal beams to support the construction and add more stability to the design. We eventually realised the design in drawing 3 will be much weaker than the designs in drawing 2 and 4, so we eliminated design 3. We also made two different design using a bow construction. We knew this is a very strong structure which already was used by the romans. The bow construction would be strong however it's much more difficult to build, because you have to bend bamboo.

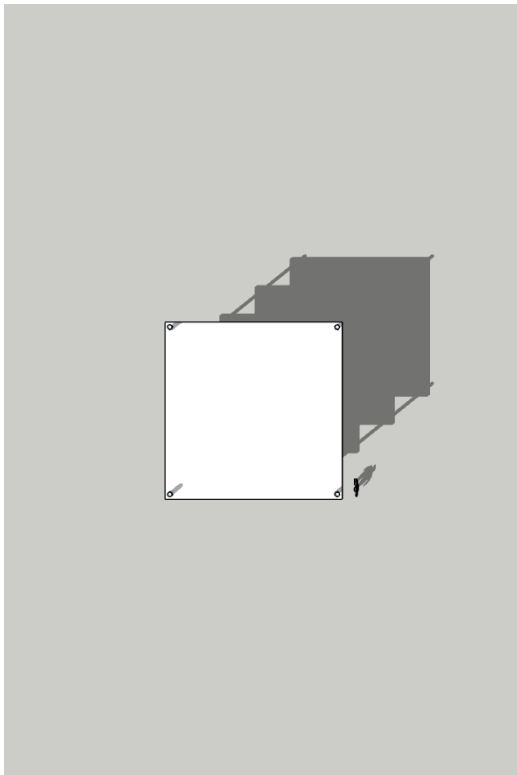
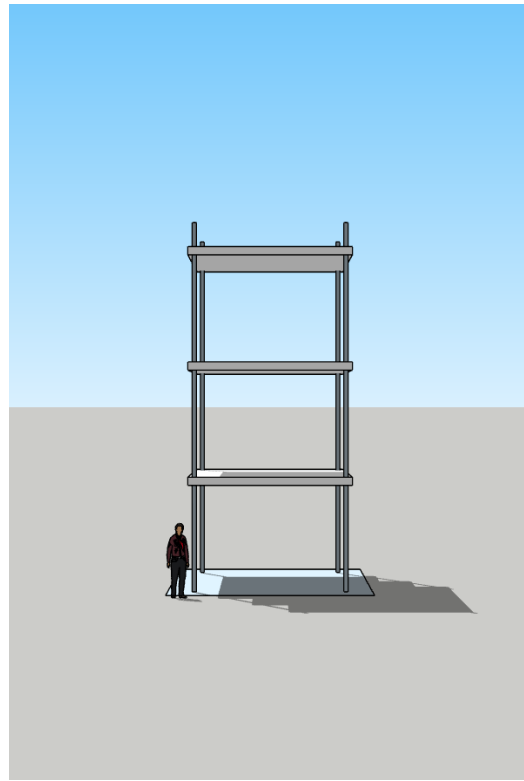
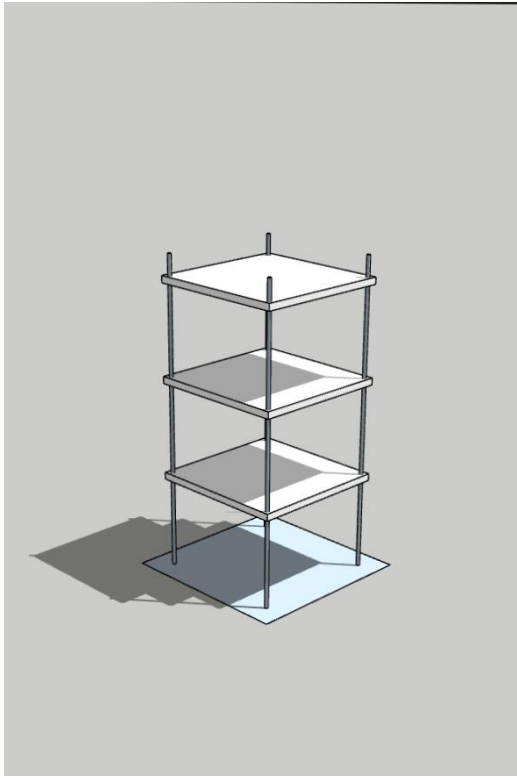




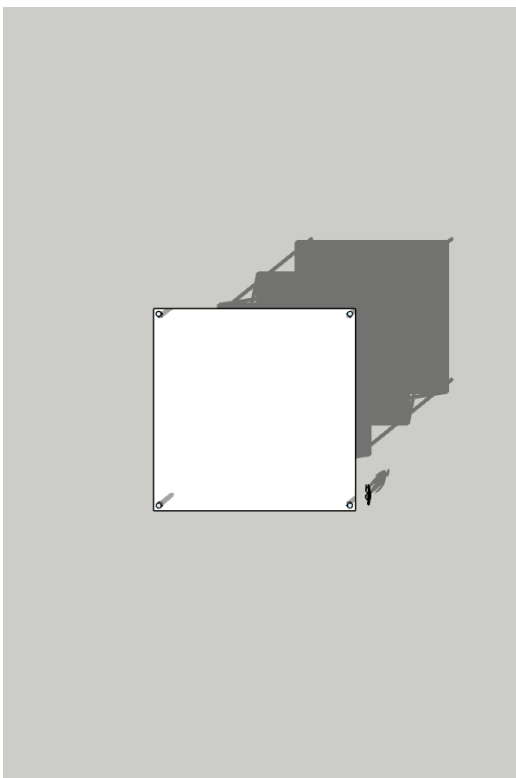
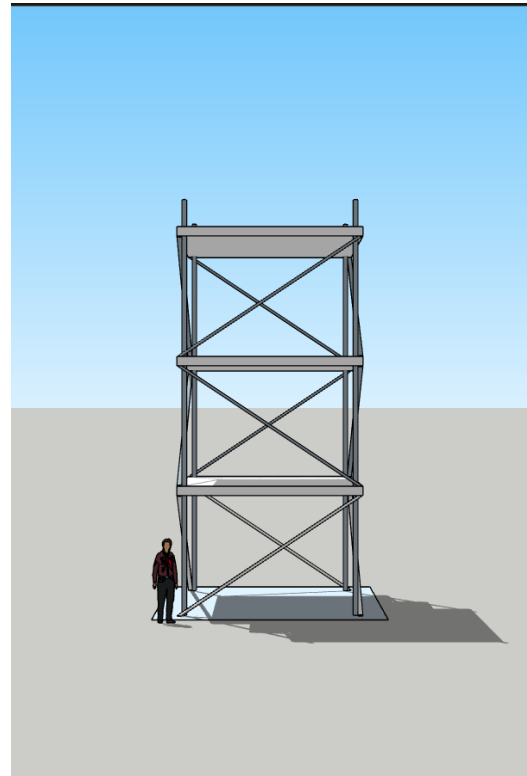
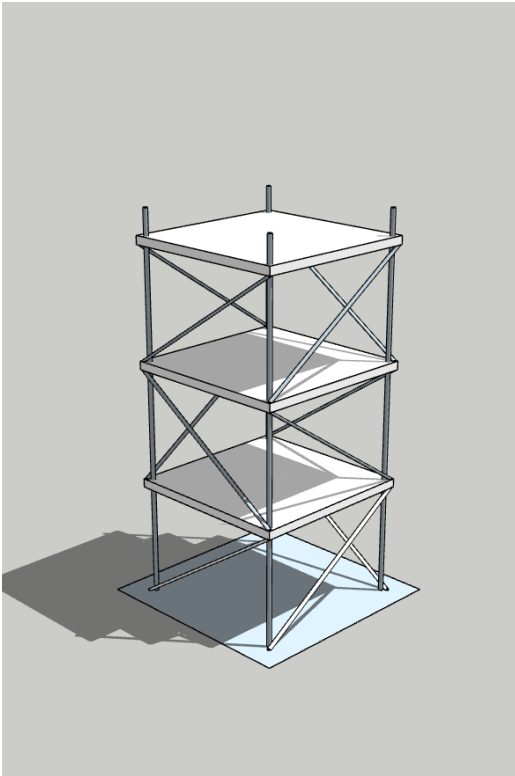
After we discussed our first six designs, we got a little more specific. We still wanted to keep the simple design as a starting point (Plan A). We chose one design with diagonal beams. We tried to make a design with less bamboo but with the same strength, this resulted in Plan B. We also still included one design with a bow construction, plan C. We chose drawing 6 above drawing 5, because the bows in the middle would support the floors, instead of the beams at the sides, which already would be supported by knots.

We started with making plan A and tested its strength. The idea was to decide which method we were going to use after we tested bending the bamboo and after we made the construction of plan A in real life.

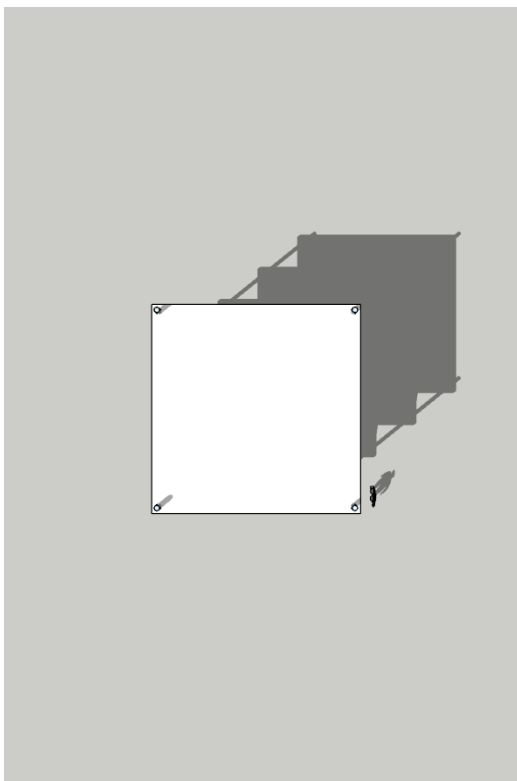
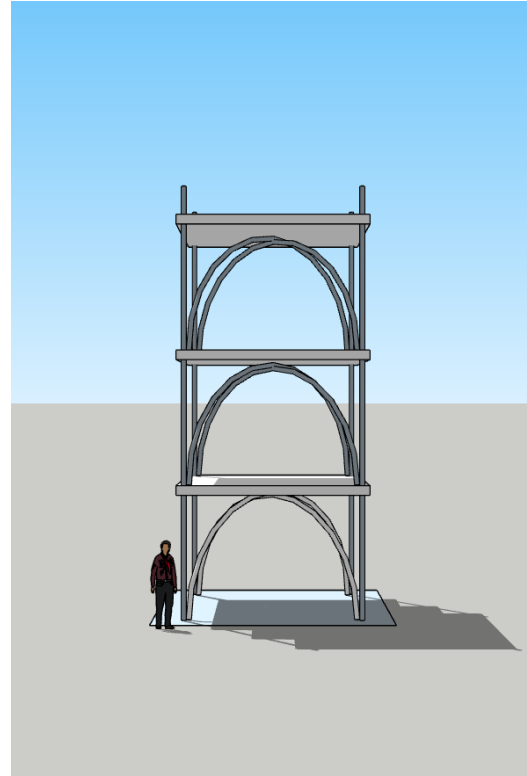
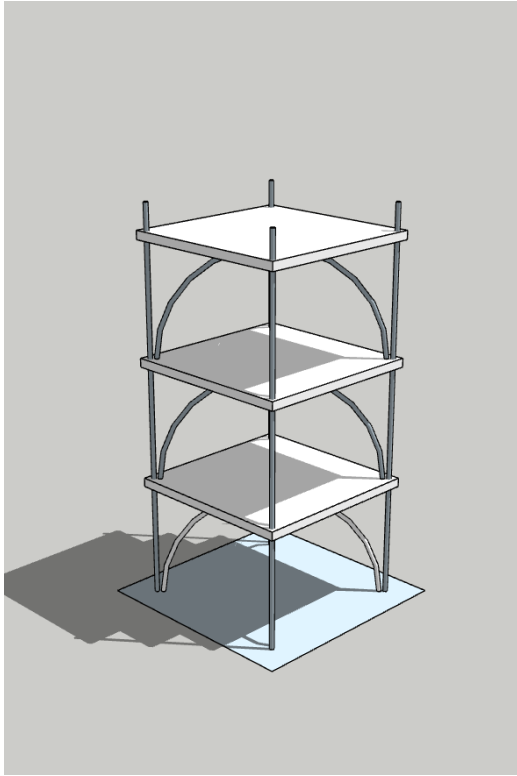
Plan A



Plan B



Plan C



Foundation

Materials

The foundation of a building is often made out of concrete with steel reinforcements. Concrete is a very strong material which will last for a long time. However the use of concrete can contribute to the emission of carbon dioxide. For the use of concrete a lot of energy is needed. This energy often comes from the burning of fossil fuels.

For the foundation of our house we would like to use a concrete alternative which is more sustainable than concrete. We searched for several alternatives, explained below.

