MASTER

Safi Sana service blocks in Accra, Ghana
appropriate design and work plan for sanitation compartments

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Appropriate design and work plan for sanitation compartments

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This thesis is the result of a final study which is accomplished for the degree of Master of Science for the department of Architecture, Building and Planning. The report has also served as standard to assess the study achievement. Conclusions, results and calculations in this report can require complementary research before it’s usable for external use. Therefore we consider this report as an internal report which may not be used for external efforts without authorization.

Dit rapport is het verslag van een eindstudie die is gedaan voor het doctoraal examen van de Masteropleiding Architecture, Building and Planning. Het rapport heeft daarbij mede gediend als toetssteen voor de beoordeling van de studieprestatie. In het rapport voorkomende conclusies, resultaten, berekeningen en dergelijke kunnen verder onderzoek vereisen alvorens voor extern gebruik geschikt te zijn. Wij beschouwen dit rapport daarom als een intern rapport dat niet zonder onze toestemming voor externe doeleinden mag worden gebruikt.

Master of Science track Construction Technology
Department of Architecture, Building and Planning
Technische Universiteit Eindhoven (TU/e)
Preface

This report has been written as final thesis within the framework of graduation project Safi Sana service blocks in Accra, Ghana to achieve the degree of Master of Science. Graduation takes place on the Master of Science track Construction Technology on the department Architecture, Building and Planning of Eindhoven University of Technology (TU/e). This complete study is accomplished in collaboration with Safi Sana (Ghana) Limited (Ltd) and dedicated for the people of Ghana.

As preparation on graduation project and to execute a research to the local building culture is Accra, the capital of Ghana, visited from 18th of June till 1st of October 2009. During this stay is also looked at other local aspects like the current situation in slum areas, existing public sanitation facilities, social-culture and environmental aspects and other constructions. This all together has been turned out to be essential and valuable information during elaboration of my graduation project, of which the remaining part has been taken place in The Netherlands since October 2009.

All results of accomplished design and research works so far, are contained by this report and exist of a designed compartment with appropriate materials and methods and a developed work plan. The process how these results are achieved becomes clear by reading through the chronologically report, following the numbered chapters.

To realise this report has a lot of work been done since December 2008 and more intense since April 2009, firstly all preparations in The Netherlands, then my stay in Ghana and finally to write this and a previous analysis and intervening report. Many thanks for all help and support is going to Mr. E.W. Vastert and Mr. P.A. Erkelens as supervisors of Eindhoven University of Technology (TU/e) and Mr. A. van den Beukel, Mr. J.P.P.M. Ernes and Mr. F. Tettey-Lowor of Safi Sana (Ghana) Ltd.

Without to forget someone, special thanks is also going to all people from the Aqua for All foundation, Aqua Vitens Rand Ltd (AVRL), EBA Architects Ltd, the Ghanaian contractors Micsat Ltd, Berock Ventures Ltd, Jescan Construction Ltd, Kingdwosco Enterprises Ltd and Adanko Contractors Ltd and all other people and companies that helped me on many different ways in Ghana and The Netherlands.

I also want to thank Evelien, who supported me all the time during my graduation project in Ghana and The Netherlands. It was an engaged period but her help and patience were of a great contribution to these results. Furthermore I am also very grateful to my family and friends, and everyone else I didn’t mention by name now.

If more information about topic and content is desired do not hesitate to contact the author by email as mentioned on the title page.

Eindhoven, 2nd of July 2010

Jacco Hulsen
Summary

Quantity of currently available public sanitation blocks in slum areas of the city Accra, the capital of Ghana, is less and the quality is even very low. The company Safi Sana (Ghana) Limited, in collaboration with the Dutch Aqua for All foundation, want to improve this situation by realising many service blocks with toilets, bucket wash, and sell of drink water. In their development is the primary problem that for those proposed service blocks a well considered generic design, with the choice of construction materials and a developed building process, is missing and desired to realise these public sanitation facilities in the slums of Accra, Ghana. Main objective of this graduation project is to develop and communicate a generic design and work plan with most appropriate construction materials and building process for the realisation of service blocks in Accra, Ghana based on the vision of Safi Sana and local conditions and needs. This is important to give people some basic needs, to help solving poverty and to support the local building culture.

To improve public sanitation facilities is firstly a research to the local building culture, aimed to design, materials, construction works and circumstances, accomplished in Accra for 3.5 months during the summer of 2009. Results of this extended local research forms the base for the analyses and finally the results of design and work plan in this graduation project.

Vision of the Safi Sana project and local conditions and needs are important factors for the realisation, design and construction, of the multifunctional service blocks. Both are extensive investigated by observations, interviews and literature and afterwards analysed. Combined it leads to fourteen criteria which form basic requirements and a regulation for the development of design and work plan for the Safi Sana service blocks.

Starting point for the building development of public sanitation blocks is the generic design. This consists of a concept with independent compartments that can be linked together and/or placed opposite, perpendicular on or beside each other to create a site specific service block that contains all desired facilities. These ideas originate from locally observed construction works and existing buildings. Every compartment covers a surface of 3.00m x 8.00m and can host up to 4 male and 4 female customers at once.

Locally are 39 different construction materials and methods investigated by visiting construction sites, markets, producers and sellers of materials around Accra. These available construction materials and methods are compared and assessed with help of the defined criteria, to determine which are most appropriate for the largest building elements of a service block. Results of the different assessments are the use of a steel roof construction covered with cellulose bitumen corrugated sheets. In every grid is only one truss proposed which span a compartment at once and is solid fixed and anchored to the concrete columns. All external and internal walls aren't load bearing and constructed of 100mm and 150mm thick hollow sand-cement blocks, made smooth with a 12mm thick plaster finish.
Columns and walls are placed on a reinforced concrete column base, strip foundation and slab. In side elevations are steel frames with burglar proofing applied for the wall openings, but in the facade, front and back elevations, are painted design blocks more useable. These steel frames forms together with the concrete columns and foundation a framed structure for the stability of a compartment. All slab and wall surfaces, in- and outside, are finally finished with a paint coating as decoration, protection and to make the service blocks cleanable. The same applies for all surfaces of the steel roof construction, steel window frames with burglar proofing and design blocks. Dimensions of these materials are used to adapt measurements of the different building elements to get the final design of a compartment.

Compartment’s final design is after analysing it, developed into a concept and final work plan. Work plan is proposed for the client but above all for the foreman of the contractor to control, supervise and instruct different workers on site to realise all construction activities. Final work plan exist of sheets which all describe only one construction activity completely with guidelines, 3-D images, its position in the building process and all necessary materials, equipment, labour and information. It’s a manual that step by step, for every construction activity describes on which way a service block should be constructed locally in a slum environment.

Concept work plan is a main, common plan for all construction activities of a project with time schedules and budget estimations and makes generally clear how a compartment should be constructed. Most important aspects are to use as many as possible labourers for construction works and transportation, who must be frequently instructed by the foreman on site. All building activities should be completely finished before following activities may start. It’s hereby advisable to realise the complete roof construction before all superstructure walls with its paint finishing. Construction time to realise a Safi Sana compartment is 90 days which is equal to around 4 months. This duration can be decreased by hiring more construction workers. Lifecycle costs to realise a single compartment with 6 cubicles is 11400GH¢, and is for a service block with two linked compartments and 12 cubicles 19800GH¢ (1 GH¢ = 0.56 euro on 24-06-2010).

The conclusions of this graduation project are mainly formed by the final design of a compartment and developed work plan. Achieved results are very appropriate for the Safi Sana project and local conditions and needs, and are proved by a review to all fourteen defined criteria. Most remarkable aspects are the construction costs which are just 48% from the current proposed service blocks from Safi Sana (Ghana) Limited, and makes the final designed and developed compartments very cost effective. Required construction time is short and well acceptable comparing to other construction projects around Accra. Finally shall designed compartments be fit on almost all required construction sites in a slum. Hereby must they be linked or when sites are smaller can single compartments be placed opposite, perpendicular on or beside each other.
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Appropriate design and work plan for Safi Sana service blocks in Accra, Ghana

1. Introduction

Number of currently present public sanitation blocks in slum areas of the city Accra, the capital of Ghana, is less and the quality is even very low. Drink water, toilets and wash facilities are a primary basic need for all people, especially in development countries where a lack of water and hygienic can cause sickness and diseases with devastating consequences. The company Safi Sana (Ghana) Limited, in collaboration with the Dutch Aqua for All foundation, want to solve this problem by realising many service blocks with toilets, bucket wash, and sell of drink water in Accra, Ghana. Missing in their development is a well considered generic design with the choice of suitable construction materials and a developed building process reported in a work plan. The location of Accra is mentioned in the maps of Ghana and Africa by image 1.1 and 1.2. [11]

This development of durable public service block which Safi Sana (Ghana) Limited wants to realise in (high) density populated areas and other public places in the region Greater Accra is also topic for my graduation project of the Master of Science track Construction Technology. Important motivation for this project is to apply construction technology knowledge to the building development and realisation of these sustainable public Safi Sana service blocks. Research objective of this graduation project is to improve public sanitation facilities for people in Accra, Ghana. Therefore is a research to the local building culture, aimed to design, materials, construction works and circumstances, accomplished in Accra for 3.5 months during the summer of 2009. Results of this extended local research forms the base for the analyses and further elaboration and comparison of different alternatives for design and work plan.

1.1 Significance

The Safi Sana graduation project has a great social and scientific significance. Main aims are to help giving people some basic needs and to help solving poverty of people living in development countries. Finally it supports the local building culture with the methodical approach and achieved results.

1.1.1 Social significance

A large part of the people in Accra lives in underdeveloped areas and houses without basic sanitation facilities. With this graduation project development of sanitation will be supported and finally it will give more people access to public toilet facilities. This helps to partially solve a hygienic problem and therefore poverty.

Graduation project is mainly part of Millennium Development Goal (MDGs) 7: Ensure environmental sustainability. One of the targets within MDGs 7 is to halve the proportion of the population without sustainable access to safe drinking water and basis sanitation. The MDGs exist of 8 goals and are adopted and signed by the United Nations Millennium Declaration in September 2000.

Realisation of Safi Sana service blocks will for the largest part be paid by aid from non-governmental organizations (NGO) and the government. Accurate use of this aid is really important and therefore of major contribution to this graduation project. With well developed plans can durable and qualitative service blocks be realised with a lower budget and more service blocks with the same budget.
1.1.2 Scientific significance

At the end of graduation project is a work plan, one is missing now, developed which can be used to realise, step by step a service block locally. The results can be used in Accra first and, if necessary with some small adaptations transferred to other cities in Ghana or other African countries where the Safi Sana concept will be established in the near future.

In this report is an overview given of alternative construction materials and methods, with their qualities and (dis)advantages, which are available or producible in or around Accra, Ghana. This will be very useful and practical information for other organisations and clients to set up housing, construction or other sanitation projects in development countries like Ghana or elsewhere.

Approach and process to develop, realise and manage the design and construction works of small buildings in Ghana is new and can be very valuable for Safi Sana or other building projects. It optimizes the use and processing of materials, applies suitable materials in the design and makes the construction cost effective. Hereby are all analysed problems and remarks solved at the end and fulfil the appropriate solutions those criteria where the emphasis is put on.

1.2 Problem proposition

Analysis of the current situation results in the following problem proposition which is answered during graduation project:

“In the Safi Sana project are for the proposed service blocks a smart generic design with the choice of construction materials and a developed building process missing and desired to realise these public sanitation facilities in slum areas of Accra, Ghana.”

1.3 Objective and research questions

To solve the described problem proposition must the following objective within the research be achieved after this graduation project Safi Sana service blocks in Accra, Ghana:

“To develop and communicate a suitable generic design and work plan with most appropriate construction materials and building process for the realisation of service blocks in Accra, Ghana based on the vision of Safi Sana and local conditions and needs.”

Given are the principal research question and all sub-research questions that are investigated during this graduation project and therefore answered into this report:

“What could be appropriate construction materials and a building process for realisation of service blocks in Accra based on defined criteria and how to communicate and report these results?”

A. Which criteria apply to the choice of construction materials and building processes for Safi Sana service blocks?
A.1 What is the vision of Safi Sana (Ghana) Limited?
A.2 What are conditions, circumstances and needs on locations where service blocks must be realised?
Image 1.3: Framework of graduation project Safi Sana service blocks
B. What could be appropriate construction materials and building process for Safi Sana service blocks based on defined criteria?
B.1 Which preferably generic design forms the base for further designs?
B.2 What alternative construction materials and methods are local available and can be used?
B.3 What alternative construction materials and methods can be found in literature?
B.4 Which combination of construction materials and building process are most appropriate, based on defined criteria, to use for realisation of service blocks?

C. What should be an appropriate way to communicate and register work plan for local realisation of service blocks?
C.1 Who of the local people need to receive information from work plan to realise service blocks?
C.2 Which way of communicating and reporting is most suitable to correspondence work plan with local people?

1.4 Process report

To reach the objective within the research are all (sub-) research questions answered which are mentioned in paragraph 1.3. This paragraph shall explain on which way process is reported in this thesis and how objective within the research is achieved. Firstly are all three research questions, with their sub-research questions answered in separate chapters:

Research question A. is completely answered in chapter 2, definition of criteria.
Research question B. is completely answered in chapter 3, design of a compartment.
Research question C. is completely answered in chapter 4, work plan.

All three chapters start with a subsection to introduce the content of that chapter. After this is for every paragraph of that chapter, in a separate subsection described what have been done by author, on which method and what are the achieved results. The different (sub-) research questions are mentioned and processed into these separately presented paragraphs.