Hempcrete and timbercrete are the best alternative for concrete compared to other, more natural, materials. In hempcrete the inner fibres of the hemp plant are used. A hemp plant is relatively fast growing and it's a renewable source. Timbercrete uses a mixture of industrial waste, sawdust and concrete. Both alternatives are relatively light compared to traditional concrete.



Figure 18, A block made out of hempcrete



Figure 19, Blocks made out of timbercrete

Another alternative is Mycelium. Mycelium is a material made from the root structure of fungi. It can be grown in all shapes. Once dried it's very light and strong.

Ferrock and ashcrete use alternative components in concrete just as hempcrete and timbercrete. Ferrock uses industrial waste including steel dust, which makes this a extremely strong material, even stronger than traditional concrete. Ferrock can absorb CO₂ in its drying process. Ashcrete makes use of fly ash, a polluting rest-product of burning coal.

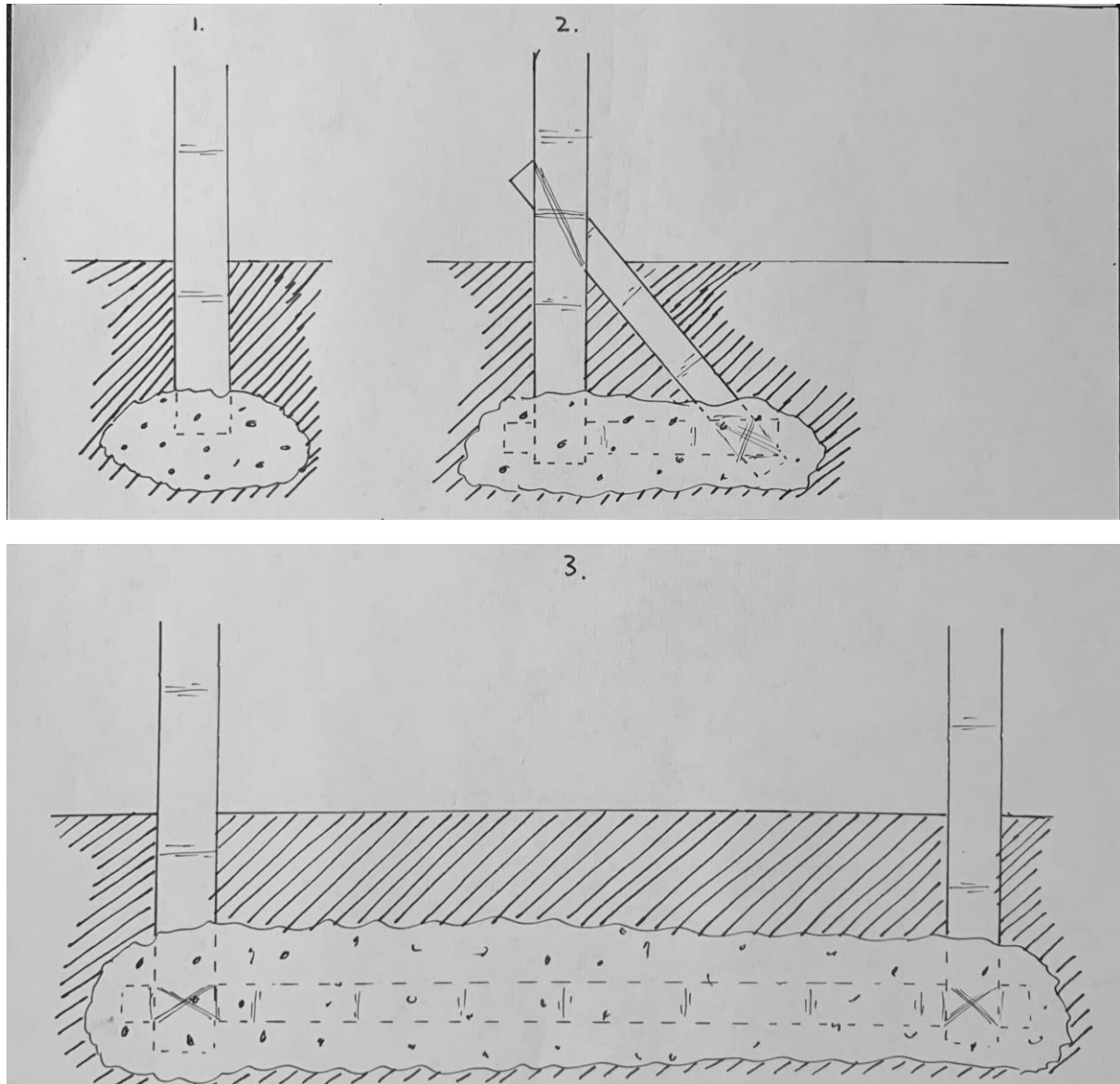
Aircrete consists of 80% recycles content. The material can be used for load bearing purposes. Aircrete is known for its smooth surface.⁶⁷

For our house we are going to use hempcrete. It's lighter than concrete, so easier to install. A large part of its resources can be grown, which makes it a more renewable source compared to traditional concrete.

⁶⁷ 5 sustainable alternatives to carbon intensive concrete. (2017, September 07). Retrieved October 24, 2018, from <https://www.worldbuild365.com/news/x4xuh5hrb/building-architecture/5-sustainable-alternatives-to-carbon-intensive-concrete>

Design

We wanted to make the foundation of our house as simple as possible, so it would be easy to build. We thought of several approaches. The first one is just a block of a concrete alternative underneath every bamboo beam. The second approach is a little more reinforcements to create a bigger area on which the entire structure is build. In the second approach we also used diagonal reinforcements for less friction between the vertical and horizontal beams. The third approach is a bamboo beam under the ground covered in a concrete alternative, covering the entire length of the house.



Walls

Materials

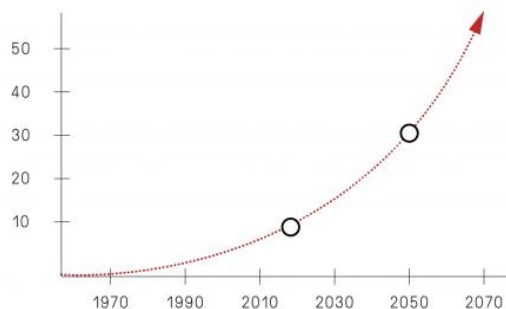
For the facade and the walls we wanted to use plastic waste. Mumbai is overloaded with plastic waste. It can be found everywhere. We want to use this plastic waste for the facade and walls of the house. Waste plastic does not have a purpose and it's very cheap. This makes it a perfect building material. Used in the right way, the plastic waste can be extremely strong. We had several ideas about using the plastic.



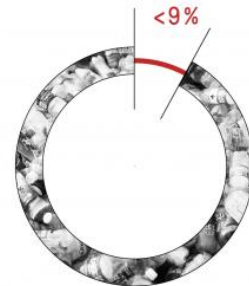
Figure 20, Plastic waste in Dharavi

The first idea is to reform the plastic to building blocks. After some research on the internet we found the company ByFusion. They make bricks out of plastic. The bricks are called ByBlocks.

According to the company humans have made 8,3 billion M tons of plastic. That is $8,3 \cdot 10^{18} \text{ kg}$. They say that the estimated mass of plastic in 2050 will be $3,4 \cdot 10^{19} \text{ kg}$. Only less than 9% is recycled according to ByFusion.



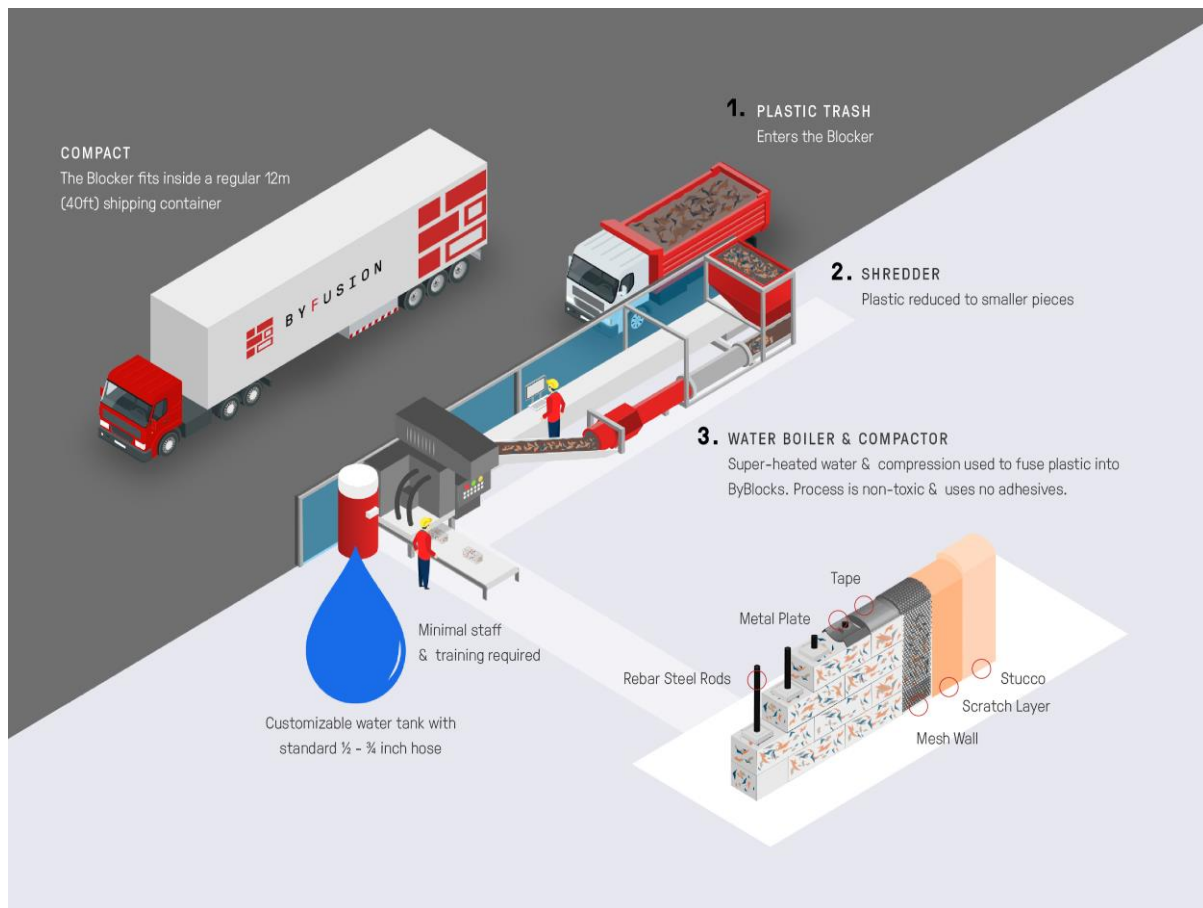
**TO DATE, HUMANS HAVE MADE 8.3BN M TONS OF PLASTIC
BY 2050 THAT NUMBER IS ESTIMATED TO INCREASE TO 34BN**



**AS OF TODAY, LESS THAN 9%
OF PLASTIC WASTE IS RECYCLED**

They claim that the ByBlocks will be better insulated than concrete and the material will be stronger than bricks.

The bricks are made in a machine called 'The Blocker'. In this machine the plastic trash is made into smaller pieces. Then the plastic runs through the water boiler and compactor in which the plastic get



compressed into a brick shapes. The process is non-toxic and doesn't make use of an adhesive.⁶⁸

We were thinking about making plastic tiles at the same way as the blocker does and creating a click system with them. However this idea has two major disadvantages. For the melting and reforming of the plastic a lot of energy is needed. The second disadvantage is that the bricks/tiles will be extremely heavy. According to the Binas most plastics have a density of 10^3 kg m^{-3} .

Using plastic bottles, filled with other plastic waste is another option for the walls. This doesn't cost as much energy and will be much lighter. The plastic waste and plastic bottles can be collected by the locals themselves or be bought for a relatively low price. However the plastic of these bottles and the other plastic waste is much weaker than common building materials for walls, so a reinforcement is needed. This can be easily made out of bamboo.

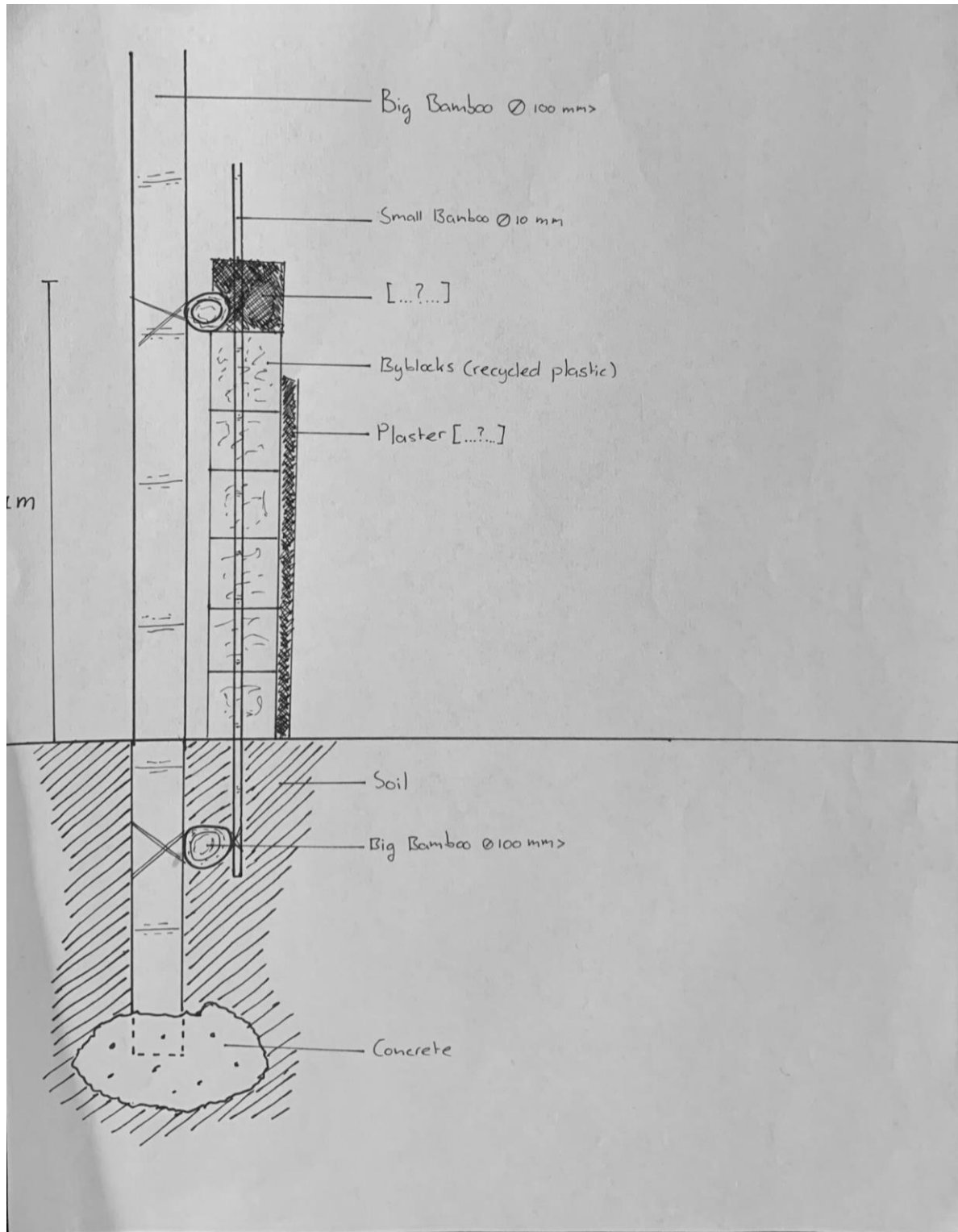
$4.8 \cdot 10^{11}$ plastic bottles were sold in 2016, which is almost a million per minute, according to statistics from Euromonitor. Only 7% of these bottles were used to make new plastic bottles.⁶⁹ According to these numbers the availability of plastic bottles won't be a problem.

⁶⁸ RESHAPING THE FUTURE OF PLASTIC. (2017). Retrieved October 8, 2018, from <https://www.bymfusion.com/>

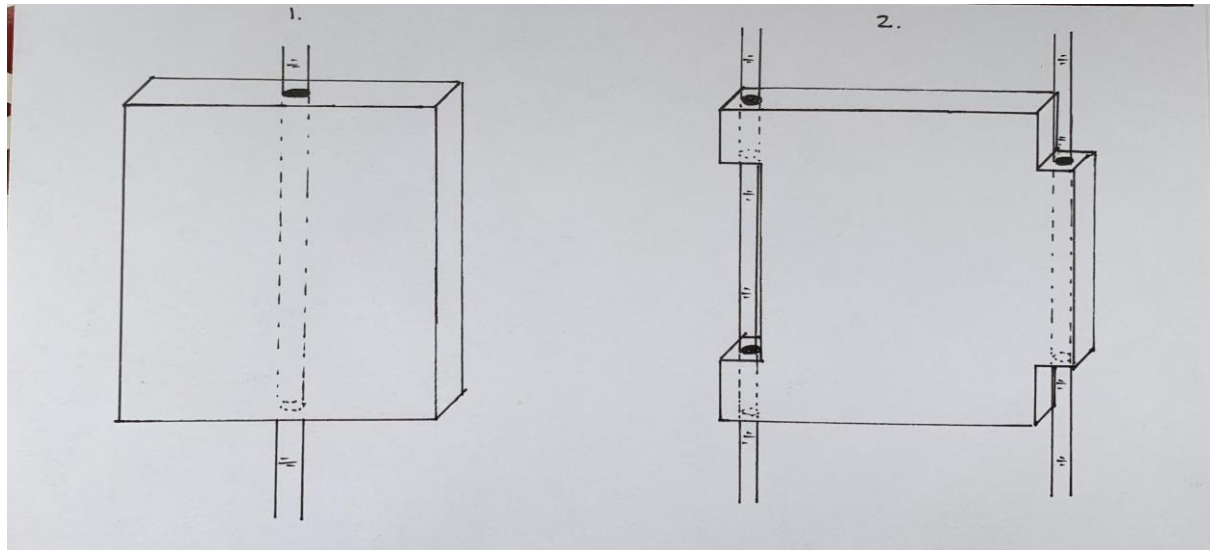
⁶⁹ Wereldbevolking consumeert 1 miljoen plastic flesjes per minuut. (2017, July 4). Retrieved December 3, 2018, from <https://www.plasticsoupfoundation.org/2017/07/1-miljoen-plastic-flesjes-per-minuut/>

Design

Using Byblocks for the walls will result in a very simple structure. They can be placed on the same way as normal bricks. The only difference is that they should be stringed with steel rods, which in our case would be replaced with bamboo.

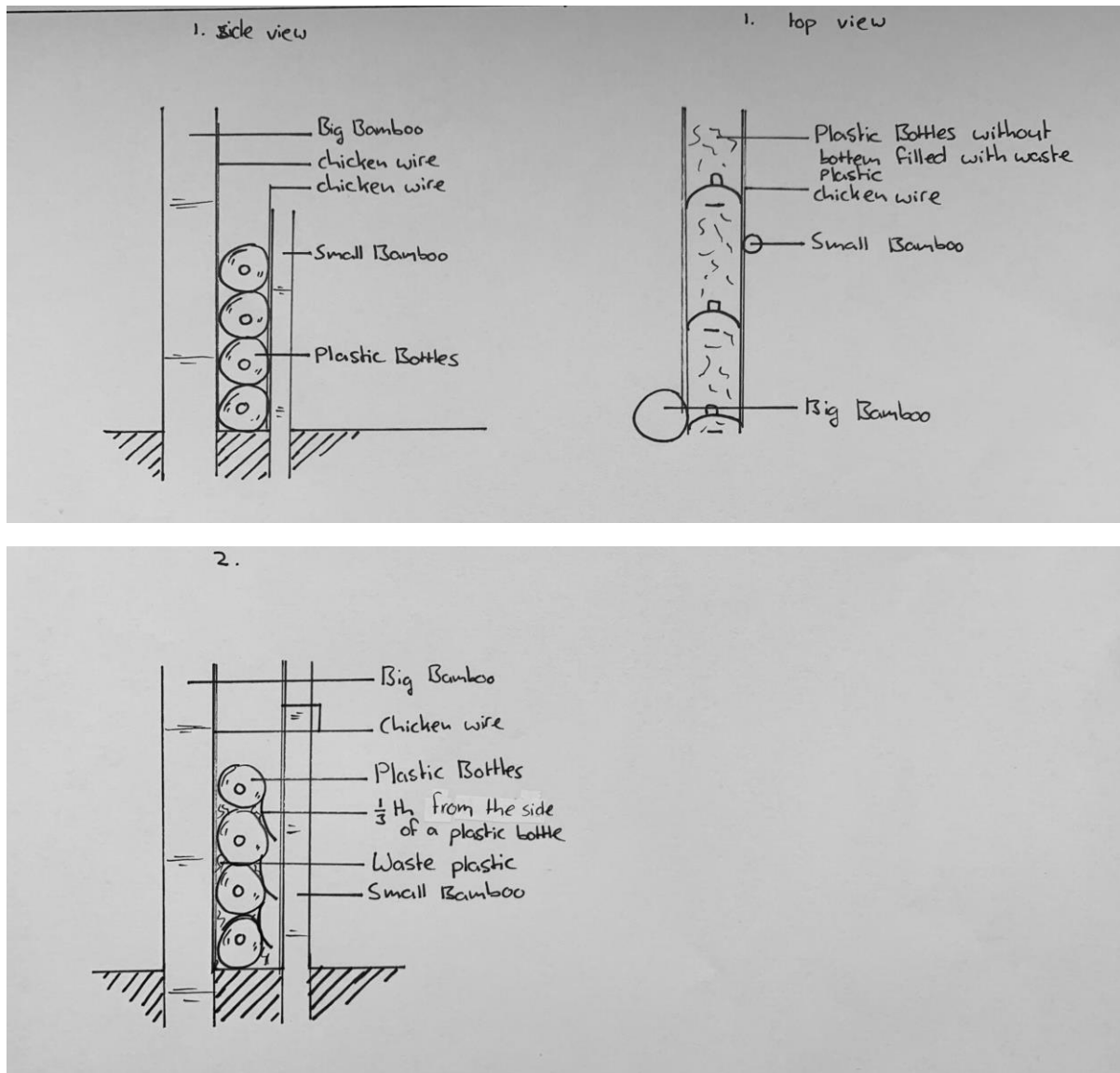


Making our own tiles would give us a lot more opportunities. We could create much larger tiles, which cover a larger area and thus will let the walls be faster to build. We designed a system in which the tiles are still stringed with bamboo for the stability of the walls. The bamboo reinforcements will be connected to the top and the bottom of every floor.