Besides these descriptions is for every chapter also a framework presented who links the different paragraphs together to make the relative context in this report clear. The complete model of graduation project Safi Sana service blocks in Accra, Ghana is diagrammatically presented on the left page by image 1.3. The three main chapters of this study are also mentioned into this framework.

1.5 Reading guide

A reader guide for this report is mentioned below:

Chapter 2: Explains the vision for design, materials and construction works of the Safi Sana service blocks. After that is a description given about the local conditions and needs with regard to design and realisation of the Safi Sana service block. Both result into fourteen criteria, which are of essential importance by the assessment of comparable alternatives for design and construction works.
Chapter 3: This chapter presents the generic design for service blocks, a concept of compartments. Local available materials and methods are investigated and reported in a database, and finally compared to define which are most suitable to apply for the largest building elements. In the last paragraph are dimensions of the most appropriate materials used to adapt measurements and to get the final design of a compartment.

Chapter 4: Problems and remarks of design and construction works are firstly analysed in this chapter which lead to a concept work plan, which explains how service blocks should be realised. After defining the most suitable way to communicate and report all this information in a paragraph, are the final work plan sheets presented which serves guidelines for the building process.

Chapter 5: Presents the final results, a designed compartment with choice of materials and methods and a work plan with guidelines how to construct a service block. To prove the quality of achieved results are all results reviewed on defined criteria. Finally are recommendations given for complementary research and development.

This complete report is printed two-sided on A4 paper size, with on the right pages all text and on the left pages all images. It gives the opportunity to present pictures and diagrams larger and clearer and it also saves paper. A list of all images isn’t included and necessary because all are direct linked to the presented text and are hereby separately numbered and titled.

The thesis is supported by an extensive background which exists of different appendices. These are all collected in a separate bookwork which is accompanying to this report. All appendices are numbered and the bookwork has an own table of contents. In this report are references admitted which refer to the numbered appendices. Some appendices must be printed on a larger paper size than A4. To the appendix is also a compact disc added with all final files of reports and presentations and includes also the final report of Master project ‘Participatory observation’.
Image 2.1: Framework of chapter 2, definition of criteria for design and work plan of Safi Sana service blocks
2. **Definition of criteria**

In this chapter is, with regard to realisation of the service blocks, the vision of Safi Sana and local conditions and needs investigated and described. Both are relevant information for the design and construction works of the blocks and are therefore analysed to filter requirements and demands. These are further elaborated into fourteen criteria, which are later on used to compare and assess alternatives of materials and plans, for the design and work plan of the proposed service blocks. All criteria should be fulfilled as much as possible to achieve a sufficient result. A framework of this chapter is presented on the left page by image 2.1.

Published articles, annual reports, business cases and correspondence like emails of the Safi Sana project are extensively studied in The Netherlands. All information that is relevant for the realisation, design and construction, of service blocks is selected, collected and grouped into the aspects functionality, image and design, sustainability, cost effective and design. This vision of the Safi Sana project forms partially the base for the criteria.

The local environment is an imported factor for design and realisation of the service blocks. Therefore is during the stay of author in Accra the situation in slums, current public sanitation facilities and social-culture aspects investigated by observations and interviews. Construction technology aspects which are of significance importance origins from “Analysis of construction works in Accra, Ghana, Final report Master project ‘Participatory observation’ by J.J.J. Hulsen”. And finally are the climate and seismic activity around Accra researched by scientific articles and internet. These local conditions and needs form the other base for the criteria.

The vision of Safi Sana (Ghana) Limited and the local conditions and needs are combined to describe fourteen criteria. All aspects that are important for the design, applied materials and developed construction works of a Safi Sana service block are processed in those criteria. These are all defined very specific to make them measurable and assessable and shall be used to determine the appropriateness of alternatives for design and work plan of a service block.
Appropriate design and work plan for Safi Sana service blocks in Accra, Ghana

Image 2.3: All 8 Millennium Development Goals with their symbol and meaning, the MDGs were an initiative from the United Nations

Image 2.4: Different types of service blocks with their facilities, image from Safi Sana business case [20]
2.1 Vision of Safi Sana

The complete Safi Sana program is set up as an umbrella which exists of realising 50 till 100 service blocks, transport and treatment of excrement in Accra, Ghana. Therefore sanitation buildings with full services as toilets, wash hand basins, bucket wash and sell of water will be realised in Accra's slums. Initiative to this project is taken by the Aqua for All foundation and aim is to improve sanitation facilities of many slum dwellers. To make access to water and sanitation better is the company Safi Sana (Ghana) established. Scope of this graduation project will be about the design and construction of those, to realise public service blocks in Accra. [1] [11]

With constructing sanitation blocks the company aims Millennium Development Goal 7: Ensure environmental sustainability. This goal means in detail, to halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation since 1990. The Millennium Development Goals exists of 8 goals with 21 definite targets, which are adopted and signed by government leaders of 189 countries in September 2000. All 8 goals are shown with their symbol and meaning in image 2.3 on the left page. [62]

Besides new service blocks also existing public toilet facilities can be rehabilitated and participate in the Safi Sana program. Both new and existing public toilets will be operated by local entrepreneurs under a franchise concept which is 'not for profit, not for loss'. Investment costs are earned back with revenues from selling of drink water and sanitation facilities. This concept joins the ‘modern way of thinking about sanitation.’ [2]

The vision of Safi Sana (Ghana) Limited is to provide cost effective water and sanitation services in the urban and peri-urban slum areas in Ghana, in order to cover basic needs and bring dignity, comfort and health to slum dwellers which will lead to sustainable development. This meaning of Safi Sana is, especially for the realisation, design and construction, of the multifunctional service blocks, extended clarified in the following aspects: functionality, image and design, human and nature, cost effective and time. [20] [21] [35] [36]

2.1.1 Functionality

To offer various services, there are four standard types of multi functional service blocks developed. From a 1-star 'toilet-block' until a sanitation block with all possible provisions, the flag store building. Each block will offer services such as toilets, bucket wash/showers, wash hand basins, sale of water and hygiene products and needs therefore all necessary building services. Which type of block is most preferred depends on the local situation, available land, specific needs and affordability of the local community. Image 2.4 on the left page, shows the first proposal of different types of service blocks with all their facilities. Dependent on local conditions and needs it's also well possible to create a facility with a mix of functions.

The Safi Sana branding stands for providing efficient and quality services whilst at the same time achieving maximum cost recovery and environmental sustainability. For realisation of service blocks there is intensive involvement of the local society, authorities and NGO’s needed. Even locally initiated service blocks can be incorporated in the Safi Sana franchising formula. Anticipated number of users for the different facilities varies strongly and depends on local situations and living circumstances. Design of service blocks must be easy adaptable to type of service block and desired number of facilities, like toilets and showers.
Image 2.5: Street view of the slum Ashaiman on 22th of June 2009
Lifetime of building and its equipment aren’t clear prescribed. Depreciation for the construction varies between 20 and 30 years and for equipment is even 10 years mentioned. Important factors can be the uncertainty of developments in slums and how it will be in, for example 15 years. Too expensive investments can be lost within these years due to new developments.

Service blocks will be expected to meet certain quality standards, conform to strength requirements and be reliable. They are user friendly and circumstances in- and outside are sufficient to fulfil their function. Accessibility is easy, also for children and disabled. The inside of service blocks must be lightened enough, thermal comfortable and without any smell. Public toilets and all used materials won’t have effect or cause any damage to health of its users.

Excellent maintenance is a critical success factor of the Safi Sana concept which is equal to tidy, clean and health. Therefore all materials and components must be easy to clean and to maintain, to keep them health and neat during its operation lifetime. Safi Sana (Ghana) Limited want to set a new (quality) standard with clean and well maintained service blocks, distinguishable from current public toilets.

2.1.2 Image and design

Aim is to set a new image and standard in the provision of public water and sanitation services. In this view design is a crucial factor in communicating the concept of Safi Sana to the general public. Architecture must support the image building of service blocks, which is set as an advertisement to all potential users. Facade and design of service blocks must be particular, recognizable and distinguishable from all other water and sanitation blocks due to choices in the design. For existing facilities it must be simple to join the Safi Sana concept and easy to return to your formal form without disturbing the building.

Image can be reached with a simple and obviously appearance by specific architecture, methods of construction and choice of materials. Or ornamentals such as rooftop rainwater harvesting, storage for grey water harvesting and specially designed overhead tanks. Additionally distinctiveness could also be derived by using specially designed windows, doors, portals, paintings, wall construction and roof composition.

Important is that all Safi Sana service blocks fit in the environment, location and inhabitants, where it is foreseen. For example it mustn’t be the most luxury and fancy building of a slum. The building should have the image of dignity, simple affordable, clean and safe, healthy and inviting, no luxury and overdone richness. Besides this, available land must be used effective. Image 2.5 shows a view of the slum Ashaiman.
Image 2.6: An example of environmental impact: deforestation on the hill that lies behind, around Koforidua (Eastern Region)

Image 2.7 & 2.8: Wasted bamboo, used as struts, on construction site Student hostel complex (left) and smart reuse of bamboo for a handmade fence to protect a private area (right)
2.1.3 Sustainability

Impact on environment and consumption of energy must be limited to a minimum. Safi Sana stands for environmental sustainability and smart and efficient energy usage in the building. To reach this, use of natural sources like rainwater, daylight and wind ventilation must be promoted. Harvested grey water and rainwater shall be used for flushing the toilet and rainwater can be reused for cleaning too. Service blocks must be designed to obtain maximum use of sunlight during the day and maximum natural wind ventilation. Dispose of waste like excreta (faeces and urine), grey water and anal cleaning materials must be done environmentally friendly. Control and limit the influence and pollution from (construction) sites to its environment.

All materials must have a minimum impact on the environment and be durable. This applies for winning and production, construction and during the lifetime of service blocks. Choice of materials and an effective construction should reflect this holistic Safi Sana vision and helps in branding it. Waste of materials must be limited to a minimum and reused when possible. Images 2.6, 2.7 and 2.8 show examples of environmental impact and how wasted materials can be used again. Materials must resist influences from climate, people in the environment and its users for the prescribed lifetime. Vandalism is mitigated by providing a bulletproof design.

Circumstances for construction workers to do their labour, production and use of materials, are safe and don’t affect their health negative. Safi Sana aims to create local employment and entrepreneurship by using local contractors and workers. Hereby must handwork be promoted and importation should be limited. To secure continuity of realisation and maintenance in the long term, necessary information will be shared with them. Above-average knowledge and skills from workers is not required and design and construction must be suitable for the local building culture. Local economy will be stimulated with purchase of materials, equipment and tools. [10] [29] [32] [41] [51] [56]

2.1.4 Cost effective

Grants for construction costs should be used optimal and must be well controlled. With this, every cost reduction will benefit the revolving fund by providing new investments for further extension to the number of service blocks. Goal is to achieve a cost effective design in terms of technology, material utilization and construction. Based on a pro-poor approach overall lifetime costs for construction, operation and maintenance must be as low as possible and well managed. Thereby it’s better to increase direct construction costs, by which long life operational and maintenance costs decreases. Low operational costs will help in achieving maximum cost recovery during running of all services.

2.1.5 Time

To return investment, by collecting payment from all users, it’s important that the construction time is as short as possible without any change on delay.
Appropriate design and work plan for Safi Sana service blocks in Accra, Ghana

Image 2.9: First acquired construction site in Old Fadama in August 2009

Image 2.10: Old Fadama, a slum where a sewerage system is missing, during rainy season in June 2009
2.2 Local conditions and needs

Safi Sana focuses on poor people (income < USD 2/day) that lack proper sanitation services and live in densely populated urban areas and unplanned urban settlements, where the provision of household water and sanitation facilities is a big challenge. In everyday speech these areas are called: ‘slums’. During the first Africa, Caribbean and Pacific (ACP) conference on urbanization and poverty reduction, held in Nairobi in June 2009, the executive director of the UN’s Human Settlements Programme (UN-Habitat), Anna Tibaijuka, argued: “Slums must be seen as a result of failed policies, bad governance, corruption, inappropriate regulation, dysfunctional land markets, unresponsive financial systems, and a fundamental lack of political will.” [21] [27]

Local conditions and needs in slums are important factors for the realisation of service blocks. Particularly those factors that have an influence on design and construction of the Safi Sana service blocks in Accra are explained in the following paragraphs: slums, public toilets, social-culture, construction technology, climate and seismic activity. With design and construction is meant the choice of construction materials and development of the building process.

2.2.1 Slums

Housing in Accra is generally grouped into 3 broad categories: low income, middle income and high income areas. The low income areas are generally unplanned and development is normally haphazard. About 58% of the population in Accra live in these low income areas and that are the locations where Safi Sana wants to start. The four, so far targeted, slums are South Teshie (Akromedokpo), North Teshie (Tsui Bleoo), Old Fadama and Ashaiman. Together these four areas in Accra comprise around 370,000 inhabitants and this number is still growing with a rate of around 4.6% / year due to birth and urbanization.

Population density in slums is extremely high, for example the Ashaiman Municipality covers an area of 5km² and has a population of about 220,000 people. Slum areas are unplanned, almost all land is already occupied and always property of someone, like an individual, family, clan or municipality. Besides this, is any administration missing. This confusion about land ownership makes it very difficult to acquire some land in a slum area.

On most of the obtained sites inhabitants are living in direct surrounding and the accessibility of sites can be difficult. There isn't much space available for transport, storage and realise construction works. On image 2.9 the first acquired construction site in the slum Old Fadama is shown. All sites are situated in areas where poor people live with a low income, construction works mustn't give them an opportunity or attraction to steal from those places.

In Accra an underground sewer system isn't everywhere present and often public toilets must gather excreta in an underground cesspool. Periodically there will be the need to collect faeces and urine by suction tankers and transport it to a treatment plant. Image 2.10 shows Old Fadama, a slum in Accra where any underground sewerage is missing, during rainy season. On left side of the picture, covered with some timber, a concrete drain is visible which is used as an open air sewer system. Sometimes a water grid is available in Accra's slums, but there isn't always enough water available to serve all grids in Accra, there are many leakages and illegal taps. In some cases it can be necessary to supply water with special water tankers and store it on site in water poly tanks.
Image 2.11: Not much and large wall openings in a public toilet in the slum Ashaiman on 22nd of June 2009

Image 2.12: Lack of cleaning and maintenance in a public toilet in the slum Ashaiman on 22nd of June 2009
2.2.2 Public toilets

Almost all existing public toilets have the same characteristics: dark, dirty, hot and smelly. Adequate lighting, daylight or artificial, is missing and there isn't much (natural) ventilation. Most of current public toilets in Accra are closed buildings with only a few and mostly small, wall openings. An example of such a service block is shown at image 2.11. Almost all toilets are a pit latrine or squat toilet pan which must be flushed manual, by throwing a small bucket of water in that pan, but this isn't always done by users. Besides this existing facilities aren't well cleaned and there is a general lack of maintenance in Ghana. This makes toilets dirty and unhygienic after a while and decreases its value and attractively for users. Image 2.12 shows the inside of an existing public toilet which isn't cleaned and maintained very well.

2.2.3 Social-culture

Safi Sana’s focus is to present basic, qualitative services for low income people that lack proper individual sanitation services and live in urban areas with a high population density. Service blocks must offer privacy, are adapted to the social, religious and cultural background of its local users and must prevent intimidate and shame of them.

Privacy for all users must be created with doors that end around 0.10m to 0.15m above the slab and a height of partition walls should be sufficient that people can't look over it. One important religious aspect is dry and wet anal cleaning. Muslims clean wet and use therefore a ‘bulta’, a sort of teapot, wherefore they need a water provision to fill the ‘bulta’. All other people use paper or other anal cleaning materials which aren't allowed to flush them. Therefore trashcans are needed. The same water provision can be used by people to do their laundry or wash them, for example Muslims before their 5 times daily prayer.

From the cultural background a separate entrance for male and female is desirable. It is anticipated that there may be different type of clients (male, female, children and disabled) for each of the facilities. The complex must therefore be designed having each of these classes and type of clients in mind and keep them separate where needed.

Design and used materials in a service block must join social and cultural background of all users and be accepted by them. People should be familiar with all applied materials and they must be wanted, affordable and having a positive appearance on the inhabitants.

The official language in Ghana is English, besides plenty local languages of which ‘Ga’ and ‘Twi’ are the most important in Accra. Already during primary school English is teach and almost all inhabitants speak it or at least can understand it. Conversations between Ghanaians are nearly always spoken in a local language.
Image 2.13: Construction works in Ghana are often done unsafe and without any protection

Image 2.14: Bar chart of temperatures and rainfall in Accra, image from BBC weather Centre [40]
2.2.4 Construction technology

Current construction works in Accra are extended observed and analysed, and finally reported in “Analysis of construction works in Accra, Ghana, Final report Master project ‘Participatory observation’ by J.J.J. Hulsen”. Conclusions of this report, which are also determined for the choice of construction materials and development of the building process, are mentioned below. [10]

Quality and safety isn’t of major importance for client, architect and contractors. All are more interested in quantity and want to spent as few as possible costs. Therefore on site safety conditions aren’t correct and health risk for workers is high. Most of the time labour is done unsafe and without any protection, see image 2.13. Furthermore aesthetic and structural quality of realised construction works is low and not conform drawings or requirements. Works becomes quickly dirty and the low quality causes a lower lifetime of realised construction works.

Level of education and skills from workers isn’t high and is only be improved by experience. Mentality of labourers is very laid-back and their production isn’t high. Labour is done individual, roughly and workers don’t feel much responsibility, currently there aren’t many jobs available in Accra.

Quality, strength and measurements of purchased materials aren’t very well and make a correct use of materials difficult. Raw materials extracted in Ghana are often obtained illegal and damage the environment. Materials are stricken by the climate and environment, like insects as termites and sea salt from the Atlantic Ocean.

Climate conditions and then especially rain mainly affect construction works of the substructure. Falling rain can flood excavations, foundation trenches and basements. Influence from weather on superstructure is limited to hiding of workers when it is raining.

Finally it often happens that activities of construction works went different and takes more time than planned before, and at the end total construction costs are mostly higher than estimated before. Applied materials and developed building process should be adaptable to this changes and delays.

2.2.5 Climate

The climate in Ghana, which is situated directly north of the equator, is tropical, but temperatures vary with season and elevation. In Accra, southeast of Ghana, maximum temperatures are all year around 26 till 32 degrees Celsius and it’s relatively dry. The highest temperatures occur in March, the lowest in August. Thereby it must be noticed that the ‘cooler’ months tend to be more humid than the warmer months. Image 2.14 shows the bar chart for Accra, Ghana with the year’s average weather conditions. [5] [40] [50]

During most months of a year small rain is falling, with the heaviest rainfall during the two rainy seasons from April to July and from September to November. Since the last few years these months have changed slightly due to likely reasons as climate change and global warming. Annual rainfall ranges from about 1.100mm in the north to about 2.100mm in the southeast.

The harmattan, a dry Sahara desert wind, blows from the northeast from December to February, lowering the humidity and creating hot days and cool nights in the north. In the south, most effects of the harmattan are mainly felt in January and reduce visibility to as little 1km. All other months of the year is the wind direction mainly south-southwest from the Atlantic Ocean.
Appropriate design and work plan for Safi Sana service blocks in Accra, Ghana

Image 2.15: Seismicity of south eastern Ghana, image from Seismic activity in Ghana: past, present and future [19]

Image 2.16: Modified Mercalli scale and Richter scale, image from the North Carolina Geological Survey, www.geology.enr.state.nc.us. There must be noticed that Mercalli is an intensity scale that reports the strength and damage effect. Richter's scale measures the magnitude of an earthquake. Both scales are thus different in perception and result.
2.2.6 Seismic activity

Ghana is located on the south-eastern margin of the West Africa craton, one of the four large masses of the African tectonic plate. It’s far away from the major earthquake zones that mark the present day lithospheric plate boundaries. Earth’s lithosphere includes the crust and the uppermost mantle and is broken into tectonic plates. However, a number of damaging earthquakes have struck the country dating as far back as 1636. An overview of Ghana’s major tremors is given below and all intensities are based on the modified Mercalli Scale of India unless otherwise stated, image 2.16. [13] [19] [23] [24]

The earliest recorded earthquake in Ghana occurred on 18th December, 1636 in the Axim district in south western Ghana with a maximum intensity of IX. In 1862 a very strong earthquake struck the capital city of Accra and caused considerable damage. Its maximum density was IX. Two severe shocks with an intensity of VIII were felt in Ho about 96km northeast of Accra in 1906. Ghana's most destructive earthquake, which caused much damage and seventeen people were killed, occurred on 22nd June, 1939 around Accra. The magnitude of this earthquake was 6.5 on the Richter scale and its maximum intensity IX. On 11th March, 1964 and 9th February, 1969 earth tremors of Richter magnitudes 4.5 and 4.7 were recorded. Both events were felt in Accra. Besides this has Ghana suffered from many earthquakes with a lower intensity.

Some extended studies indicate that most of the epicentres are located south of Weija, image 2.15. This suggests there is a low level of seismic activity in the vicinity of the capital city, Accra. The seismicity is associated with active faulting in this area. Most of the earthquakes occur in the western part of Accra around the junction of two major fault systems namely, the east-west Coastal boundary fault and north-northeast trending Akwapin fault zone. A fault is a break in the layers of rock of the earth's crust. The seismicity of south eastern Ghana with locations of Accra, Weija and both faults is presented on image 2.15.

Continuous seismic recording of earthquakes in the past and the existence of two active faults zone has confirmed that local seismic activity is continuing with an earthquake of magnitude 6 on Richter scale every 50 years or there about. The time lapse since the last major earthquake and the evidence of continuing activity gives ground for concern that another major earthquake may occur in not too distant future. They are liable to take place within the vicinity of the intersection of the Akwapim fault zone and the Coastal boundary fault.

Strong earthquakes in combination with poor constructed buildings can be very destructive and cause much damage, injured and even loss of many lives. Plenty of these examples are seen all around the world like Bam, Iran in 2003 and Puerto Prince, Haiti in 2010. In view of the liability on an earthquake in Accra structural precautions in constructions are recommended to prevent extensive damage during seismic activity. Buildings and other structures shall be designed and constructed to safely resist these earthquake effects or seismic forces, which is also according to regulation 43 (1) of the National Building Regulations, 1996 L.I. of the Republic of Ghana.
Image 2.17: Image building: appearance must be simple, obviously, recognizable and set as an advertisement to all potential users by choices in the design
2.3 Criteria

With formulated Safi Sana vision for realisation of all service blocks and described local conditions and needs in paragraph 2.1 and 2.2, are fourteen criteria developed. Goal of these criteria is to assess comparable alternatives of construction materials and building processes, for design and construction works of the new Safi Sana service blocks. Developed criteria are clarified and made measurable and assessable to determine which (combination of) materials and processes are most appropriate for the service blocks.

All criteria together apply on the entire design, applied materials and to realise construction works of a Safi Sana service block. Important is that not for every assessment of alternatives all formulated criteria are essential or assessable, but this is mentioned before in the specific paragraphs. Hierarchy in which the criteria are presented correspond partially with the order design, materials and construction works.

1. **Image building:** Appearance of the building by architecture and construction must, due to choices in the design, be simple and obviously, particular, recognizable, distinguishable and set as an advertisement to all potential users.

2. **Social acceptance:** Design and materials of public toilets offer privacy and are adapted to the social, religious and cultural background of all users and fit in inhabitants’ slum environment, local people wanted and are familiar with the applied materials.

3. **Fit building services:** Possibility to fix all necessary cables, lighting, pipes, sanitary equipment and sewerage system in service blocks.

4. **Usability and energy:** Service blocks are lightened enough, thermal comfortable, without smell and noise and don’t affect comfort and health of its users, moreover energy consumption must be limited and the use of sustainable energy sources like rainwater, natural lighting and wind ventilation must be promoted.

5. **Cleaning:** Possibility to clean all materials and elements of the public toilets easy, to keep them health and neat during its operational lifetime.

6. **Environmental sustainability:** Impact of extraction, production and use of materials, construction works, maintenance and demolition on the environment must be limited to a minimum and (re-) use of sustainable products must be stimulated.

7. **Long term quality, maintenance and reliability:** All materials and construction of service blocks must fulfil structural requirements with less maintenance and resist all influences from climate, ecology, environment (direct surrounding and inhabitants) and all users during its life cycle: like rain, wind and sunshine, sea salt, insects especially termites, earthquakes and vandalism.

8. **Labour circumstances:** Production, use and maintain of materials and construction works are safe for construction workers and may not affect their health negative.
Image 2.18: Creation of local employment and stimulation of the local economy with handwork is important to create more jobs
9. **Technical acceptance:** Design and building process are suitable for the local building culture and labour mentality, above-average knowledge and skills from workers isn’t required.

10. **Adjustment of plans:** Design and construction works must be adaptable to changed or delayed results of previous construction activities during the building process.

11. **Realizable in slums:** Area needed for construction works, storage and transportation is restricted, change to stealing and pollution on direct environment is kept down to a minimum and influence from climate on construction works is limited.

12. **Local employment and economy:** Creation of local employment and stimulation of the local economy with realisation of the service blocks.

13. **Lifecycle costs:** Overall lifetime, direct construction and indirect maintenance, costs must be kept as low as possible, with a focus to reduce maintenance costs.

14. **Construction time:** Time for construction works should be in proportion with the expected time with a restricted change on delay.
Image 3.1: Framework of chapter 3, design of Safi Sana service block compartments with the most appropriate materials and methods
3. **Design of a compartment**

A concept of independent compartments is most usable for the Safi Sana service blocks and elaborated to a generic design as first. It forms the starting point in this chapter to achieve at the end a final design for a compartment, with the most appropriate materials and methods. With help of the criteria, as defined in chapter 2, are local available and investigated materials and methods compared and assessed to determine which are most appropriate. This is done for the foundation, slab and walls including their finishing, windows, roof construction and the roof finishing. The results of this are finally adapted to dimensions of the used materials to get the final design of a compartment. Image 3.1 on the left page shows the framework of this chapter.

During the stay in Ghana is by observations of construction works and existing buildings, including sanitary facilities, ideas originate of a suitable design that fulfil the defined Safi Sana criteria. This generic design is already discussed in Ghana and further designed in The Netherlands to a top view with cross sections added by images. Own ideas of author are filled up by information and examples from literature.

By visiting construction sites, markets, producers and sellers of construction materials around Accra are many different alternative construction materials and methods investigated. Used demarcation is that all investigated materials are obtainable or producible in southern Ghana. Besides this it's only done for the most expensive construction elements, rough and finishing works, of a structure. Relevant information is collected by observing, interviewing and sometimes even taking measurements and added by theory and applications from literature. All materials are directly assessed by the fourteen described criteria with a score from unknown till excellent.

In totally are there 39 materials investigated and together with their scores reported in an extensive database to make the collected information noticeable and useable by assessments for the Safi Sana project or other construction projects. Hereby are the materials divided into 5 groups: basic materials, rough work of foundation, slab and walls, wall and slab finishing, windows and roofing materials.