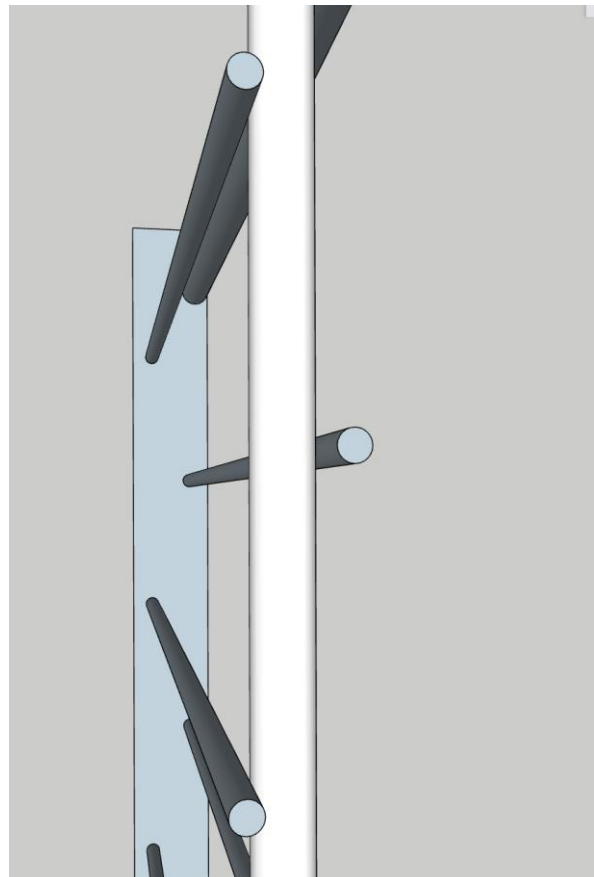
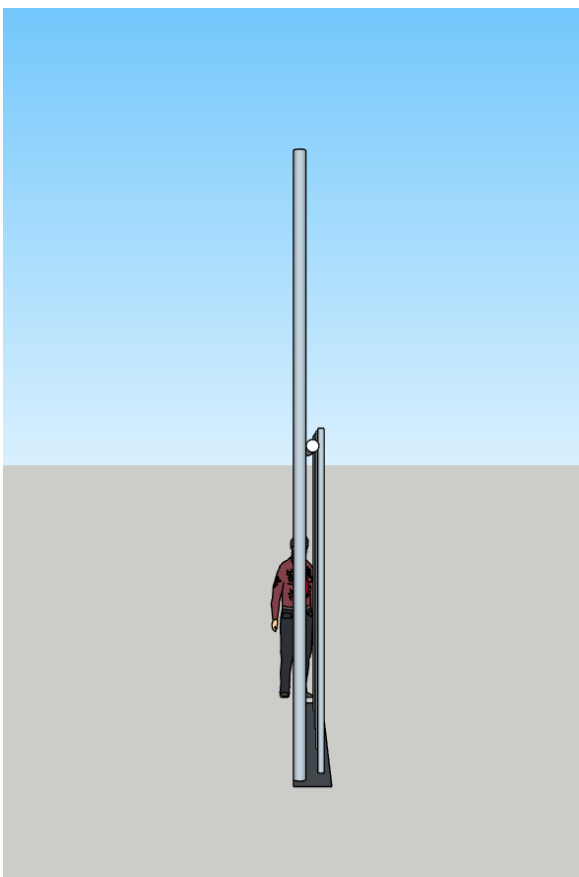
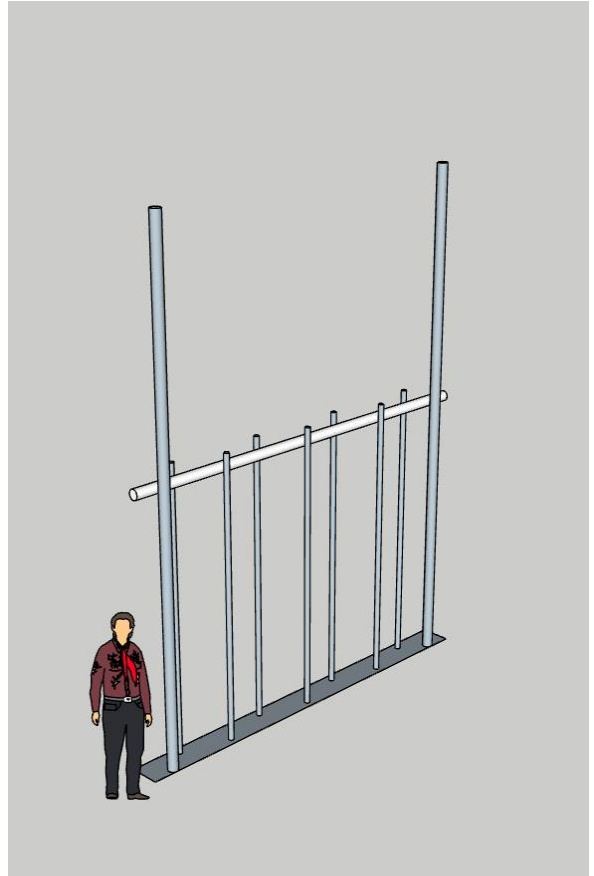
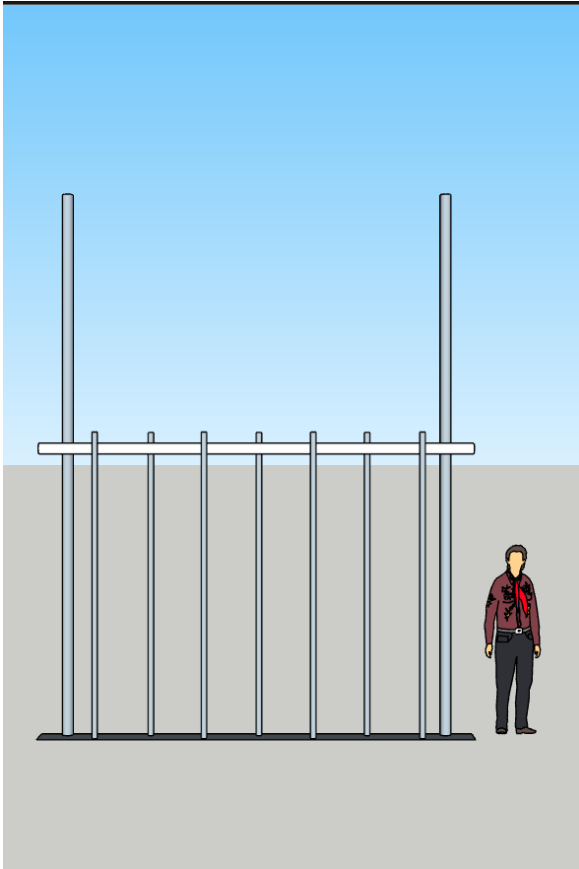
Assuming, the density of these tiles would be 10^3 kg m^{-3} . The total mass per wall will be just under 12 000 kg. Considering the fact that we don't want to use heavy machines for the installation of the walls we thought about other ideas for the walls. Using plastic bottles for the walls would create a little more complex walls, however plastic bottles filled with other plastic waste is much lighter and plastic bottles are already there and don't have to be made with a lot of energy by the residents. We had several ideas about using the plastic bottles for the walls. Our best idea is explained on the next page.

Plan 1 would have slits between the bottles, this could cause water and wind to come inside, so we thought of solution and we came up with plan 2, the idea of using one third from the side of a plastic bottle and creating a vertical plastic beam/sheet with this which could be attached to the walls, so the house would be protected from water and wind.



The method of using plastic bottles for the walls asks for an extra reinforcement in the walls, because only using plastic bottles is not strong enough for a wall. A reinforcement can be easily made out of bamboo. It should create an open space between which the plastic bottles can be placed.

The walls can be developed over time. First only the plastic bottles, plastic waste and the plastic beams/sheets have to be build. When there is new money available a layer of plaster can be added to the walls to close up the walls and improve the isolation of the house. Gaps for the windows can be kept free.



Roof

In our design we would like to use the space on top of the roof, so the shortage of space in Mumbai can be solved.

Materials

The roof will be made from bamboo and a large, strong and water resistant plastic sheet covered with sand, in which plants can grow.

Possible plants for on the roof:

All kinds of small and rather low plants, which grow in Mumbai can be used for the roof. The plants can be herbs, vegetables or ornamental plants. This are two possible plants which can be used on top of the roof.

The *Plectranthus amboinicus* is a plant which grows in Mumbai. It is a herb with an oregano-like flavour. This herb can be used in the kitchen, but it also works as a mosquito and insect repellent. The plant is fast growing, so the people need to be aware of the fact that it might grow big in a rather short period of time. Ajwain is a plant which looks a lot like this plant, and is very suitable as well.



Figure 21. *Plectranthus amboinicus*



Figure 22, *Stevia*

Stevia is an option as well. This plant needs low care and grows fast. The leaves can be used for sweetener in food or drinks.⁷⁰

The hemp plant would be an option as well. The inner fibres can be used for the hempcrete, used in the foundation. Hemp plants however do get a little bigger, so more sand is needed on the roof, resulting in a higher mass on the roof.

70 Samu. (2018, January 10). Try these ideal plants for Mumbai climate | Blog.Nurserylive.com | gardening in india. Retrieved December 13, 2018, from <http://blog.nurserylive.com/2017/12/29/try-these-ideal-plants-for-mumbai-climate-and-gardening-in-india>

Design

In our design we planned to use the roof as a garden for the residents to win space, since there is a lack of space in Dharavi. This will provide the city with more plants which has a positive effect on the amount of CO₂ in the city, which has a positive effect on the air quality. This is because plants can convert CO₂ into O₂ and carbohydrates by the use of the sunlight. This is photosynthesis.⁷¹ Plants on the roof of a building also has a positive effect on the climate in the building. It insulates as well. With this option we have to keep in mind the effects the monsoon can have on the roof garden.

We had some other ideas while brainstorming. For example: the roof could be used to generate electricity. The advantages of generating electricity is that the residents of the house are independent of the electricity network. However, there are some disadvantages. The installation of solar panels for example will be rather complex and it will cost a lot of money. Electricity generation won't be the priority for inhabitants of Dharavi.

The space on the roof also could be used as a roof terrace. This will provide the residents with more living space. The disadvantage however is that the construction should be strong enough to hold at least 10 people on the highest point of the building. This could be realised, but the amount of bamboo needed for this options should be taken in mind.

Drainage system if the water gets over 5 cm on the roof. The extra water should be saved in a tank underneath the house. This can help with cooling down the house and can maybe even be consumed, thanks to the plants. Otherwise it still can be used for cleaning or other water purposes. Water Pipes can be made out of bamboo.

71 UCSB Science line. (n.d.). Retrieved December 13, 2018, from <https://scienceline.ucsb.edu/getkey.php?key=2860>

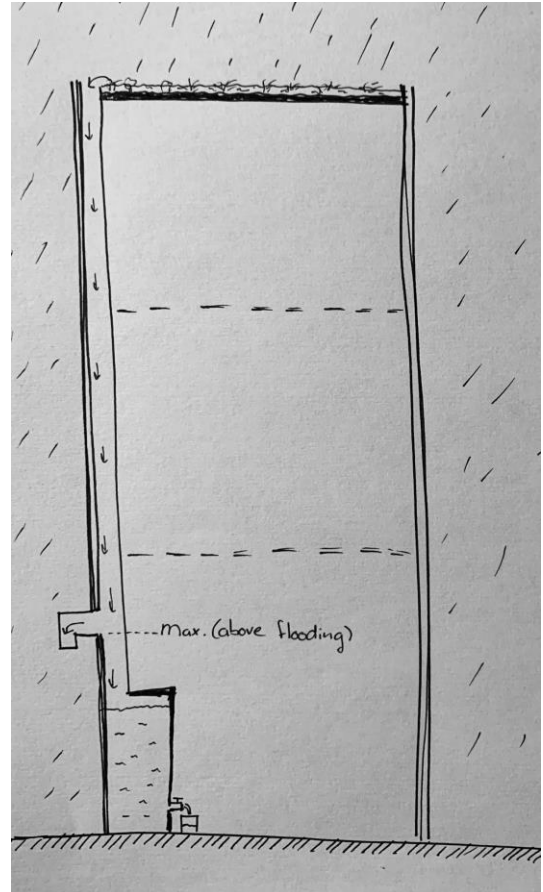
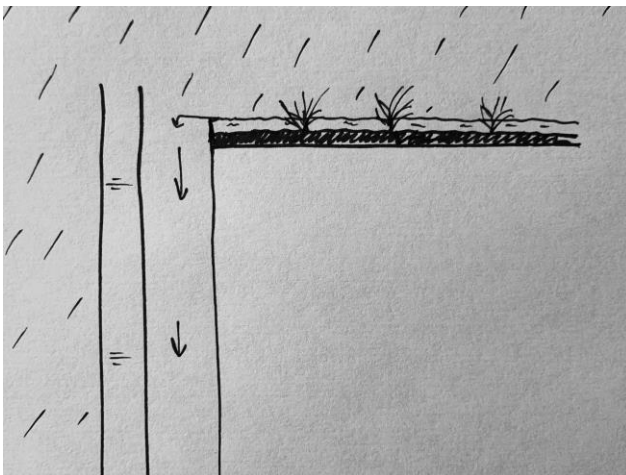
Water system

Materials

For the water system hollowed out bamboo can be used as water pipes. Bamboo is very strong and treated with the right chemicals, bamboo is water resistant and durable. To store the water, lots of things can be used, for example plastic tubs. These can be bought or can be collected from the waste.

Design

The roof of the house can be used to collect the water. For the design of a water system it is important that the plants on the roof still have enough water. During the monsoon a lot of rain falls in a short period of time. The water system should be able to collect a maximum amount of water and make sure that it won't run over causing plants to float away and causing the roof to be too heavy. The top of the tubs should be closed so when a flood occurs there is no change for polluted water to come into the system.



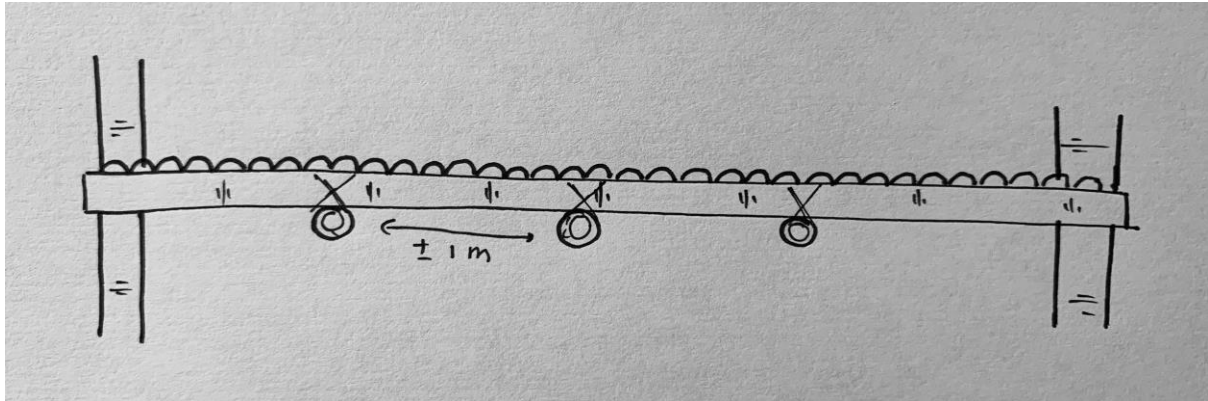
Floors

Materials

For the floors of the house bamboo would be a great option. Bamboo is strong enough for floors.

Design

The floors of our house will be made out of bamboo sticks with a diameter of 10 cm, the poles will be placed with approximately a metre between them. Smaller split bamboo poles will be attached on the bigger poles. A gap in every floor is kept free for the stairs.



How we improve the living conditions with our design

Our design is a design which consists of three parts. The construction, the walls and the roof. People in Dharavi can choose which part of their house they want to improve or if they want to build a whole new house. For example with our design it is possible to choose to make the bamboo construction, but use corrugated sheets for the walls and the roof. It is the choice of the people, but with our design we show the possibilities. The construction is made of materials which last for a long period of time. The bamboo for the construction is a very strong, light and cheap material which grows very fast. This has as an effect that the durable housing alternative is affordable. This improves the living conditions since more people can afford a house or at least a strong construction for a house.

In the experiments we did, we proved that a roof covered with plants insulates much better than the corrugated sheet. The temperature in the houses becomes very high when a corrugated sheet is used. In our design the temperature of the house decreases which makes it more comfortable to live in the house.