With use of the defined criteria and the scoring of all alternative materials in the database, is for every group of materials that shall be compared an assessment diagram made. With help of these diagrams will be defined which materials and methods are most appropriate and must be applied in a service block. It can be necessary to do some more elaboration and calculations to make these assessment diagrams, especially for the roof construction and structure type and wall construction.

To make a choice between the alternatives is an emphasis made to the criteria. This is done by a quality level, which exists of the criteria 2, 4, 5, 6, 7 and 8, and forms a kind of basic requirements to where all materials must be sufficient. After this quality level is the criterion lifecycle costs most important, this should be as low as possible. The other criteria apply also to every assessment but have more the character of wishes than requirements. Results of these different assessments are those construction materials and methods that are most appropriate for realising the designed compartments of a Safi Sana service block.

At the end are measurements of the different building elements adapted to dimensions of the used materials to get the final design of a compartment. To establish the definitive height and length of blockwork walls are the dimensions of blocks with joints considered to occur thick joints and many broken blocks. Finally are dimensions of other building elements like steel frames adapted to these measurements.
Appropriate design and work plan for Safi Sana service blocks in Accra, Ghana

Image 3.2 & 3.3: Cross section and top view of a single compartment

Image 3.4 & 3.5: Collection of rainwater can be done with gutters, pipes and a tank, linking of 3 compartments offer 20 cubicles and space for 4 wash hand basins on a area of 5.60 x 9.00m
3.1 Generic design of service blocks

Proposed design for Safi Sana service blocks is based on a concept of independent compartments that stand on its own. These can be linked together and/or placed beside and opposite each other to create a service blocks that suits to all desired facilities. Besides this is the concept easily adaptable to available length and slope of obtained construction sites. On the left page are a floor plan and cross section of a single compartment given together with the layout of a public facility that exists of 3 compartments and offer services for 10 male and 10 female toilets with on both sides space for 2 wash hand basins. This paragraph explains the purpose of those compartments and presents a guideline for further development of service blocks in a tropical country. [7] [13] [14] [16] [18]

3.1.1 Compartments, walls and foundation

All compartments cover the same surface of 3.00 x 5.60m and have a wall height of 2.50m. With a high partition wall in the middle is every compartment separated into 2 corridors, one for male and one for female. At the outside of every corridor are cubicles foreseen for sanitation facilities like toilets, bucket wash / showers, wash hand basins and storage rooms. Sewerage pipes are laid through the external walls and flow directly into outside placed inspection chambers. This occurs that congestion can take place beneath the slab of a service block. Slab and wall construction and its finishing surface are of great importance in terms of comfort, cleanliness, construction works and maintenance.

There are two ways of building the structure, with massive, load bearing walls or with a frame construction and non-load bearing walls. Exclusively the red coloured walls are available to carry any loads. Because of its height, weight and loads is a concrete strip foundation required for these three walls. In case of columns is a pad foundation needed to form a column base. Both foundation types are well possible on the hard laterite (sub) soil in Ghana. The remaining blue coloured walls are non-load bearing, partition walls to create cubicles in a service block. These walls can be placed on every wished position and the width between two walls can be adapted to its proposed function, partition walls can even be omitted. Inside length of a cubicle is around 1.50m and is for all cubicles the same.

3.1.2 Roof

Roof type and structure depends strongly on the design, span and roof finishing. A sloped roof is more common in predominantly warm humid regions with significant rainfall. Most appropriate is a double pitch roof or in everyday speech a ‘gable roof’ instead of the so called ‘butterfly roof’. This safes materials for walls and roof construction and keeps the collection of rainwater outside the construction which is better in case of leakages. Harvesting of rainwater should be done quickly with gutters, downpipes and a storage tank as shown on image 3.4. The first rainwater flush that is collected can be polluted with sand and dust from roof surface.

To promote effective use of materials and labour are only in the grids roof trusses placed which mean that all purlins must span 3.00m. The pitch of the roof construction depends on applied roof covering material. Roof construction and finishing should be well fixed with an anchoring and enough screws and nails to protect them for blowing off during storm winds, especially when large parts of the wall areas are open windows, and not to collapse by seismic activities. The ridge of roofing sheets should be covered with a ridge cap. To fix this cap sufficient it’s better to use two purlins in the ridge, on a 6” distance of each other instead of one purlin, see ridge of the roof construction in image 3.7.
Image 3.6: Vertical airshaft and image building of the roof construction with a ridge opening (above) and broken pitch roof (below)

Image 3.7 & 3.8: A structure with no ceiling promotes the internal air movement (left) and the ‘umbrella roof concept’ (right), image from Construction Technology for a Tropical Development Country [14]

Image 3.9: Foundation detail with a reinforced concrete strip foundation
### 3.1.3 Climate responsive design

Design of the public service blocks must bring a comfortable building that is useable in Accra’s hot and humid climate. Most of the heat is carried away by wind and therefore should the construction as open as possible but still offering enough privacy to all its users, besides this must the structure be protected to solar radiation. When possible must the building be orientated on the East-West axis to reduce the sun radiation on buildings surfaces and achieve maximal ventilation. This orientation direction should be together with natural lighting, solar penetration and ventilation be considered in the design, according to regulation 16 (1) of the National Building Regulations, 1996 L.I. 1630 of the Republic of Ghana.

Large wall openings promote natural lighting and wind ventilation and also prevent the smell inside a service block. The total clear wall opening should be equivalent to at least one sixth (16%) of the floor area according to regulation 86 (5) and all rooms shall have at least two windows to ensure effective air movement and cross ventilation. The total area available for natural ventilation of a toilet cubicle may not be less than 0.20m² according to regulation 89 (8). Larger open windows, especially in the walls orientated on the main wind direction, are advisable to promote and optimize ventilation in the building.

Natural ventilation should be achieved by enough openings in the construction itself and less by neighbouring structures or landscape elements because the environment where service blocks are realised is constantly different. Possibilities for more ventilation are thus larger wall openings faced into the direction of prevailing breezes and a broken pitch or ridge opening in the roof construction to make a vertical airshaft as mentioned in image 3.6.

To shade and protect external walls from heating up by sun radiation and direct rainfall they can be covered with a roof overhang. In Accra the dimension should be around 1.00m due to sun shading angles and is advised by Domod Roof Ltd., a roofing company in Accra, see image 3.2. The front and back elevation, which aren’t designed for the compartments, should also have a large overhang, which must be larger than 1.00m at the ridge. For sun oriented surfaces that aren’t shaded must heat reflective materials be used. Hereby should roofing materials be made of a dense material with a high thermal resistance to reduce solar heat conduction through the roof structure and limit the noise of drumming rain. Also is a light coloured roof finishing more suitable than a dark coloured one because of more (sun) light reflection.

Large wall openings and a roof overhang is very climate responsive and take care for a usable and comfortable building. Combining these two leads to the ‘umbrella roof concept’ as shown in image 3.8. For a full ventilated construction it is better not to use a ceiling and place wall openings above and at the same height as the cubicles. This promotes the internal air movement and results in a very open construction as shown in image 3.7.

Heavy rainfall can cause flooding and washing away of the (sub) soil. To keep a dry concrete slab in the service block and to protect the reinforced concrete (strip) foundation carefully, they are situated sufficiently high and low regarding to the surrounding land, see the standard foundation detail of image 3.9. Height ‘y’ should be adapted to the local circumstances and the application of a pavement and will probably vary between 300 to 600mm. The slab must be supported by substructure walls to occur that insects enter the construction between wall and slab, prevent absorption of moisture through the blockwork wall and not taking place that the back filled laterite crumbles down.
Image 3.10: Simple sketch idea of a combined toll point, water kiosk and overhead tank storage
3.1.4 Image building and toll point

Image building of the service blocks should be achieved by an effectively use of materials and simple and obviously supplements and adaptations that also fulfil a function in the construction. One possibility is smart openings in the roof construction to provide more ventilation and give the building a nice appearance like image 3.6. Another opportunity is to paint the facade in recognizable and specific colours with male – female symbols and attractive door and wall openings. For the roof finishing should a coloured roofing material be applied that doesn't peel off or fade away during life time of the construction and gives the building a nice performance.

It's advisable to combine the toll point with water kiosk, sell of hygienic products and overhead drink water storage to one (round) construction with a flat concrete roof and high and low tapping points. This saves a large steel structure for getting an overhead water tank and the ‘new’ office can be placed on every wished location on site, to still have an overview on all entrances and keep the selling of water away from unhygienic places. A simple proposal sketch of this toll point with overhead water tank is shown in image 3.10. It gives an idea of the combined functions and the design can be extended and made more special as wanted.
All investigated materials are divided into these five groups:

A  Basic materials  
B  Rough work of foundation, slab and walls  
C  Wall and slab finishing  
D  Windows  
E  Roofing materials

Described aspects in the database of local available materials and methods:

- Unity  
- Specifications  
- Applications  
- Processing possibilities  
- Availability and where to find  
- Others

- Image building  
- Social acceptance  
- Fit building services  
- Usability and energy  
- Cleaning  
- Environmental sustainability  
- Long term quality, maintenance and reliability  
- Labour circumstances  
- Technical acceptance  
- Adjustment of plans  
- Realizable in slums  
- Local employment and economy  
- Lifecycle costs  
- Construction time

Scoring classes with their indication colours:

<table>
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<tr>
<th>Unknown</th>
<th>Inferior</th>
<th>No good</th>
<th>Sufficient</th>
<th>Good</th>
<th>Excellent</th>
</tr>
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<tbody>
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<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
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3.2 Local available materials and methods

In the summer of 2009 is during a 3.5 month stay in Accra, Ghana an extended research accomplished to collect relevant information about available construction materials and methods around Accra - Ghana with the realisation of public service blocks in mind. These are local extracted (natural) materials, imported materials and locally produced (man-made) materials. Investigated of the different products are for example costs, dimensions, applications, origin, strength, durability, acceptation by local people and how materials are processed to a construction element. Used demarcation for this research is that all investigated materials are obtainable or producible in southern Ghana. Besides this the research is only done for the most expensive construction elements, rough and finishing works, of a structure: foundation, walls, slab, windows, roof construction and roofing. All gathered information from the research in Ghana is completed with information from literature and websites.

To make the collected information noticeable and useable for assessments it's reported in an extensive database, which is presented in appendix 1. In this database are all investigated materials and methods dividedly presented into these five groups as mentioned on the left page.

On the left page are all aspects mentioned which for every construction material are described in the database. The first 6 are standard aspects and the other 14 are the criteria as presented in paragraph 3.1. Not all these 14 criteria apply on every group of materials. For all groups is in the database separate mentioned which materials and methods it contains and which aspects are relevant. In the database is for all these aspects the collected information reported and a score on the current situation is given which ranges from unknown till excellent, see also the scoring classes on the left page.

To guarantee a prescribed quality should all materials be conform specifications and requirements of the applied Ghana Standards, British Standards and the National Building Regulations, 1996 L.I. 1630 of the Republic of Ghana but this isn't always so. The British influence is a result of Ghana's colonial history and causes also the disorderly use of metric (meters) and imperial (inches) system for dimensions in drawings and materials.

All given costs for the purchase of materials are including 15% VAT & NHIL allowance and delivery on site unless other mentioned. It is possible that reported prices of materials and rates are increased due to inflation and higher importation costs. Noticed prices are from the summer of 2009 and the references of material costs and rates are for every material mentioned in the database.

For labour costs are the rates for company workers used, which is 7.20 GH¢ / 8 hours for a labourer and 9.20 GH¢ / 8 hours for a skilled worker, this information is given by local contractor Jescan Construction Ltd. in Accra. This salary is including 15% VAT & NHIL allowance, health insurance, Social Security and National Insurance (SSNIT) contribution and 21 days off every year.

Presented rates in the database are for the complete realisation of construction elements and are including purchase or production, transport and processing of the materials with necessary labour, equipment and most fixing materials and also with wastage, profit and overhead unless other mentioned. Prices can in- or decrease slightly due to a changing workforce on site.

Following references are consulted to collect information for the database: [3] [6] [10] [12] [13] [14] [16] [18] [22] [25] [26] [28] [30] [31] [37] [39] [42] [43] [44] [45] [46] [47] [48] [49] [52] [54] [57] [58] [59] [60] [61]
Appropriate design and work plan for Safi Sana service blocks in Accra, Ghana

Image 3.11 & 3.12: A correct design and choice of materials is of essential importance for the functionality of a building
3.3 **Appropriate construction materials and methods**

Not all available construction materials and methods as described in the database of appendix 1 are suitable to apply in a building and more specific in the Safi Sana public service blocks. In this paragraph is for every group of the database a selection of the investigated materials made to find out which are most appropriate to use. For all five groups of materials, A till E, is shortly their main function repeated and are investigated materials discussed and compared with help of the database and shown assessment diagrams. This is done to achieve necessary conclusions and choices about which materials are the most appropriate. Only those materials and methods that are suitable will be used for further development of the design and building process of Safi Sana service blocks.

3.3.1 **How to define appropriateness**

In this paragraph shall be explained how the selection of materials has gone with an emphasis on the criteria. In compliance with the defined criteria of paragraph 2.3 and generic design of paragraph 3.1 must to realise service blocks meet a certain quality level. This quality level is defined by the criteria 2, 4, 5, 6, 7, 8 which form a sort of basic requirements. To reach that level of quality should materials have a score which is at least sufficient to these six criteria to make them suitable.

By suitability of more than one alternative shall now be watched to criteria 13, lifecycle costs, which is also very important for development aid projects. Finally applies the other remaining criteria too, but they more the character of wishes than requirements.