The privacy in Dharavi is another ongoing problem. Since lots of people live in Dharavi, there is no clear way that solves the privacy problem, but our design has more floors, so people can live in more privacy. Also the space problem is solved with this, since creating more floors leads to the effect that more people can live on the same amount of square meters. People can also choose to let the same amount of people live on the particular square meters, but by creating more floors, they have more space and privacy.

The walls are made of waste. Using waste helps cleaning Dharavi, which is full of waste. Also is waste very accessible and cheap for everyone. All the waste releases a terrible smell. We put the waste in bottles which creates the effect that the smell is literally locked.

Also the bottles allow the light to go through. They can create their own windows by not putting waste in a bottle. Our design makes it possible to create their ideal house. The bottles are partly filled with air. Air isolates much better than the corrugated sheets. Together with the roof, our design leads to a better insulation.

During the monsoon people in Dharavi can lose their house. The water can be 1 meter high which causes their houses to flood away. When our design as a whole is build, it is possible to remove the walls from the ground floor. This creates less force of the water on the house, so less damage. The people and stuff can live on the other floor and when the water is gone, they can move back in the ground floor.

For the water problem in Dharavi we have a solution. It is not a long term solution, because to really improve the living conditions concerning water, a whole new water system should be build. Our idea for the water system on the roof is that during the monsoon or during rainfall, the water will be drained and collected in a tub. The water can be used for washing clothes or cooking. Since the water has no contact with the ground, it is rather clean and therefore can be used for cooking.

Possible organizations we could approach

These are two possible organizations that we could approach to realize our design. In India, People can talk English which makes it easier to contact these organizations.

The NSDF (National Slum Dwellers Federation) is an organization which is led by inhabitants of slums and informal settlements. It was founded in the mid-1970s and started working together with the SPARC in 1986.

The SPARC (Society for the Promotion of Area Resource Centres) is a NGO which was founded in 1984. It works on housing and infrastructure issues.⁷² This is why this is a possible organization which we can approach, since our design is a design for a durable housing alternative, and this has to do with housing. The only possible problem is that this organization is an organization which is partly led by the government. The government is very corrupt and therefore the plans they make could be only in their interest. This is a risk, but when we have a look at the things they delivered, and the fact that they work together with inhabitants of the slums, we can conclude that they are interested in improving the living conditions of the people in Dharavi.

The Slum Aid organization is an organization which is not really focusing on housing, but this organization is a volunteering organization which has nothing to do with the government. They are really willing to “make lasting differences to the lives of others” especially to the poor. They are mainly focusing on healthcare and education, but because they are willing to make a differences, there is a change that they are interested to pass on our design.⁷³

⁷² ABOUT SPARC. (n.d.). Retrieved December 14, 2018, from <http://www.sparcindia.org/aboutsparc.php>

⁷³ About Us – SlumAid. (n.d.). Retrieved December 14, 2018, from <http://slumaid.org/about-us/>

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Financial plan

Costs

Please note that all prices are estimates based on prices, given by Indiamarket.⁷⁴

| Material: | Price: | Amount: | Total price in €: | Total price in Rs: |
|------------------|---------------|----------------|--------------------------|---------------------------|
| Bamboo | €0,20/m | 300 m | €60,00 | ₹5.000,00 |
| Concrete mix | €0,50/kg | 20 kg | €10,00 | ₹820,00 |
| Hemp fibre | €0,10/kg | 50 kg | €5,00 | ₹410,00 |
| Rope | €0,10/m | 500 m | €50,00 | ₹4.100,00 |
| Seeds | €1,50/kg | 1 kg | €1,50 | ₹120,00 |
| Plastic bottles | €0,05/kg | 20 kg | €1,00 | ₹80,00 |
| Waste plastic | €0,01/kg | 50 kg | €0,50 | ₹40,00 |
| Water tank | €20,00 | 1 | €20,00 | ₹1620,00 |

The costs can be limited when the residents decide to use other materials for for example the water tank. The costs can be limited as well by only using parts of the design.

So, the costs are ₹15.000,00 for the whole house with a floor area of 37 m². The average costs per month to rent in Dharavi for this floor area is ₹10.000,00.⁷⁵

⁷⁴ Hemp. (n.d.). Retrieved December 16, 2018, from <https://dir.indiamart.com/search.mp?ss=hemp>

⁷⁵ Flats, Apartments On Rent in Dharavi, Mumbai | Dharavi Rental Flats. (n.d.). Retrieved December 16, 2018, from https://www.nobroker.in/flats-for-rent-in-dharavi_mumbai

Experimental section

Our design consists of four different parts; the construction, the foundation, the walls and the roof. For all the different parts we did different experiments. At first you read the materials and equipment's we used for the experiments. In the method we will describe the methods used for the experiments. We came up with a lot of different ideas for the four different parts of the design. Only the methods of the used ideas are described below. Please note this chapter is only about the experiments and the prototype.

Materials and equipment's

Materials for the construction

- 25 m, \varnothing 0.010 m bamboo
- 150 m polyester rope
- Wooden plate 0.5 x 0.5 x 0.02 m
- Wooden plate 0.4 x 0.4 x 0.006 m
- Scale (with an accuracy of 0.00 kg)
- 8 bottles filled with water
- Knife
- Ducttape
- Jigsaw
- Hacksaw
- Drill
- Pencil

Materials for the foundation

- 8 bottles filled with water
- Scale (with an accuracy of 0.00 kg)
- 10 m polyester rope

Materials for the walls

- Plastic bottles (PET)
- Plastic waste
- Knife

Materials for the roof

- Sand + leaves
- Corrugated sheet 0.5 x 0.5 m
- Styrofoam box
- Construction lamp
- Infrared thermometer

Method

Method for the construction

To attach the bamboo sticks to each other, polyester rope was used. For the knot a combination of the clove hitch and the lashing was used. The steps are shown below.

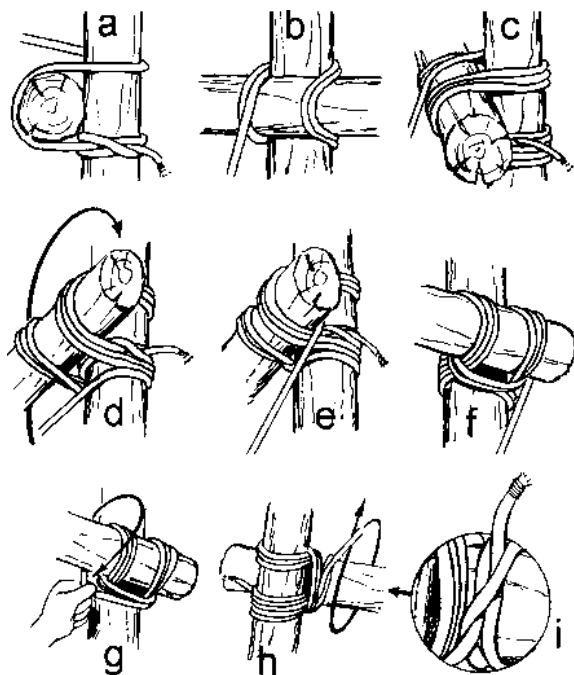
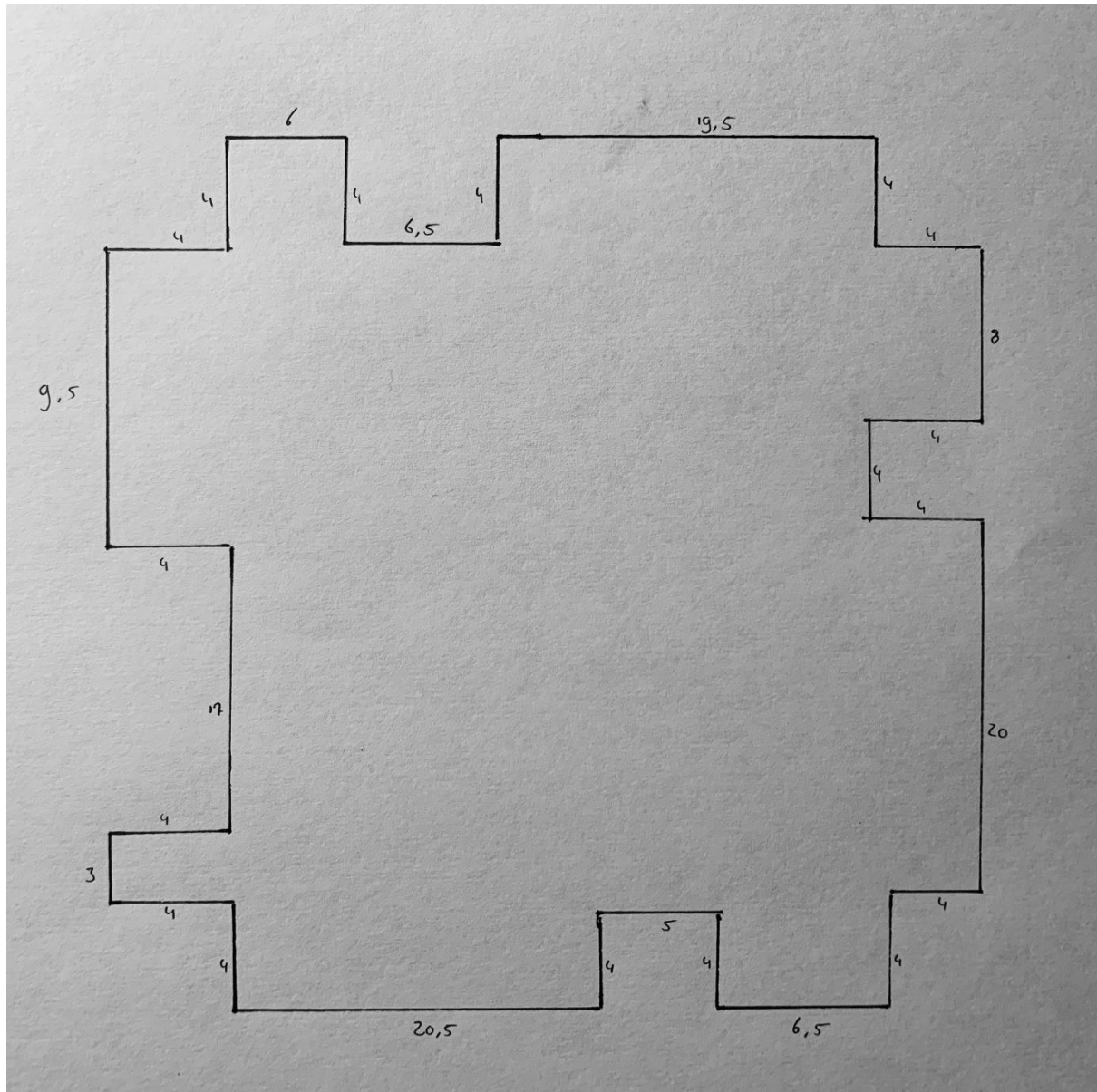


Figure 23, The knot

First a wooden plate with a thickness of 0.02 m was sawn with the jigsaw with a measurement of approximately 0.5 x 0.5 metres. Holes with a diameter of 0.012 m were drilled in a wooden plate in a square with a distance of 0.35 m from each other.



After this the wooden plate with a thickness of 0.006 m was sawn in the right shape according to the drawing above.

Please note that all the bamboo sticks mentioned in the method have a diameter of 0.010 m.

Construction 1

For construction 1 four bamboo sticks of 0.91 metres and twelve sticks of 0.40m were sawn with the hacksaw. The four sticks of 0.91 m were placed in the holes of the wooden plate, forcing the sticks to stay up. At a height of 0.28 m from the wooden plate four sticks of 0.40 m were attached to the four vertical sticks. While knotting, the sticks were kept in place with duct tape. The same process was repeated at a height of 0.56 m and 0.84 m. An extra bamboo stick is added to the first floor over the z-axis.





Construction 2

For construction 2, four sticks with a length of 0.64 m were sawn with the hacksaw. These sticks were diagonally attached to the structure on every side. They were placed along the first and second floor. Note that the sticks are attached on the outside of the vertical sticks and stringed through the inside of the second floor.



Construction 3/4

The diagonal sticks attached for construction 2 were disassembled. For construction 3, four bamboo sticks with a length of 0.91 m were sawn with the hacksaw. These were attached diagonally to the four vertical sticks. Note that the sticks are attached on the outside of the vertical sticks and stringed through the inside of the first and second floor.

For construction 4, twelve sticks with a length of 0.26 m were sawn with the hacksaw. These were attached to the four vertical sticks in the corners of the structure. Note that they were carefully placed under the horizontal sticks of the floors and resting on the floor underneath, withholding the horizontal sticks of the floors to slide down.



Construction 4



Construction 5/6

For construction 5, twelve sticks with a length of 0.40 m were sawn with the hacksaw. These were attached to the first and second floor. At every floor three sticks were placed over the x-axis and three sticks were placed over the z-axis with a distance of 0.08 m between every pair of sticks. Note that the sticks placed over the z-axis were attached to the 'bottom' of the floor.

For construction 6, two sticks with a length of 0.40 m were sawn with the hacksaw. These two sticks were diagonally attached to the roof.