To define the appropriateness of materials are the given scores, which ranges from inferior to excellent, of the database be used. With these scores is the current situation of materials be reported and assessed. It's therefore possible that current unsatisfactory materials of the database can be made appropriate by improving them.
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**Image 3.13: Assessment diagram of group A - Basic materials**

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*One bag has a weight of 50kg.

**For materials A1 to A12, all rates mentioned for the purchasing costs are including wastage. Note that the purchasing cost per m3 of concrete is 2.45 GĦ. All rates are excluding profit and overhead.

***Costs for purchasing a piece depends on section type and its dimensions, see database for all specific prices.

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**Contents:**

- **No.**
- **A1**
- **A2**
- **A3**
- **A4**
- **A5**
- **A6**
- **A7**
- **A8**
- **A9**
- **A10**
- **A11**
- **A12**
- **A13**

**Unity:**

- **m3**

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**J.J.J. Hulsen  
Thesis  
July 2010  
50**
3.3.2 Basic materials

Basic materials are the so-called ‘raw materials’ and are used as construction material on their own or form the base for locally produced materials. All these materials aren't assessed to determine which are the most appropriate, but to give an overview about their advantages and disadvantages and possibilities to use for construction of the service blocks.

Acceptation of materials by local people depends strongly on the origin of materials and present examples in the building environment. Modern materials with a western image like Portland cement, steel, and locally extracted materials to produce reinforced concrete and sand-cement mortar are very wanted. Many decayed constructions made of laterite and clay are visible in Ghana and makes the material less accepted and usable.

Use of illegal cut timber should be restricted to prevent a further deforestation of tropical forests in Ghana. Extraction of soils as sand, clay, and stones must be done carefully and well controlled to protect inlands and banks of rivers and lakes. Influence of imported materials on the Ghanaian environment is unknown, but also on the environment where it is extracted and produced.

If clay and laterite constructions aren't treated or protected is their long term quality not good. The structural quality of most basic materials depends mainly on their processing into other construction materials like concrete and blocks and is therefore sufficient. When both are equally protected is steel a more durable construction material then timber that will be affected earlier due to different influences and needs more maintenance.

Incorrect labour circumstances are mainly caused by carrying too much weight by one worker and the presence of cement dust on the workplace. This can be easily solved with some clear provisions on site. Processing of all basic materials isn't very difficult and necessary workmanship is enough available around Accra.

When the extraction and production of materials is done mainly by labourers and less mechanically, it has an excellent influence on the local employment and economy. The supporting of imported materials is just sufficient. Therefore should the use of Ghanaian pozzolana cement be stimulated and must Portland cement partially be replaced with this cheaper cement. The application of pozzolana cement should be extendedly tested before its wide application in mixtures.
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* Mentioned rate is including wastage but without profit and overhead
* * Given rate is without formwork and reinforcement

Image 3.14: Assessment diagram of group B - Rough work of foundation, slab and walls
3.3.3 **Rough work of foundation, slab and walls**

Stability of a building depends primarily on the foundation it is built, which must divert and spread loads to the soil. A slab covers the soil, transfers loads and forms a solid base for the final floor finishing. Main functions of a wall construction are protecting to climatic and environmental elements and regulation of the indoor climate, aesthetic appearance, offering privacy, security against unwished entering and finally to support the roof construction.

The possibility to clean any of the compared materials is of a very low rank due to the absorption level and roughness of those materials. It’s almost impossible to make them waterproof and cleanable for a public toilet. Therefore it’s advisable to cover all walls and slab surfaces that will become dirty with a finishing material that is easier to clean.

Reinforced concrete is a qualitative and strong material that excellently resists compression and tension forces in a construction, at least if concrete works are realised well. Production and processing of concrete requires accurate preparations and guiding on site what is well possible. Reinforced concrete which also needs a formwork is a very expensive construction material and should therefore only be used for necessary elements as foundation, slab and columns. Concrete walls will be too expensive and difficult to construct for the local workers.

The Moladi building system with plastic formwork is a very useful construction method with an excellent result. Disadvantage is the low adaptability of formwork and it’s only affordable when there are many, identical constructions at one location, making it inappropriate to use for the construction of service blocks.

Sand-cement blocks are very weak and need a plaster finish as protection and covering. They can only be used as filling of walls in a framed construction and non-load bearing walls. Producing and laying of these blocks is very simple and all masons are familiar with this product. It’s the cheapest available material to use for the rough construction works of a wall.

To improve its quality can cement and quarry dust be added to the mixture making it concrete blocks. These are much stronger and harder but their costs are around 35% higher than sand-cement blocks. Joining advantage is that a plaster finish isn’t necessary making the costs almost comparable. To lay these blocks without a final wall finishing require some workmanship what isn’t commonly present in Ghana. It can be solved by using a simplifying interlocking system that also increases the production rate. Extra reinforced stability provisions should be fit in a concrete blockwork wall, to extend the structural capacity for anchoring and carrying the roof construction and be earthquake resistant.

Laterite blocks, laid with the interlocking Hydraform technology, erode during the time and can only be used as wall filling, not for load bearing walls. Therefore is an extra structural frame and wall finishing needed in a construction. On top of the already high costs for a laterite blockwork wall shall this be too expensive, compared to sand-cement blocks which need exactly the same provisions. The simple interlocking system binds blocks strongly together to a solid wall with correct measurements and a high aesthetic appearance. When large blocks with an interlocking system are used a high production rate can be achieved.
Image 3.15: Interlocking concrete blocks simplify and fasten the processing of concrete blocks, image from www.litebuilt.com
Bricks are around 2.5 to 3 times more expensive than concrete blocks making them not really suitable for applying in a service block. The social acceptance and image building of bricks isn't very well and doesn't justify the use of such a costly material. Besides this must bricks, due to the absence of a finishing layer, laid exactly straight and at one level which is very difficult for local masons and doesn't fit in the local building culture.

After assessing and comparing the available materials can be conclude that reinforced concrete is the strongest and most desired construction material. But due its extremely high costs must an unlimited apply of concrete be avoided. Reinforced concrete is most appropriate for foundation and slab and, dependant on the type of structure, for columns. Using plastic formwork of the Moladi building system to realise concrete works isn't an achievable solution due to the missing repetition and changing locations. For the foundation and slab are no alternative construction materials available.

Sand-cement or concrete blocks are most appropriate to fill in the space between those concrete columns and for non-load bearing walls. Possibly can concrete blocks be placed in a square and filled with reinforcement bars and concrete to replace reinforced concrete columns. The use of laterite blocks with the Hydraform technology isn't advisable to use as filling because of their high costs comparing to sand-cement or concrete blocks.

To create a construction with massive, load bearing walls it's the best to use concrete blocks due to their high strength and durability and low costs. Highly recommended is to fit in reinforcement provisions to achieve a stabile construction and the use of a (dry stacked) interlocking system to simplify and fasten the laying of concrete blocks, see image 3.15. These interlocking concrete blocks can also be used as wall filling in a frame structure. Due to their high price are clay bricks not an appropriate construction material for these load bearing walls.

The composition of materials and combination of materials for a structure, which are assessed as most appropriate, can change slightly to the determination of finishing materials for walls and slab.
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* Mentioned rate is excluding wastage, profit and overhead
** Given rate is only for one complete, undercoat and topcoat, without repairing
*** Mentioned rate is including wastage but without profit and overhead
**** Costs are only for purchase of the material, rate is unknown

Image 3.16: Assessment diagram of group C - Wall and slab finishing
### 3.3.4 Wall and slab finishing

The finished slab should provide a clean and levelled surface where all proposed sanitation activities can take place and people move over. Most important function of a wall finishing is to offer a neat surface which is easy to clean and keeps usability of service blocks high. Both wall and slab finishing aren’t part of the structure.

Paint is simple to process and can be applied on almost all used materials for rough construction works like masonry, timber and steel, whereby changes or delays aren’t a real problem. Labour circumstances can be improved by taking care for the prescribed provisions. When qualitative, industrial paints are applied correctly it shall fulfils its function well and is very easy to clean. Quality of paint decreases little during the time and after some (8) years it must be repainted, what increases the maintenance costs. Besides its excellent local acceptance can paint support the image building and protect underlying materials making it a very appropriate finishing material for the in- and outside of walls and slab.

Wall and floor tiles are also very suitable finishing materials for a service block. There costs are up to 3.5 times higher than paint but maintenance costs will be reduced to almost zero and tiles are also easy to clean. A correctly fixing of tiles requires some more workmanship and carefulness of all workers. Adjustment to already realized slab and walls should really be improved in the design and during construction works. Tiles are appropriate for the inside of a service block due its excellent cleaning possibilities and durability. For the outside, which become less dirty, are tiles too expensive and are probably other finishing materials more suitable.

A terrazzo slab and/or wall finishing aren’t a very common and affordable finishing material in a slum environment, and therefore not really accepted by local people. Their scoring on the different criteria is almost equal to tiles except the costs which are around 50 to 75% higher, making terrazzo less appropriate for a service block. Epoxy finishing material is comparable with the qualities of terrazzo but is even much more expensive, making it also not appropriate for a toilet facility in slum areas.

Terracotta tiles become dirty after a while due its rough and porous character and therefore low possibility to clean them. This really affects the usability and appropriateness of terracotta as finishing material for a slab and doesn’t fit in the vision of clean and proper service blocks.

Screed bed or granolithic screed must be covered with floor tiles or a floor paint coating to get a surface that is well cleanable. Both beds are appropriate to provide a smooth slab for receiving the final floor finishing and to cover service pipes. It's a useful but expensive intermediate bed which is better to omit when possible.

A smooth plaster finish is required as bonding and protection of a sand-cement blockwork wall and is in that case necessary. For concrete (blockwork) surfaces it's also more like an expensive intermediate layer to provide a smooth surface which should be omit. Cleaning possibilities of a plaster finish is low and should, also for its long term quality, always be covered with paint or tiles.
Image 3.17: A toilet facility near a primary school in Ashaiman, walls are made of concrete blocks, a textured splatter dash and finally a grey paint finish.
A splatter dash finishing must also be painted for protection, cleaning and decoration, making it another intermediate layer between the wall filling and final finishing. It should only be applied on concrete (blockwork) surfaces when a rough structure for bounding or finishing is required. Bounding with different layers should be done sufficient with enough cement to guarantee a long term quality. The social acceptance and comfort of sharp splatter dash isn’t very well and should be avoided to use for the inside, outside shall not give any problems, see image 3.17 on the left page.

Laying of cladding slices doesn’t fit in the local building culture and is far too difficult. Besides this practical problem it is too expensive to use as wall finishing material. The same applies to the CHIC Liquid vinyl system which lifecycle costs are also too high. Except these high costs are the usability and specifications of the CHIC system almost comparable with a paint finish.

Comparing and evaluating the assessment diagram gives the result that terrazzo, epoxy, terracotta floor tiles, cladding and the CHIC Liquid vinyl system aren’t appropriate construction materials for the finishing of wall and slabs. The cleaning and long term qualities of terracotta floor tiles aren’t sufficient and all other finishing materials are too expensive.

The materials screed bed, smooth plaster and splatter dash are all not cleanable enough for using as final finishing in a public service block. And need therefore an own finishing to protect its long term quality and to give it a coloured decoration. All three are appropriate to use as intermediate layer between the wall filling and final finish to provide a qualitative bonding and a base, smooth or textured, surface for applying the final finish.

As final wall and slab finishing for the inside are both tiles and paint very appropriate. Investigated, industrial paints are from a high quality and therefore well cleanable. The little decreasing of quality with regularly repainting and thereby high maintenance costs is a disadvantage. Thereby must in case of such a repainting the service block (partially) closed for around a week. Quality of tiles is much higher and maintenance is restricted to a minimum, but this also asks some investment costs that are much higher than paint, for example up to 3.5 times for the slab.

Advisable is to use a paint coating for the final wall and slab finishing at the in- and outside of a service block. The small difference in quality and little nuisance during repainting doesn’t compensate to the much higher lifecycle costs of tiles. Important is that qualitative, and for the slab industrial, paints from reliable suppliers will be used and correctly applied by skilled painters according to prescribed instructions. During rough construction works must special attention be given to the slab, to provide a smooth level surface which can receive the final paint finish. Finally can repainting be done phased instead of a complete service block at once.
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* Not relevant aspect
** Mentioned rate is without wastage, profit and overhead

Image 3.18: Assessment diagram of group D - Windows
3.3.5 Windows

Windows surfaces should be large and placed on a way that maximum cross ventilation is encouraged through a service block. Beside ventilation is also important the admission of daylight, necessary security against forced entry and finally can windows be a prominent part of the overall architectural composition of a building. When wall openings aren’t closed with glass blades but open with design blocks or open window frames, the roof construction needs an overhang to prevent that (wind driven) rain falls inside.

Frames with burglar proofing are simple, open, solid and very durable. The simplicity and used materials like steel and timber shall be accepted by local people but will not support the image building of a construction. Less and strong materials are used which create a maximum wall opening for ventilation and daylight and restricts the quantity of cleaning and maintenance. Effect on the environment from using steel is unknown but the use of timber will support deforestation. Use of steel is around 10% cheaper than timber and both materials are comparable with design blocks.

Naco standard louvres are 3 times more expensive than frames with burglar proofing or design blocks. The products are very fragile, too detailed and they require a correct measured window frame which is very difficult to realise for the local building culture. Finally has louvres an image of richness and doesn’t fit well in a slum environment.