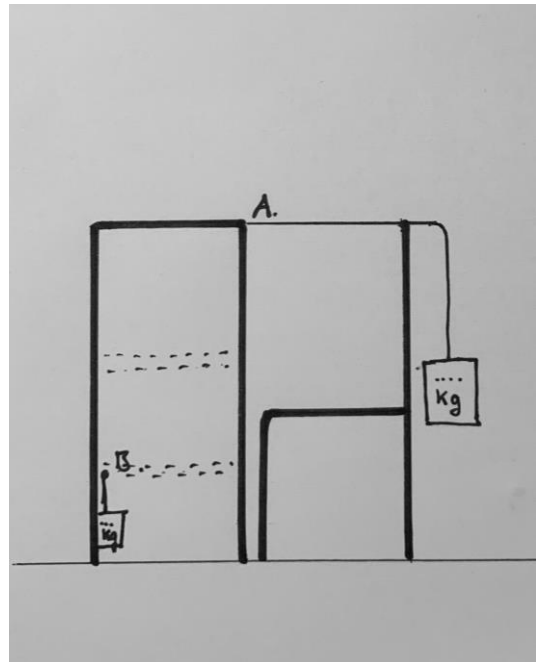


Method for the foundation

A chair, with a height of approximately 0.91 m was placed next to the structure. A rope was attached to one side of the roof, point A. The rope was led over the chair and a weight of 1 kg (in this case a plastic bottle filled with water) was attached to the rope. The mass at point B, which is at the side of the first floor and at the opposite side of point A, was decreased until the structure felt over. This process was repeated at all four sides.

Thanks to the process described above, the weakest side of the structure could be determined. The next experiments all are going to take place on the weakest side of the structure.

A chair, with a height of approximately 0.91 m was placed next to the opposite side of the weakest side of the structure. The weight attached to the rope from point A was being varied from 1.0 kg, 1.5 kg, 3.0 kg and 4.6 kg. The minimal weight at point B was being determined.





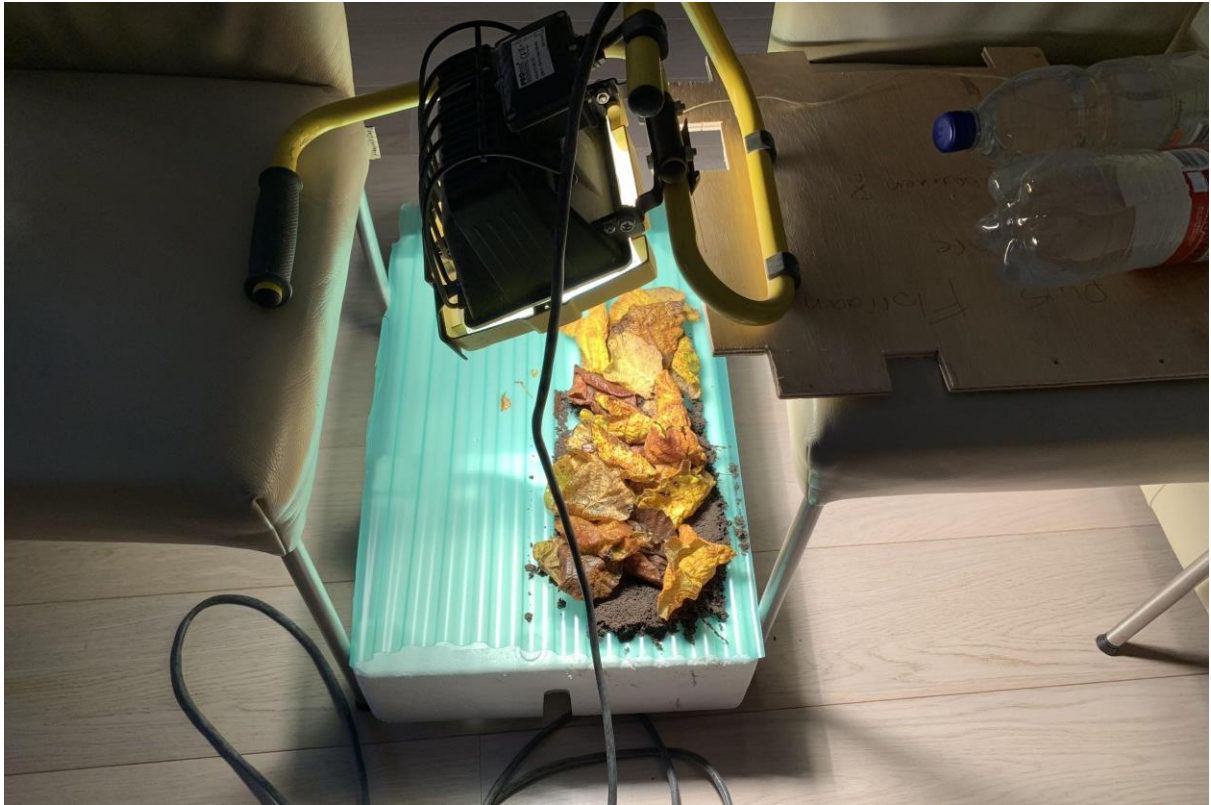
Method for the walls

For the walls. Plastic bottles are used (PET). The bottom of the bottles was cut off. The bottom was put upside down into the bottle. Another bottle from approximately the same size was put into the cut-open end of the bottle. Please note that in every empty space in the bottle a desirable amount of plastic can be applied.



Method for the roof

For the roof a corrugated sheet was cut into a piece of 0.6 x 0.4 m. The sheet was placed on top of a styrofoam box. A 0.002 m layer of sand was placed on top of the corrugated sheet and some leaves were placed on top of the sand. Two chairs were placed alongside the styrofoam box and a construction lamp was placed above the corrugated sheet with sand and leaves using the chairs. Every five minutes the temperature inside and outside the styrofoam box was determined over total period of 20 minutes.



Results

Observations

Construction

For the testing of the construction, weight had to be put on the floors. We used humans for the testing because weights of 85 kg weren't available.





For the construction we also tried to bend bamboo. We tried to bend bamboo on three different ways. The upper one was by heating with a butane burner and keeping the bamboo wet. During the experiment we noticed some motion, however it was only a small angle and eventually it broke down. The middle sticks was tried to bend by only using water. We tried to bend the bamboo while it was wet. However also this didn't worked out so well. The bamboo stick in the bottom of the picture was bend by making small slits in the bamboo. This did work. However the bamboo did lost firmness. We also noticed it was very difficult to get the bamboo bended in a precise angle.



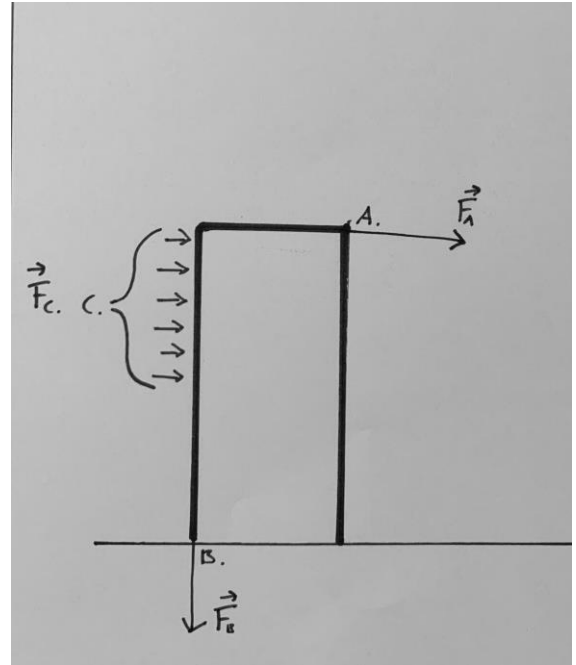
Numbers

Construction

| Construction | Description | Mass (in kg) | Notes |
|--------------|---|---|--|
| 1 | Only vertical and horizontal sticks. | First floor: 40 | Still very weak. A lot of wobbling noticeable. |
| 2 | Vertical and horizontal sticks with diagonal support for on the second and third floor. | First floor: 40 | The structure is a lot stiffer. However we noticed some wobbling on the sticks at the base floor. |
| 3 | Vertical and horizontal sticks with diagonal sticks supporting the entire structure. | First floor: 40 | The structure is very stiff. However we still saw a small amount of wobbling on the sticks at the base floor |
| 4 | Vertical and horizontal sticks with diagonal sticks supporting the entire structure. Bamboo sticks were added to the four supporting sticks. | First floor: 60 Second floor: 60 | The structure is very stiff. The wobbling was gone. We noticed all the mass ended up at only four sticks at both floors. |
| 5 | Vertical and horizontal sticks with diagonal sticks supporting the entire structure. Bamboo sticks were added to the four supporting sticks. 3 horizontal sticks were added at the x-axis and the z-axis. at both floors. | First floor: 85 Second floor: 85 | Thanks to the extra horizontal sticks the structure was able to hold a higher mass without wobbling. However we noticed the structure could turn a little bit. |
| 6 | Vertical and horizontal sticks with diagonal sticks supporting the entire structure. Bamboo sticks were added to the four supporting sticks. 3 horizontal sticks were added at the x-axis and the z-axis. at both floors. We added two diagonal stocks at the roof. | First floor: 85 Second floor: 85 | The structure was very stiff. No wobbling was noticeable with the eye. Thanks to the diagonal sticks the structure couldn't turn anymore. |

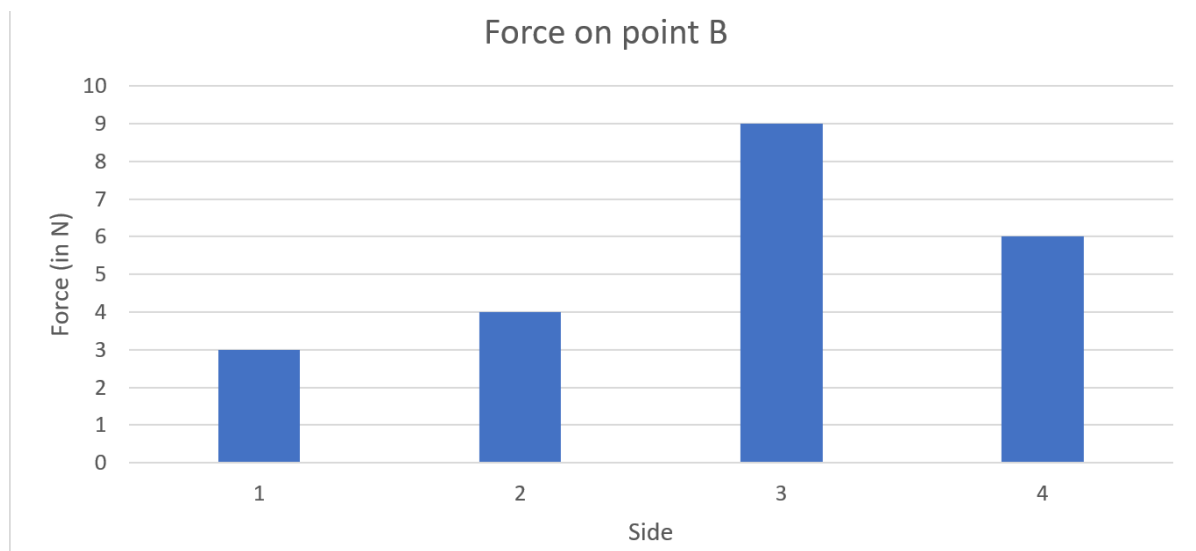
Foundation

To get to know the weight of the foundation we had to determine the relation between the force of the wind (Force C) and the force the foundation had to have on the building during high amounts of wind. To make the experiment easier we turned Force C into a pulling force (Force A). Force C and Force A are equal to each other. To determine how big Force B had to be we determined the relation between Force A and B.



First the weakest side of the structure was determined. The results of this experiment are shown below.