To give the construction a nice appearance are design blocks the most suitable. There are many possibilities with different types and finishing colours and the blocks can be laid in every wished shape. The acceptance from local people is great and they are familiar with this material. Realising windows with design blocks is more difficult than frames with burglar proofing but shouldn’t be a problem with some sufficient preparations and skilled workers. In the diagram are lifecycle costs for a square meter almost equal to frames. But to get the same opening in a wall is a larger surface of design blocks required, because they contain only a small opening for entering wind ventilation and daylight.

Of the three available window materials are only frames with burglar proofing and design blocks appropriate to fill wall openings of a service block. Their costs are almost comparable and both can be realised in a slum area whereby present difficulties can be solved. Finally design blocks shall support more the image and has a higher acceptance level but frames are more usable, cleanable and stronger. To realise frames is steel more desired than timber because of its lower price, more durability and it doesn’t support deforestation.

Advisable is to use design blocks for the facade and when prominent visible also for the back elevation, to create a simple and obvious appearance to all users. To make the building recognizable and distinguishable the design blocks must be painted in specific Safi Sana colours. Steel frames with burglar proofing should be used for large, square wall openings in the side elevations, whereby all frames must be painted in the same colour as the design blocks of the facade to create unity.

Steel frames must be designed and fixed on such a way that they connect columns or load bearing walls that support the roof trusses. Wherefore a reinforced concrete ring beam for transferring tensile loads in the structure isn’t required anymore.
<table>
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<tr>
<th>Criteria</th>
<th>No.</th>
<th>E1</th>
<th>E2</th>
<th>E3</th>
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</table>

* To carry this roofing material is an extended roof construction necessary
** Mentioned rate is without wastage, profit and overhead

Image 3.19: Assessment diagram of group E - Roofing materials
3.3.6 Roofing materials

Main function of a roof construction and its finishing is to span a space and shelter visitors from the elements, to give them a feeling of safety and comfort. Weight and loads shall be transmitted safely to the walls or beams which support it and beside this protecting and structural function must a roof in a tropical environment fulfil various other functions at the same time. To shade the external walls, to insulate against solar heat penetration and noise from rain, to shed and collect rainwater quickly and to withstand storm winds.

Concrete tiles are very usable and have a high long term quality with less maintenance. Main disadvantage is the heavy weight of 40.0 kg / m² which requires an extended and strong roof construction and the little adjustment of plans, making concrete tiles less appropriate. The local building culture isn’t very capable to place purlins parallel and exactly on their prescribed position.

Production and use of asbestos fibres in concrete products can cause serious illness, even (lung) cancer, to workers, users and inhabitants that live in the surrounding of a public toilet. The use of this toxic material doesn’t fit in the vision and perception of Safi Sana and is therefore not wanted.

Cellulose bitumen corrugated sheets have an overall score between sufficient and good and is highly recommended to use as roof finishing. They contribute the nice appearance and inside comfort of a service block and, with some necessary preparations and supervision, aren’t difficult to process on site. Costs are equal to other available roofing materials and due to its low weight per square meter is a light roof construction sufficient. One minus is the need to place every 0.45m a purlin to prevent sagging of bituminous roof covering.

A roof made of 0.6mm thick aluminium sheets is almost comparable to the appropriate bitumen sheets, even in costs and production rate. Only the ability to reduce heat conduction of aluminium is much lower than cellulose bitumen with a thermal resistance, \( R: 2.94 \times 10^{-6} \text{ m}^2 \cdot \text{°C}/\text{W} \) facing 0.03 m².°C/W for bitumen sheets. This is a material specification that can only be improved by making the sheets thicker which increases its weight and costs significant. Thin aluminium sheets shall also make much more noise during rainfall than a concrete or bituminous roof covering but purlins can be placed around 0.80m, reducing the number of purlins with about 35% comparing to bitumen sheets.

All three remaining roof finishing materials, zinc aluminium, zinc and galvanised steel, have the common specification that they will be affected and corrode by sea salt in coastal areas, making rain water harvesting impossible and decrease the lifetime really. These red-brown coloured surfaces with its disadvantages don’t support the image building of a service block and aren’t very accepted by local people. To increase the lifetime of a roof finishing can coatings be applied but this will result into high, unwished maintenance costs.

Most appropriate roof finishing for a service block are cellulose bitumen corrugated sheets which give the most comfortable performance during lifetime and still is affordable. Construction works are well possible but need some accurate preparations and instructions. The result shall be a usable facility that has a good appearance on all users and inhabitants and allows entering of daylight through transparent sheets. A timber and steel roof construction can be used to support the roof finishing.

Despite that thermal resistance of bitumen sheets is the highest, it is still not very high and proves that large wall openings to promote wind ventilation are required. When usability is less important and lifecycle costs become a main issue can aluminium roofing sheets be considered to save material by purlins in the roof construction.
3.3.7 Overview

With help of the 14 applying criteria and all information and scorings given in the database are for every group the containing materials compared to find out which are most appropriate to apply. Mostly the usability of a material follows from its own advantages and qualities but also from the unsuitability and disadvantages of other construction materials in a group. In this paragraph is with an overview shortly repeated which materials are most appropriate and shall be used for further development of the designed compartments for Safi Sana service blocks.

Use of Portland cement in various concrete and mortar mixtures should be reduced with around one third and be replaced for pozzolana cement, but this should be extendedly tested before it may use in mixtures.

Blinding bed, foundation and slab should be made of (reinforced) concrete.

According to paragraph 3.1.1 and 3.3.3 there are different materials appropriate to build the rough construction of the two structure types. First is a frame construction with columns and a non-load bearing wall filling, second is with massive, load bearing walls. Columns can be realised with formwork, reinforcement and concrete or with concrete blocks that are filled later on with reinforcement and concrete. The non-load bearing wall filling can be made of sand-cement or concrete blocks. For the massive, load bearing walls must concrete blocks be used with possibly an interlocking system and reinforcement provisions where needed.

Non-load bearing walls for the partition walls to form cubicles should also be made of sand-cement or concrete blocks.

The materials sand-cement and granolithic screed bed, smooth plaster finish and splatter dash can be used as intermediate layer between the rough construction and final finishing of slab and walls when needed. To provide a qualitative bonding and a base, smooth or textured, surface for applying the final paint finish.

Paint is the most appropriate construction material to use for the in- and outside finishing of every wall and slab in the service block.

For wall openings are in the facade of a building and when prominent visible also for the back elevation, painted design blocks the most suitable, but in the side elevations are painted steel frames with burglar proofing more usable.

Of all roof coverings it's the best to use cellulose bitumen corrugated sheets, for the roof construction can be used either a timber or steel structure.

Which structure type and construction materials are used to realise the rough construction works of external and internal walls is topic for further research in the following two paragraphs. The same applies to the roof construction which can be realised in timber and steel.
Appropriate design and work plan for Safi Sana service blocks in Accra, Ghana

Image 3.20: Dimensions and pitch of the roof construction

Image 3.21: Position of all 10 purlins at one side of the roof construction, with ridge and overhang at eaves

Image 3.22: Timber roof construction on building project EPP in Accra

Image 3.23: Timber roof construction in a public toilet in Teshie - Accra
3.4 Roof construction

Bitumen corrugated sheets which are used to cover the roof can be applied on a timber or steel roof construction. In this paragraph shall be defined which of these two materials is most appropriate to use for the roof of a compartment. Therefore are firstly roof constructions designed and elaborated and then afterwards compared. Generic design of paragraph 2.3 forms starting point for designing the roof construction and the final selection will be done with help of all defined criteria of paragraph 2.3.

Design of roof constructions are based on observed applications of local sold construction materials in building projects around southern Ghana and further completed with information from literature. These are for example the models of trusses and dimensions of chords, members and purlins in timber and steel. There are no structural calculations established to check if bearing loads are smaller than the structural capacity of the roof construction and if all loads are safely transmitted to walls or columns which support it. Loads are own weight of the roof construction and its finishing, super imposed loads of construction and repair works and wind loads. Especially during rainy season can strong winds and rainstorms take place. [6] [8] [13] [14]

3.4.1 Roof design

On service blocks is a sloped roof foreseen, type double pitch, with in every grid one truss. This mean they are placed 3.00m centre to centre making the necessary length of purlins also 3.00m. Trusses are supported by three load bearing columns or walls making the spans short and keep the material dimensions limited. The span of a truss is two times 2.80m with on both sides 1.00m extra overhang. When wanted it is possible to span 5.60m at once with a truss. This can be useful when the middle wall isn't constructed as a load bearing one, for example by sand-cement blockwork or design blocks.

As roof covering are cellulose bitumen corrugated sheets used which are extended described in the database of appendix 1, material E3. All information that applies to the roof construction is shortly repeated here. Roof pitch should be between 10 to 30° and to occur sagging of sheets must purlins be placed around 0.40 to 0.50m centre to centre. To fix the ridge cap well, should two purlins be fixed in the ridge on a 6” (0.15m.) distance and the overhang at eaves must be around 0.08m. Weight of bitumen corrugated sheets is 3.20 kg/m². To increase light reflection must light coloured roofing sheets be used instead of dark ones, also can a few transparent sheets be applied to promote natural lighting but there heat conduction is insignificant.

The roof slope should be sufficient to drain off rainwater and be within the appropriate pitch of bitumen sheets, 10 to 30°. This pitch has also a strong effect on the amount of construction materials that are needed for walls and roof of the building, in general are low pitches cheaper than steep ones. Finally must roof slopes be expressed with round numbers and in simple relations between height and span instead of angles with degrees. This is much easier to measure for local workers during realisation of the roof construction. All above mentioned leads to image 3.20 which presents dimensions and pitch of the roof construction. Image 3.21 shows the position of all purlins in the roof construction what is equal for steel and timber, for every roof side are 10 purlins needed.
Image 3.24: Example models and terms of timber roof constructions, image from Construction Technology for a Tropical Development Country [14]

Image 3.25: Sketch of a timber roof construction for 3 supporting walls or columns

Image 3.26: Sketch of a timber roof construction for 2 supporting walls or columns
3.4.2 Timber roof construction

To achieve necessary durability for the long term quality should for a timber roof construction only hardwood be used and no softwood. Available hardwood on the timber market in Accra is mentioned below. Moisture content of sold timber is high, it has an unknown strength and is curved, making processing more difficult. Production rate for processing timber is 0.3 hours / m³ for a carpenter assisted by one labourer. More specific information about timber is presented in the database of appendix 1, material A11. A length of 14 foot is equal to around 4.25 meter. Given prices are only for purchasing hardwood on a local timber market, costs for transport to site is unknown.

<table>
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<th>Hardwood Size</th>
<th>Price per Piece GH¢</th>
<th>Price per m³ GH¢/m³</th>
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<td>2” x 2” x 14 foot (50 x 50mm)</td>
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<td>0.81</td>
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<tr>
<td>4” x 2” x 14 foot (50 x 100mm)</td>
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<td>1.41</td>
</tr>
<tr>
<td>6” x 2” x 14 foot (50 x 150mm)</td>
<td>8.28</td>
<td>1.95</td>
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</table>

Image 3.22 on the previous page shows the roof construction on building project EPP in East Legon – Accra. All roof trusses are placed on 3.00m centre to centre, making the span for purlins also 3.00m. For purlins is hardwood 4” x 2” used, which can safely span those 3.00m and shall not sag due its own weight plus different loads. On smaller spans and for ceilings are normally purlins of 2” x 2” used. Trusses are built with hardwood 6” x 2” for top and bottom chords and vertical members, and hardwood 4” x 2” is used for the diagonal web members. Roof trusses are supported in the middle with a concrete slab.

The roof construction of a public toilet facility in Teshie – Accra is presented on image 3.23. Hardwood timber 6” x 2” is used for the top chords and 4” x 2” for the bottom chords. Span in direction of the truss is almost equal to the proposed compartments, but span of purlins is much shorter than 3.00m by which in this case timber 2” x 2” is sufficient to use for the purlins.

Two other models of roof trusses are together with some terms shown in image 3.24 on the left page. All trusses make use of triangles which are not deformable and structural very strong. These suitable examples forms together with a useable example of the book ‘Low cost timber roof truss’ the base for timber roof constructions. [8]

There are two different trusses designed of which sketches and their required timber dimensions and lengths are given on the left page. Only hardwood timber 6” x 2” and 4” x 2” are used for the roof construction. The roof truss of image 3.25 is made for three supporting walls and a span of two times 2.80m, which is according to the generic design. Image 3.26 shows a roof truss with only two supporting walls and one span of 5.60m.

Because of the large span between two trusses, which is 3.00m, are purlins with dimensions 4” x 2” applied. This means that for one compartment, with on both roof sides 10 purlins, totally 60.0m of 4” x 2” hardwood purlins are required.

Timber should be well protected and decorative painted with a wood preservative primer and two coloured gloss top coats as finishing. This is needed to guarantee the long life quality of hardwood timber, prevent rotting and give it a nice appearance, also because there is no ceiling in the service block. Repainting is estimated for every 8 years, so within a lifetime of 25 years shall all timber be coated 3 times. In the database of appendix 1, material C1, is more detailed information about paint presented.
Image 3.27: Steel roof construction at a project of the Foundation to Build on Alorkpem Island

Image 3.28: Sketch of a steel roof construction for 2 and 3 supporting walls or columns
3.4.3 Steel roof construction

A roof construction for small buildings made of steel isn’t very common in Ghana. The Dutch organization Foundation to Build has steel successfully applied on two school projects in Klikor and Alorkpem Island, both are situated in south-east Ghana. Image 3.27 shows such a steel roof construction which doesn’t need a third supporting wall or column in the middle and can span the width of a building at once. The shown span is much wider than the span in a compartment, which is just 2.80m or when done at once, 5.60m. For the roof trusses in image 3.27 are only square pipes 1.25” x 1.25” (30 x 30 x 1.5mm) be used and for all purlins angle bars with dimensions 1” x 1” (25 x 25 x 3mm).