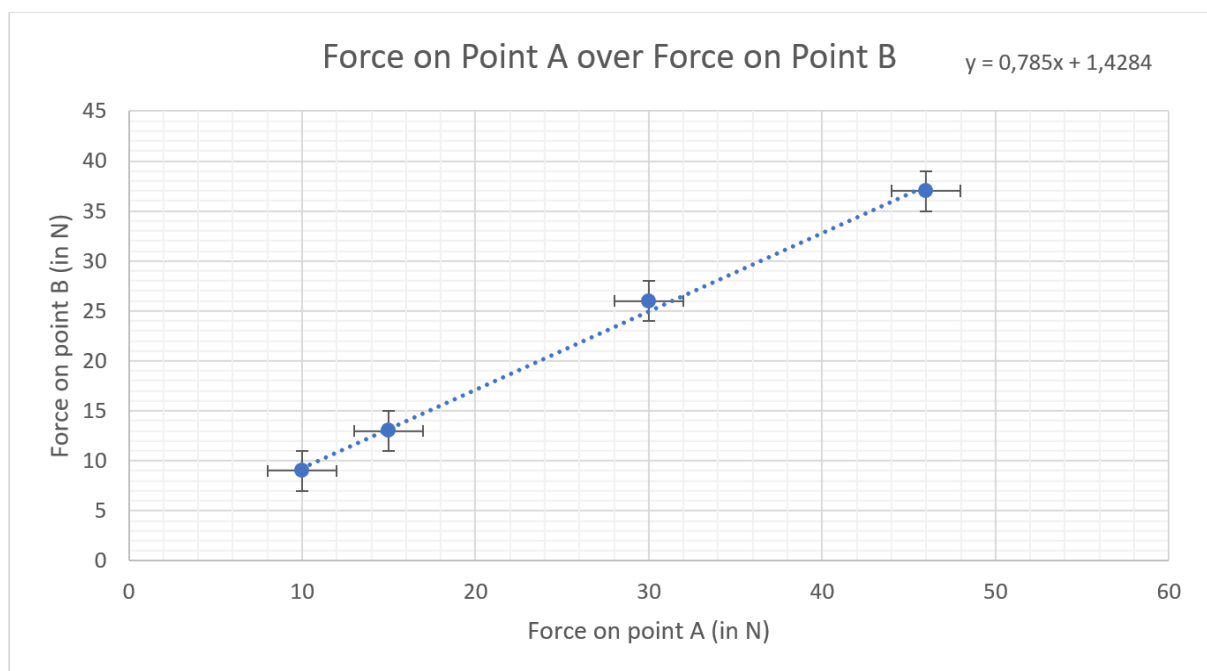
| Side | Mass in point A (in kg) | Force in point A (in N) | Mass in point B (in kg) | Force in point B (in N) |
|------|-------------------------|-------------------------|-------------------------|-------------------------|
| 1 | 1,0 | 9,8 | 0,3 | 2,9 |
| 2 | 1,0 | 9,8 | 0,4 | 3,9 |
| 3 | 1,0 | 9,8 | 0,9 | 8,8 |
| 4 | 1,0 | 9,8 | 0,6 | 5,9 |



After the weakest side was determined, all the experiments were done on the weakest side. The mass in point a was varied to determine the relation between Force A and Force B. The mass in point B is the minimum mass to prevent the structure from falling over.

Relation in Force and Mass between point A and B. Please note all the results in point B are minimum numbers.

| <i>Experiment</i> | <i>Mass in point A (in kg)</i> | <i>Force in point A (in N)</i> | <i>Mass in point B (in kg)</i> | <i>Force in point B (in N)</i> |
|--------------------------|---|---|---|---|
| 1 | 1,0 | 9,8 | 0,9 | 8,8 |
| 2 | 1,5 | 15 | 1,3 | 13 |
| 3 | 3,0 | 29 | 2,0 | 20 |
| 4 | 4,6 | 45 | 3,7 | 36 |



Formula made by excel:

$$y = 0.785x + 1.4284 \text{ [Formula 1]}$$

Processed Formula on scale (1:10):

$$F_B = 0.8 \cdot F_A + 1.4 \text{ [Formula 2]}$$

Processed Formula in reality:

$$F_B = 0.8 \cdot F_A + 14 \text{ [Formula 3]}$$

Maximum force at point C:

$$F_C = F_A \text{ [Formula 4]}$$

$$F_C = F_A = \frac{1}{2} \rho C_w A v^2 \text{ [Formula 5, Binas 35A]}$$

$$\rho = 1.293 \text{ kg m}^{-3} \text{ (Density of air)}$$

$$C_w = 2.1 \text{ (Same as a brick, both a cubus like structure without rounded corners.}^{76})$$

$A = 20 \text{ m}^2$ (We use only half of the total surface of the side, because only this can be seen as point A. If you use the total surface, the force at the lower half won't cause the structure to fall over.)

$$v = 22 \text{ m s}^{-1} \text{ (An estimated maximum windspeed, 80 km/h)}$$

$$F_C = F_A = \frac{1}{2} \cdot 1.293 \cdot 2.1 \cdot 20 \cdot 22^2 = 1.3 \cdot 10^4 \text{ N}$$

$$F_B = 0.8 \cdot F_{A=c} + 14 \text{ [Formula 3]}$$

$$F_B = 0.8 \cdot 1.3 \cdot 10^4 + 14 = 1.0 \cdot 10^4 \text{ N}$$

This means, the structure needs a force of $1.0 \cdot 10^4 \text{ N}$ pointing down on every side, a total force down of $4.2 \cdot 10^4 \text{ N}$. Please note that this is the minimum force necessary to keep the structure standing by wind speeds of maximum 80 km/h

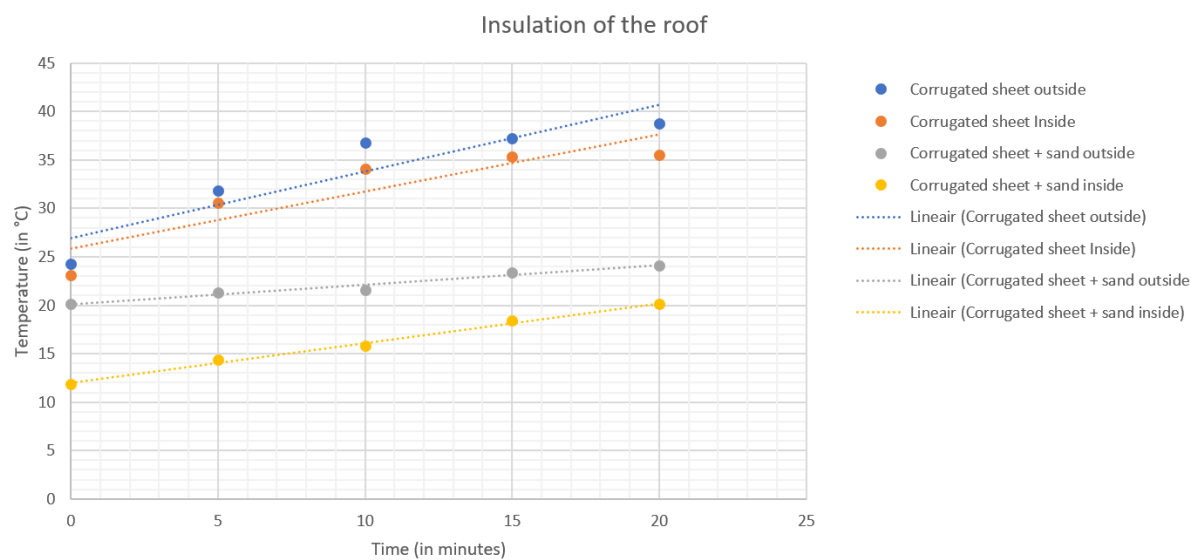
This means the foundation of the structure has to have a mass of minimum $4.3 \cdot 10^3 \text{ kg}$. A mass of $6.0 \cdot 10^3 \text{ kg}$ would be more realistic, keeping in mind the experiments were only done with the mass of the construction. Floors and walls will bring up the mass of the structure and thus will change the results from the experiment done above.

⁷⁶ Weerstandscoefficient. (n.d.). Retrieved December 9, 2018, from <https://nl.wikipedia.org/wiki/Weerstandscoefficient>

Roof

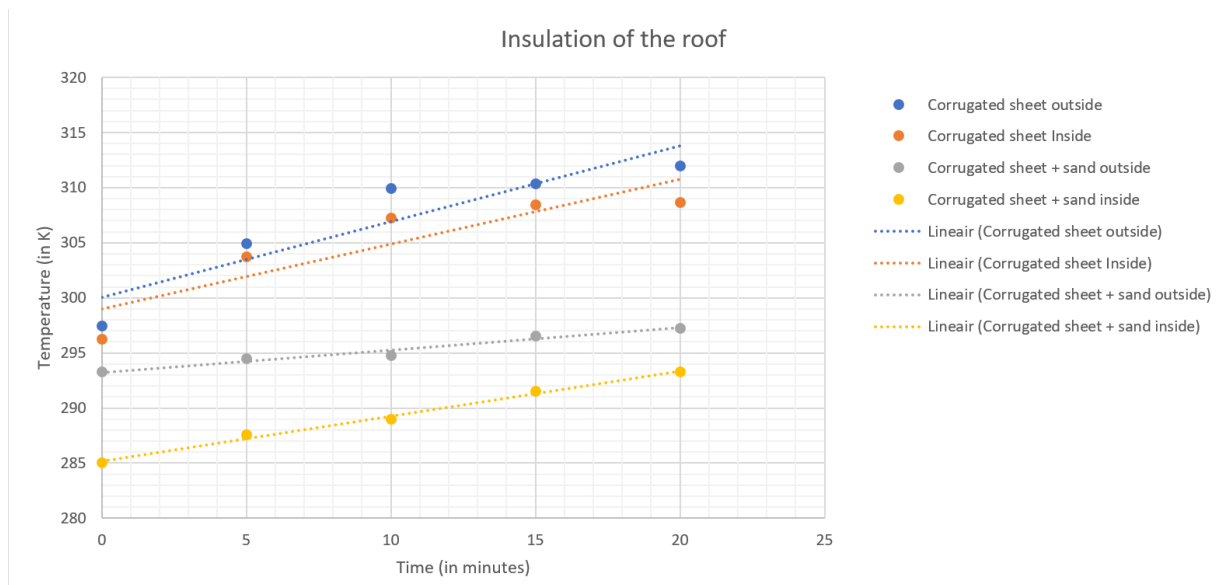
In the table and graph below the temperatures (in °C) over a time of 20 minutes are shown determined during the experiment.

| <i>Time (min)</i> | <i>Temperature (in °C) Corrugated sheet outside</i> | <i>Temperature (in °C) Corrugated sheet Inside</i> | <i>Temperature (in °C) Corrugated sheet + sand outside</i> | <i>Temperature (in °C) Corrugated sheet + sand outside</i> |
|------------------------------|--|---|---|---|
| 0 | 24,3 | 23,1 | 20,1 | 11,9 |
| 5 | 31,8 | 30,6 | 21,3 | 14,4 |
| 10 | 36,8 | 34,1 | 21,6 | 15,8 |
| 15 | 37,2 | 35,3 | 23,4 | 18,4 |
| 20 | 38,8 | 35,5 | 24,1 | 20,1 |



In the table and graph below the temperatures (in K) over a time of 20 minutes are shown determined during the experiment.

| <i>Time (min)</i> | <i>Temperature (in °C) Corrugated sheet outside</i> | <i>Temperature (in °C) Corrugated sheet Inside</i> | <i>Temperature (in °C) Corrugated sheet + sand outside</i> | <i>Temperature (in °C) Corrugated sheet + sand outside</i> |
|------------------------------|--|---|---|---|
| 0 | 297,45 | 296,25 | 293,25 | 285,05 |
| 5 | 304,95 | 303,75 | 294,45 | 287,55 |
| 10 | 309,95 | 307,25 | 294,75 | 288,95 |
| 15 | 310,35 | 308,45 | 296,55 | 291,55 |
| 20 | 311,95 | 308,65 | 297,25 | 293,25 |



Conclusion

Answer to the main research question

When designing a durable housing alternative for the current houses in the slum Dharavi, it is important to do a lot of research about the location and the context. Also a lot of research about available materials in Dharavi, and research about building methods have to be done. After the theoretical research is done, the problems for every designing element have to be clear, than ideas are going to be worked out, prototypes are going to be made and these are going to be tested and evaluated. This cycle is repeated several times before the final prototype is assembled. During the process towards the final prototype, some ideas have to be reformulated or even eliminated, but there will be new problems for which solutions have to be found.

Answers to the sub questions

A lot can be said about the general situation in Dharavi. In short, Dharavi is one of the largest slums in the world which developed throughout the years because of over-urbanization. There was no time and no money to build proper houses, so the houses are in a very bad condition. Dharavi has its own informal economy and therefore makes a lot of money, but besides this, the living conditions are terrible. This is partly because of the monsoon climate and partly because of other factors. Dharavi has an open sewage system and bad air circulation which leads to a terrible smell, also they have only access to water for a few hours a day. These things have to do with the corruption in the politics of Mumbai. Overall a lot of improvements need to be made to improve the living conditions in Dharavi.

The durable design for a house in Dharavi will be made out of a lot of waste materials and out of plants and trees which grow fast and will last for a relatively long period of time. Also with the design more space and more green is added to the district, which makes our design a durable alternative.

The durable alternative design for the current houses can be made available for the people in Dharavi by working together with organisations which are operating in Dharavi and by providing a well understandable instruction for the alternative housing design for the inhabitants. To be able to help as much people as possible with an alternative design it is important that different parts of the design can be used separately. In this way not only entire houses can be improved, but also part of a house.

The design

The design of the house is divided into several components, the construction, the foundation, the walls, the floors, the roof and a water system.

The design of the constructions consists of bamboo and rope. It is designed with as less bamboo as possible, to keep the costs low. However the structure had to be strong enough to hold ten people at once per floor. A lot of diagonal sticks are used to keep the structure stiff.

The foundation of the house consists of bamboo and hempcrete, with a meter sand upon it for extra weight. The design of the foundation will be just four blocks of hempcrete in which the four longest vertical bamboo sticks rest.

The walls of the house will be made from plastic bottles stringed into each other. The empty spaces in the walls will be filled with other plastic waste. The wall can be improved over time by adding a layer of hempcrete over the wall to create a more dense and clean wall.