Observed roof construction leads together with examples from literature to a designed roof truss which is presented in image 3.28. This truss fits to the walls and supports the roof finishing well. Here are also triangles used which are structural very strong and dimensions of steel elements are restricted to limit the weight and simplify processing. This model of roof truss can be used on two and three supporting columns or walls. Because of a smaller span than by observed projects should dimensions of chords and members be adjusted. In case of three supporting points must square pipes 1” x 1” (25 x 25 x 1.5mm) be used and in case of only 2 supporting points shall square pipes of 1.25” x 1.25” (30 x 30 x 1.5mm) be sufficient.

For the purlins are also angle bars 1” x 1” (25 x 25 x 3mm) used which can span 3.00m. In totally there is 60.0m of steel purlins needed for one compartment, based on 10 purlins for every roof side.

Just like timber must also steel be well painted with a primer and two coloured gloss top coats as finishing. This is to give the structure some appearance and prevent from rust corrosion, especially in coastal areas. Repainting is estimated to be required every 8 years, give the roof construction a guaranteed life time of 25 years.

Steel sections have a well known strength and are straight, making processing easier, but steel must be welded which takes also more time. Thickness and quality of the welding joint is very important for the final quality of the structure. Production rate for a welder and a labourer to process and weld steel together to a roof construction is unknown. A careful estimation is 0.60 hours / m^2 for each, which is a doubling of the rate for processing timber. Used steel pipes and bars have a length of 5.8m and their purchasing costs including transport to site are presented below. More detailed information about steel can be found in the database of appendix 1, material A10.

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<td>2.32 GH¢/m^2</td>
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</table>
Appropriate design and work plan for Safi Sana service blocks in Accra, Ghana

Image 3.29: Anchoring of a timber roof truss on construction project EPP, located around Accra

Image 3.30: Placing of prefabricated roof trusses, image from Construction Technology for a Tropical Development Country [14]

Image 3.31: Purlins are supported with timber and to connect two top chords is a scarf joint applied

Image 3.32: Steel angle bars, the purlins, are connected to the roof truss with small steel cleats, image from Roofs for Warm Climates [15]

Image 3.33: Steel square pipes and steel purlins are connected by welding to one roof construction at a project of the Foundation to Build on Alorkpem Island.
3.4.4 Remains

In previous paragraphs are for both, steel and timber, two roof constructions designed, elaborated and presented with necessary explanation and images. Some aspects of the roof construction and finishing are not yet mentioned in previous paragraphs but will be discussed in this paragraph. [60]

To guarantee the stability of a building and make them more earthquake resistant, must between trusses wind bracings be placed. This should be done around every 3 or 4 compartments, with a minimum of 1 complete wind bracing for every structure. A complete wind bracing exist of two crossed steel or timber members on both roof sides and between two trusses. Bracings should only be fixed to trusses and not to purlins.

Roof trusses must be fixed properly to walls or columns to prevent blowing off by storm winds. Anchoring can be done with a wall plate or a reinforced anchor and depends on used concrete or blockwork building structure, an example is given on image 3.29.

The expected wind ventilation inside a service block is most likely sufficient enough to get a comfortable indoor climate, due to many large wall openings, an open construction inside the building without a ceiling and the small width of the compartments. Therefore is a ridge opening or broken pitch roof optional and not involved into this roof design. Such openings can be made of timber and steel. Gutters for harvesting rainwater can be fixed on the lowest purlin and shall fit with the overhang at eaves. The bottom chords can be well used to fix building services like electricity, lighting and water pipes inside the building.

All required number of trusses can completely be prefabricated on ground level and afterwards placed on their supporting positions or they can be produced directly into the work. Both are well possible and choice shall be dependent on weight of a truss and the possibility to reach the work place safely. Purlins and wind bracings are almost always fixed into the work. Image 3.30 shows an opportunity to place prefabricated roof trusses. In both cases must the complete realisation of roof construction and bitumen corrugated sheets be well prepared and supervised by client and contractor. The roof is the most essential part of a building and difficult to reach afterwards for any repair works.

All hardwood is connected together with nails and to link timber members together are scarf joints used. Small pieces of timber are used to fix and support purlins to the roof trusses. Steel pipes and bars are connected and linked by welding. To place purlins to roof trusses are small cleats of steel angle bars welded on top chords. Image 3.31 to 3.33 shows some examples of steel and timber joints and connections. [15]
<table>
<thead>
<tr>
<th>Criteria</th>
<th>No.</th>
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<tr>
<td></td>
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<td>Timber roof construction</td>
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<tr>
<td>Construction time (hours / unity)</td>
<td>14</td>
<td>x</td>
</tr>
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<td>Lifecycle costs (GH₵ / unity)</td>
<td>13</td>
<td>435.12 - 459.43</td>
</tr>
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<td>Local employment and economy</td>
<td>12</td>
<td>4</td>
</tr>
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<td>Realizable in slums</td>
<td>11</td>
<td>3</td>
</tr>
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<td>Adjustment of plans</td>
<td>10</td>
<td>3</td>
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<tr>
<td>Technical acceptance</td>
<td>9</td>
<td>4</td>
</tr>
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<td>Labour circumstances</td>
<td>8</td>
<td>3</td>
</tr>
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<td>Long term quality, maintenance and reliability</td>
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<td>4</td>
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<td>Environmental sustainability</td>
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<td>Cleaning</td>
<td>5</td>
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<tr>
<td>Usability and energy</td>
<td>4</td>
<td>*</td>
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<td>Fit building services</td>
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<td>Social acceptance</td>
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<td>3</td>
</tr>
<tr>
<td>Image building</td>
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<td>3</td>
</tr>
</tbody>
</table>

* Not relevant aspect

Image 3.34: Assessment diagram of two different roof constructions
3.4.5 **Appropriate roof construction**

The painted basic materials, timber and steel, are compared in this paragraph to define which of these two is most appropriate for the roof construction of Safi Sana service blocks. This is done with help of the presented information of both materials in paragraph 3.4, the database of appendix 1 and all 14 defined criteria of paragraph 2.3. An assessment diagram is presented by image 3.34.

Timber and steel are both finished with a coloured paint, making it not such a big difference for the image building and social acceptance of the roof constructions. Building services can be fixed on the bottom chords and is for both alternatives the same. Usability and energy and cleaning of the roof construction are not relevant criteria for assessment.

Effect of timber on the local environment is inferior due to its illegal cut and deforestation. Using of it must be limited to protect tropical forests in Ghana. Steel is an imported product and effect on the Ghanaian environment is unknown, but also on the environment where it is extracted and produced. Timber and steel are both well coated to protect them against various influences and shall fulfil the long term quality. But in general shall timber earlier be affected by rotting or insects like termites than steel by corrosion, making steel a more durable construction material than timber.

Labour circumstances for processing steel and timber to a roof construction are for both assessed as good and don’t affect safety and health of construction workers. On restriction that necessary safety provisions are taken to protect workers from falling down.

Carpenters are plenty available and above-average skills to process timber aren’t required, curved timber makes construction works more difficult. Processing steel requires some skilled welders which are more difficult to find but present in Accra. All imported steel bars and pipes are straight which simplifies processing. Overall can be said that the technical acceptance of timber is better than steel.

Steel and timber roof trusses must be placed on exactly the same supporting walls or columns making the adjustment of plans equally. The same applies for realising a roof construction in a slum which can be done directly into the work or with prefabricated trusses and shall not make such a difference between timber and steel.

Local employment and economy will be more stimulated by timber due its local cutting than steel because of its large importation. The benefit of processing timber and steel to a roof construction shall be comparable.

On the next page are costs shown for the main materials, paint and labour to realise the roof construction of one compartment. This exists of two roof trusses connected by 3.00m of purlins. By linking more compartments costs become cheaper, because for every following compartment is only one roof truss more needed. Lifecycle costs are compared and therefore is painting three times calculated, gives the construction a lifetime of around 3 times 8 years is 24 years. Supporting steel and timber, wind braces, nails, welding sticks and equipment aren’t included. The same is for wastage, profit and overhead which percentages for timber and steel are probably equal. Finally is the transport of timber to site unknown and therefore not included. The costs as presented by image 3.34 are almost equal to each other and don’t deviate much, maximum 6%.
### Painted timber roof construction for 3 supporting walls or columns

<table>
<thead>
<tr>
<th>Item</th>
<th>Elements</th>
<th>Quantity</th>
<th>Unit</th>
<th>Rate</th>
<th>GH¢</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
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<td>m1</td>
<td>@ 1.41</td>
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</tr>
<tr>
<td>1.</td>
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<td>m1</td>
<td>@ 1.41</td>
<td>84.60</td>
</tr>
<tr>
<td>2.</td>
<td>Hardwood timber 6&quot; x 2&quot; (trusses)</td>
<td>29.4</td>
<td>m1</td>
<td>@ 1.95</td>
<td>57.33</td>
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<tr>
<td>3.</td>
<td>Timber paint, one preservative and two gloss topcoats</td>
<td>89.4</td>
<td>m2</td>
<td>@ 1.38</td>
<td>123.37</td>
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<td><strong>B</strong></td>
<td>LABOUR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>1 Carpenter (0.30 hours / m1)</td>
<td>26.8</td>
<td>Hrs</td>
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<td>2.</td>
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<td>Hrs</td>
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<td>Hrs</td>
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<td>102.81</td>
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<tr>
<td>4.</td>
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<td>Hrs</td>
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</table>

### Painted timber roof construction for 2 supporting walls or columns

<table>
<thead>
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<th>Item</th>
<th>Elements</th>
<th>Quantity</th>
<th>Unit</th>
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<th>GH¢</th>
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<td><strong>A</strong></td>
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<td>m1</td>
<td>@ 1.41</td>
<td>84.60</td>
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<td>1.</td>
<td>Hardwood timber 4&quot; x 2&quot; (purlins)</td>
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<td>2.</td>
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<td><strong>B</strong></td>
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<td></td>
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<tr>
<td>1.</td>
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<tr>
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<td>Hrs</td>
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<td>108.33</td>
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<tr>
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<td>459.43</td>
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### Painted steel roof construction for 3 supporting walls or columns

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<th>Unit</th>
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<th>GH¢</th>
</tr>
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<td>m1</td>
<td>@ 2.14</td>
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<td>1.</td>
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<td>@ 2.14</td>
<td>128.40</td>
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<td>2.</td>
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<td>m1</td>
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<td>70.64</td>
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<td>m2</td>
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<td>66.62</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>1.</td>
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<td>Hrs</td>
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<td>75.44</td>
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<td>1 Labourer to assist welder (0.60 hours / m1)</td>
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<td>Hrs</td>
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<td>59.04</td>
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### Painted steel roof construction for 2 supporting walls or columns

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<td>m1</td>
<td>@ 2.14</td>
<td>128.40</td>
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<td>1.</td>
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<td>2.</td>
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<td>m2</td>
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<td></td>
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</tr>
<tr>
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<td>Hrs</td>
<td>@ 1.15</td>
<td>75.44</td>
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<td>2.</td>
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<td>Hrs</td>
<td>@ 0.90</td>
<td>59.04</td>
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<tr>
<td>3.</td>
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<td>Hrs</td>
<td>@ 1.15</td>
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<td>Hrs</td>
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<td><strong>Cost per compartment</strong></td>
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<td></td>
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</table>

*Image 3.35: Costs of main materials and labour for realising the roof construction of a compartment*
Construction time for steel is estimated on two times the production rate of timber, 0.6 hours/m$^1$ facing 0.3 hours/m$^1$.

Differences between timber and steel are marginal, especially in costs. Timber is less appropriate due its damaging effect on the local environment and its lower durability, but timber is easier and much faster to process than steel. Nailing is still simpler than welding but on the other hand curved timber doesn’t stimulate the processing very well. Steel is imported from abroad and supports the local employment and economy not as much as timber. It requires some more attention, preparation and construction time in the beginning but when realised it will be longer lasting than timber and doesn’t affect the environment so much. Concluding the above mentioned differences makes it steel a little more appropriate construction material for the roof construction than timber.

The choice for a roof truss with one or two spans and thus two or three supporting points depends on the applied structure type, wall construction materials and construction costs and shall be defined in the next paragraph.
Image 3.36 & 3.37: Final external and internal walls and wall openings in a cross section and top view of one Safi Sana compartment
3.5 Structure type and wall construction

External and internal walls are imported elements of a building, to offer privacy and protection against various influences and to support the roof construction. The building structure is part of the wall construction and there are two possible types. One is a frame construction with columns and non-load bearing walls and the other is with only massive, load bearing walls. Both types require other materials for rough construction works and different combinations of columns and walls. Most appropriate materials for mentioned applications are already defined in paragraph 3.3: reinforced concrete, hollow and solid sand-cement and concrete blocks, smooth plaster finish and splatter dash.

In this paragraph are these final appropriate materials and two structure types be combined, elaborated and compared to define which are most suitable for applying to all external and internal walls of a compartment. To assess and select various alternatives are all the criteria of paragraph 2.3 be used. For getting a fair comparison between different constructions is only one wall design be applied which is firstly detailed in paragraph 3.5.1.

All information, specifications and figures, about construction materials that are mentioned in this paragraph is given by the database of appendix 1. When facts are edited or used for calculations it is named in the text or presented on the left pages with an image. [6] [13] [14] [16]

3.5.1 Wall design

Starting point for elaboration of structure type and wall construction is the generic design of compartments which is presented in paragraph 3.1. The strip foundation, with column bases where necessary, forms the base for all walls that are heavy and require any load bearing capacity. All other, mostly partition walls can be realised directly on the concrete ground floor slab.