The floors of the house will be made from bamboo only. Bamboo sticks split in half, will be attached to the construction to create floors.

The roof of the house will be made from a combination between bamboo and a waterproof plastic canvas. On top of this canvas a layer of sand with a dept of approximately 3 cm will be placed. Plants can grow here and water can be collected here.

A large part of the non-drinking water of the house will be collected on the roof. The water will be led down through a bamboo water pipe to a water tub.

Discussion

When designing the durable house again, we would do some things differently. At first we would go to Dharavi ourselves. Now we based our design on a lot of research done on the internet. When we go to Dharavi ourselves, our design is more reliable and it would be easier to get a clear indication of the available materials, space, the current living conditions and the desires of the inhabitants of Dharavi.

To do better and more reliable experiments, more prototypes have to be made. For example, small knotting mistakes can have huge effects. When making more prototypes more problems in the construction can be tackled. Also a higher amount of experiments will make the outcomes more reliable.

When tested enough with the small prototypes, a true size prototype can be made to do new experiments. New problems can be tackled and the design could be improved.

Hypotheses-check

We have designed an alternative house to the current houses in the slum Dharavi. In this design a construction and a new method for a foundation and for walls is included. We added an extra idea to our design, which is a design for the roof and a design for a water system. However, more tests, for safety, weather conditions and durability have to be done with all parts of the house before the design can be introduced to the people in Dharavi.

Did we meet the requirements

The construction we made is a scale model which can hold at least 85 KG. This means that the real life construction can hold at least 10 people. The design can be built by the locals of Dharavi themselves without the use of big machines. Doing research about Dharavi and the inhabitants of Dharavi helped us to create a design which will not disturb any living or working patterns. The inhabitants can decide for themselves what and how they want to change things. All the materials which are used for the design are available in and around Dharavi, which was an important requirements as well. We managed to design a construction with a total of three floors including the ground floor. We did not test the design in the weather conditions of the monsoon, but the research we did about the materials shows us that the design can deal with the weather conditions during a monsoon (for a more reliable conclusion experiments need to be done.) The walls and the roof are insulating better, and therefore might reduce the dirty odours inside the house. The dirty odours will defiantly not reduce much, since there still are places in the design through which the smell can enter the house. Overall, we did meet almost all the requirements.

Estimation of magnitude of the errors

The experiments for the construction all have been done one time. Before adopting the results, the same experiment have to be repeated several times. To be more sure about the strength of the construction the same prototype have to be made at least five times. The strength of the structure depends a lot on the tightness of the knots. To be aware of the effects of failing knots, tests have to be done without particular knots. The estimated percentage of the magnitude from the experiments with the construction is 10%. The largest part of the magnitude probably has occurred during the knotting,

The magnitude of the error during the experiments for the foundation is large. The experiments have been done with the construction only, so without walls, floors and potential residents. The effect of this is that the results may differ from the results with walls, floors and potential residents. To be sure of the weight of the foundation new experiments have to be done with walls, floors and potential residents. No statements can be done about the percentage of the magnitude thanks to the incomplete experiments.

The experiments of the roof are relatively reliable. We have used very precise measuring equipment. A clear connection between the addition of sand and leaves and the lower temperature was noticeable. The estimated percentage of the magnitude is 5%. The magnitude probably has occurred with the different starting temperatures between the two measurements.

Continuation research

If this research would be continued several continuations could take place.

The lacking of a working sewage system in Dharavi is a big problem. It causes a lot of diseases and has a negative effect on the health of the population in Dharavi. A solution for the current sewage system problem in Dharavi can be researched, so the living conditions will be improved as well.

Another possible continuation research can be the development and improvement of a material which can be used for informal construction and can be made from waste available in slums. This will improve the houses as well and thus the living conditions.

Also a research to a well working water distribution network can be done. This may give the residents a 24 hour water supply and improve their living conditions.

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Picture on the front page

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Figure 1, Dharavi (this picture has no rights)

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Figure 2, location of Mumbai

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Figure 3, Blue area is AW climate

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Figure 4, Summer monsoon

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Figure 5, Red area is Dharavi

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Figure 10, Religion

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Figure 11, This graph shows the number of inhabitants in urban and rural areas in India.

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Figure 12, Example of redevelopment plan

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Figure 14, House including inhabitants

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Figure 16, Some houses made from bricks and sheets

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Figure 17, A women walking on a pipe next to all the waste

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Figure 20, Plastic waste in Dharavi

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Manual

Introduction

Dharavi is a complex, but interesting slum. Dharavi is one of the largest slums in the world which developed throughout the years because of over-urbanization. There was no time and no money to build proper houses, so the houses are in a bad condition. Dharavi has its own informal economy and therefore makes a lot of money, but besides this, the living conditions are terrible. This is partly because of the monsoon climate and partly because of other factors. Dharavi has an open sewage system and bad air circulation which leads to a terrible smell, also they have only access to water for a few hours a day. These things have to do with the corruption in the politics of Mumbai. Overall a lot of improvements need to be made to improve the living conditions in Dharavi.

This design is a step closer towards a more pleasant Dharavi. The design will improve several living conditions and the design can be built by the locals themselves. The inhabitants can choose to only use parts of the design, and therefore the design is accessible for more people which leads to more improved houses, which leads to better living conditions.

In this document you will read a quick version of a manual for the alternative house. The manual consists of a construction, foundation, walls, floors, roof and water system.

Materials

| Material: | Amount: |
|-----------------|--------------------|
| Bamboo | 300 m |
| Concrete mix | 20 kg |
| Hemp fibre | 50 kg |
| Rope | 500 m |
| Seeds | 1 kg |
| Plastic bottles | 20 kg |
| Waste plastic | 50 kg |
| Water tank | 1 |
| Chicken wire | 200 m ² |
| Plastic sheet | 25 m ² |

Manual

Construction

8 pieces of bamboo with a length of 10 m have to be sawed.

32 pieces of bamboo with a length of 4 m have to be sawed.

12 pieces of bamboo with a length of 2,7 m have to be sawed.

4 sticks of 40 m have to be placed 1 metre into the ground/foundation (see Manual > Foundation). At a height of 2,8 metre from the ground 4 horizontal sticks of 4 metre have to be attached with a knot (see Manual > Construction > Knot) to the 4 vertical sticks of 10 metre. At a height of 5,6 and 8,4 metre from the ground the same process is repeated. Note that while knotting the sticks have to be kept in place.

Then 12 sticks of 2,7 metre are attached to the vertical sticks. 4 per floor.

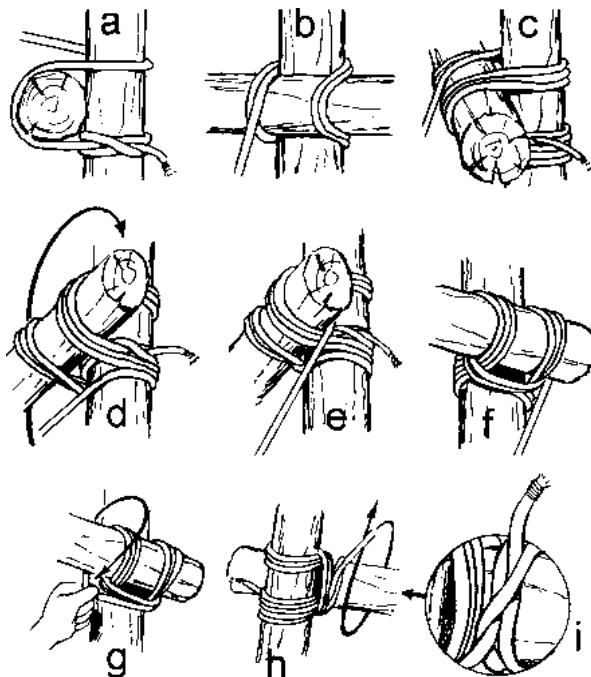
Then the 4 remaining sticks with a length of 10 metre are attached diagonally to the vertical sticks.

Then 3 sticks per floor were attached over the x-axis and 3 sticks per floor were attached over the z-axis.

At last 2 sticks are attached to the roof diagonally.



The Knot⁷⁷



⁷⁷ http://www.woodcraftsurvival.com/Survival%20skills/Survival_technieken/touwen%20en%20knooptechnieken/knopen_steken_en_sjorringen.htm

Foundation

For the foundation 4 holes are dug with a measurement of 1x1x1 metre. The holes will half filled with hempcrete with the four vertical sticks of 10 metre in the middle. The hempcrete has to cure for a week.

Then the holes can be closed with sand again.

Walls

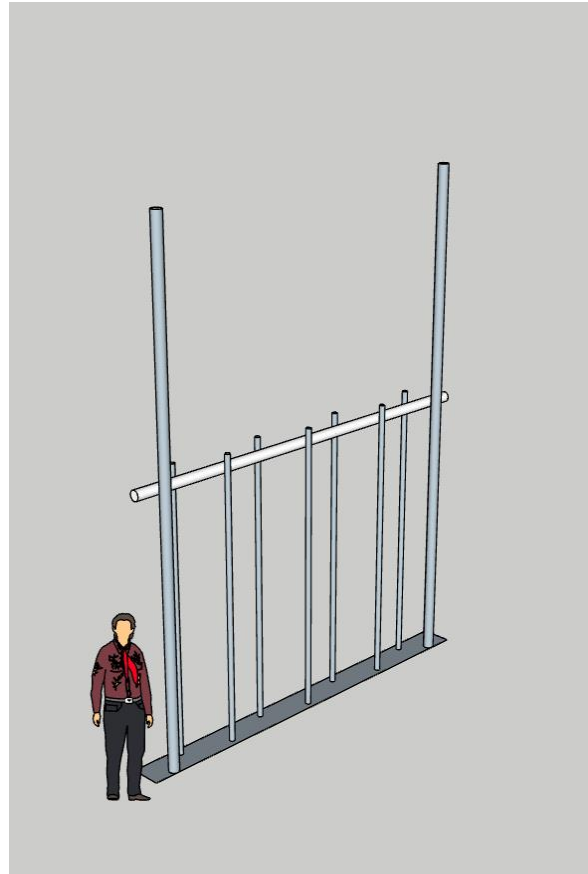
For the walls a lot of empty plastic bottles and other plastic waste is needed. First a lot of beams of 4 metre are made by cutting of the bottom of the bottles and placing it in the bottle upside down again. All empty spaces within the beam can be filled with other plastic waste.

Then a framework for the walls can be made from bamboo. Vertical bamboo sticks have to be placed with 1 metre between them. In the space between the vertical sticks. The plastic bottle beams can be placed.

Before the plastic bottles can be placed, chicken wire has to be attached to the inside of the space between the vertical bamboo sticks.

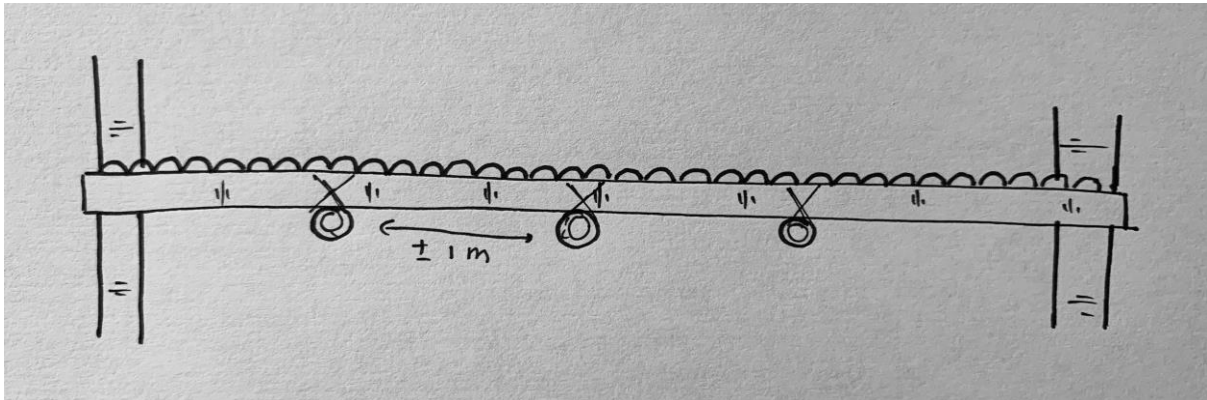
At last beams with a length of 4 metre can be made from 1/3 of a plastic bottle, cut in the vertical direction. These beams can be placed over the slits from the plastic bottle beams.

If wanted the walls can be finished with a layer of plaster.



Floors

The floors will be made from bamboo. On top of the sticks from the construction split bamboo sticks will be attached.



Roof

The roof will be made from bamboo and a plastic sheet. First a same construction as used for the floors is made.

Then the plastic sheet is laid on top of this. The plastic sheet gets attached to the construction and the bamboo roof.

On top of the plastic sheet a layer of 3 cm of sand is placed. In this sand plants can be sown.

Water system

A hole is drilled in the roof. A hollowed out bamboo sticks is connected to this hole and placed in a water tank. The hollowed out bamboo stick, sticks out 5 cm to the roof.

At a height of 1,2 metre a hole is drilled in the side of the hollowed out bamboo stick.