Height of walls should be sufficient enough to guarantee privacy and prevent people from looking inside a service block, into other cubicles or from male to female side and otherwise. On the other hand should wall openings as large as possible to promote natural wind ventilation and entering of daylight. According to the National Building Regulations 86 (5) must the total clear wall opening at least one sixth (16%) of the floor area.

The two external walls must be around 1.90m high, measured from the surrounding soil, with above this wall a 0.80m high window opening over the whole width of a compartment, see also image 9.1 and 9.2. Openings are than above and at the same height as all cubicles. Required wall opening conform to building regulation is $1/6 \times (2.8 \times 3.0) = 1.4m^2$. Proposed external wall opening is $0.8 \times 2.7 = 2.2m^2$ and thus sufficient. Be alert that enough daylight enters through the wall openings, due to the large overhang in combination with height of wall openings. If this happen it can be easily solved by using small strips of transparent corrugated sheets in the roof finishing.

For the middle wall, which is 2.50m high, should the lowest 2.20m be closed to occur that people of different sexes sees each other. The uppermost 0.30m, to bottom chord of roof truss, may be open to promote more wind ventilation inside the construction, making the wall non-load bearing. It’s best to do this with design blocks because these keep some more privacy feeling to all users. Internal walls to form cubicles have a length of 1.60m and a height of 2.00m. This should be high enough for people, not to look into other cubicles and doesn’t stop too much internal wind ventilation.
### Reinforced concrete columns 300 x 300mm and 3.30m high

<table>
<thead>
<tr>
<th>Item</th>
<th>Elements</th>
<th>Quantity</th>
<th>Unit</th>
<th>Rate</th>
<th>GH¢</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Formwork to vertical sides of columns</td>
<td>4.0</td>
<td>m2</td>
<td>@ 14.83 =</td>
<td>59.32</td>
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<tr>
<td>2.</td>
<td>Mild steel round bar reinforcement</td>
<td>29.7</td>
<td>kg</td>
<td>@ 1.36 =</td>
<td>40.39</td>
</tr>
<tr>
<td>3.</td>
<td>Reinforced in-situ vibrated concrete (1:2:4)</td>
<td>0.3</td>
<td>m3</td>
<td>@ 152.91 =</td>
<td>45.87</td>
</tr>
<tr>
<td>4.</td>
<td>Masonry paint for concrete, 3 times</td>
<td>9.0</td>
<td>m2</td>
<td>@ 2.32 =</td>
<td>20.88</td>
</tr>
</tbody>
</table>

Add Profit and Overheads | 0 | % | = | 0.00 |

Cost per column | 166.46 |

*Image 3.38: Dimensions and ratio of concrete columns*

*Image 3.39: Budget estimation for realising concrete columns*
In the building structure must provisions be present to place and fix all roof trusses sufficient on a load bearing element. This comes very accurate and requires an anchoring to resist pressure and tensile stresses, even by storm winds and seismic activities.

External walls are for the greatest part protected from sun radiation and direct rainfall by a wide roof overhang. Unlike this are all walls of the construction be coated with a paint finish for decorative covering and a protection, making the facility cleanable during operation. In all calculations in this paragraph is painted counted for 3 times. Repainting is estimated to be necessary every 8 years which give the construction a guaranteed lifetime of 25 years. Material C1 in the database of appendix 1 shows more specific information about paint.

3.5.2 Frame construction, columns with non-load bearing walls

In a frame construction are all loads carried and transferred by columns that are interconnected with beams to one framework. Beams are already present in the design in the form of a reinforced concrete strip foundation and steel window frames. The space between columns and beams is filled with non-load bearing walls made of sand-cement or concrete blocks. Appropriate materials for columns are reinforced concrete, stacked concrete blocks filled with reinforcement bars and concrete and finally are steel beams considered. In this paragraph are all three different columns and two wall fillings worked out and considered to define which materials are most appropriate for a frame construction.

3.5.2.1 Reinforced concrete columns

Height of a column is 3.30m, measured from the column base foundation to its topside. In accordance with National Building Regulation 38 and general guidelines must ratio of column height to its width not exceed 12. Also shall the amount of reinforcement not be less than 0.8 percent of the concrete sectional area, with minimal four bars in every corner and each with a minimum diameter of 12mm. Diameter of stirrups, which are also called ‘binders’, must be at least 10mm with an interval that is not greater than 300mm. Concrete covering on reinforcement bars may not be less than 40mm.

With a column cross-section of 300 x 300mm (0.8% = 720mm²) is the height-width ratio 11, smaller than 12 and therefore correct. To cast concrete is a column formwork needed according to material A11 of the database in appendix 1. For reinforcement are 4 bars of ø16mm (804mm²) sufficient with stirrups ø10mm placed centre to centre 250mm. Length of all reinforcement bars in one column is 27.2m, which gave a weight of 29.7kg and is converted 99kg reinforcement per m³ concrete. For casting is reinforced in-situ vibrated concrete (1:2:4) with 20mm aggregate required that has a minimum strength of 20N/mm² after 28 days. At the end shall the top 2.7m of a column be coated with masonry paint for plaster finish and concrete, hereby is assumed that a plaster finish on concrete isn't needed because of improved construction works. Dimensions and ratio of concrete columns are presented by image 3.38 on the left page.

A budget estimation to realise reinforced concrete columns is 166.46 GH¢ / column and shown by image 3.39. The unit rate analyses from the specific construction materials are extended clarified in the database of appendix 1. Beside square columns is it also well possible to realise circular columns which can increase the appearance of a service block.
### Stacked concrete blocks filled with reinforcement bars and concrete

<table>
<thead>
<tr>
<th>Item</th>
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</tr>
</thead>
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<td>@</td>
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<tr>
<td>3. Reinforced in-situ vibrated concrete (1:2:4)</td>
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<td>m³</td>
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<td>m²</td>
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<td>3.02</td>
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<td>%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Cost per column**

192.99

*Image 3.40: 100mm solid concrete blocks laid in a square to create an inside opening for reinforcement bars and concrete*

*Image 3.41: Budget estimation for realising columns by stacking concrete blocks and filling the opening with concrete and reinforcement*
3.5.2.2 Filling stacked concrete blocks

These columns exist of 100mm thick, solid concrete blocks that are stacked on a column base foundation. Two whole and two half blocks with some normally sand-cement mortar, are sufficient to lay a square and create an inside opening of 200 x 200mm, see image 3.40. This is smaller than a concrete column but the structural co-operation of the concrete blocks can be counted too. Including these blocks are the outside dimensions of such a column 400 x 400mm.

To carry the whole roof construction and anchor it must the complete opening be filled with reinforcement bars and in-situ vibrated concrete (1:2:4). For reinforcement is the same amount calculated as for concrete columns, 4 bars of ø16mm with stirrups ø10mm placed centre to centre 250mm. The highest 2.70m of these concrete blocks must be protected and decorated with masonry paint for concrete blockwork. Image 3.41 shows the budget estimation for realising columns by stacking blocks filled with concrete and reinforcement which costs are 192.99 GH¢ / column.

3.5.2.3 Steel beams

In paragraph 3.3.5 and 3.4.5 is concluded that steel is the most appropriate construction material to apply for window frames and roof construction. Therefore it’s also very valuable to consider the suitability of steel beams as alternative material for columns in a frame structure. The beam can be casted in or fixed on a concrete foundation and afterwards can blockwork be laid against this steel profile. Required steel section is mainly determined by buckling of a steel beam in relation to its dimensions and height which is 3.30m. Guideline says that for square pipes the ratio of height to its width should be 20 to 35, which mean a square steel section of 100 to 160mm. [4]

Largest available section is 100 x 100mm with thicknesses of 3, 4, 6 and 8mm. Due to small available sections in comparison with required larger sections must applied thickness be higher, 6 or 8mm. Costs for only purchasing a steel square pipe, 100 x 100 x 6mm with a length of 3.30m, is 168.42 GH¢. This is already more expensive than a concrete column and costs for fixing and painting the steel beam aren’t even calculated. Another opportunity of buying a 2.4 x 1.2m large and 6mm thick steel plate and cut and weld a steel beam yourself is even much more expensive.

Besides these costs is placing of steel beams very difficult for local construction workers. Steel beams are very narrow and makes the connection with the roof construction very tight. When they aren’t fixed straight in or on the column base foundation, but a little bit sloped, shall the topside of a steel column not on its correct place to join and carry the roof construction.

3.5.2.4 Appropriate columns

To define which construction materials are most suitable for realisation the columns in a frame structure are all three alternatives compared in this paragraph. Criteria of paragraph 2.3 are used to assess different column constructions and to substantiate which of the three must be applied in a compartment.

A steel beam isn’t a very appropriate construction material to use for columns of a service block. Their material costs are already higher than others and besides this has it two disadvantages. The adjustment of plans to previous and following activities of foundation and roof construction is unsatisfactory and difficult to realise.
Image 3.42: Realising concrete columns at once on a construction site in Accra
This adjustment can be solved by doing measurements extremely accurate what doesn't fit in the local building culture. And finally will by applying steel all the money invest to buy imported materials which don't really support the local employment and economy.

The image building and social acceptance of concrete columns is little better than stacked concrete blocks due its slenderness, which appears a more effective use of materials. At the end are both columns coated with a coloured paint, making it for the appearance and acceptance not such a difference which materials are used at the outside. The criteria fit building services, usability and energy and cleaning aren't relevant for this assessment.

Formwork to cast concrete columns is made of softwood timber and can only be used for three times, when it's lost and shall be used for firewood. The continuous demand for timber has a negative effect on the environment and should be restricted by reusing formwork more often. Stacked concrete blocks don't use timber to make columns and has a smaller effect on the environment.

Both reinforced concrete and concrete blocks have a guaranteed long term quality for life and shall not be affected so quickly by different influences, especially when both are protected with a paint coat and overhang. Maintenance is also equal for two optional columns making this criterion almost equal for the alternatives.

By realising two different column constructions they should be watchful that workers don't carry too much weight, especially by heavy formwork panels. Provisions should be taken to prevent this and that their health isn't affected. In the current situation are labour circumstances for stacking concrete blocks little better than for realising concrete columns.

Technical acceptance of both alternatives is not very good and requires above-average workmanship and responsibility feeling. Processing and curing of concrete needs special attention to produce structural qualitative columns and laying concrete blocks should be done very straight in two directions because none thick plaster finish is applied.

Placing concrete blocks happens more controlled and gives the opportunity to modify measurements of the column. This makes connection with the roof construction and thus adjustment of plans little better than concrete columns. They are casted at once with prefabricated formwork but have a large sectional area where the roof construction can be always fixed and anchored on, see also image 9.7.

Realising concrete columns or stacked blocks filled with reinforced concrete in a slum environment doesn't make such a difference. The same is for supporting local economy and employment, both are labour intensive activities made with locally produced or extracted materials except reinforcement.

Budget estimations shows that stacked concrete blocks are more expensive than concrete columns. Difference is 26.43 GH¢, which makes that stacked blocks are 16% costlier. None of the two possibilities requires enormous much time and shall really delay the process. Total construction time is strongly depended on available number of construction workers and not specific defined here.

Differences between concrete and stacked concrete block columns are little for the design and realisation of it. Both can be qualitative well constructed in a slum environment and shall fit into the building process of a compartment. Provisions must be taken that labour circumstances during realisation of the columns are correct. This makes lifecycle costs the conclusive criteria what makes that concrete columns are more appropriate than stacked concrete blocks filled with mortar. The price difference of 16% is significant enough to make a difference between the two remaining alternatives.
### Non-load bearing walls

<table>
<thead>
<tr>
<th>Item</th>
<th>Walls</th>
<th>L</th>
<th>H</th>
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<th>m2</th>
</tr>
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<tr>
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<td>2</td>
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<tr>
<td>2.</td>
<td>Middle wall</td>
<td>3.00</td>
<td>3.00</td>
<td>1</td>
<td>9.00</td>
</tr>
<tr>
<td>3.</td>
<td>Partition walls</td>
<td>1.60</td>
<td>2.00</td>
<td>1</td>
<td>32.00</td>
</tr>
</tbody>
</table>

Total wall surface: 54.50 m²

### Sand-cement blockwork wall

<table>
<thead>
<tr>
<th>Item</th>
<th>Elements</th>
<th>Quantity</th>
<th>Unit</th>
<th>Rate</th>
<th>GH¢</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>100mm Hollow sand-cement blockwork wall</td>
<td>32.0</td>
<td>m²</td>
<td>15.76</td>
<td>504.32</td>
</tr>
<tr>
<td>2.</td>
<td>150mm Hollow sand-cement blockwork wall</td>
<td>22.5</td>
<td>m²</td>
<td>19.38</td>
<td>436.05</td>
</tr>
<tr>
<td>3.</td>
<td>Smooth plaster finish (1:4) on outside walls</td>
<td>13.5</td>
<td>m²</td>
<td>4.02</td>
<td>54.27</td>
</tr>
<tr>
<td>4.</td>
<td>Smooth plaster finish (1:6) on inside walls</td>
<td>95.5</td>
<td>m²</td>
<td>3.61</td>
<td>344.76</td>
</tr>
<tr>
<td>5.</td>
<td>Masonry paint for plaster finish, 3 times</td>
<td>286.8</td>
<td>m²</td>
<td>2.32</td>
<td>665.38</td>
</tr>
</tbody>
</table>

Cost per compartment: 2004.78 GH¢

### Concrete blockwork wall

<table>
<thead>
<tr>
<th>Item</th>
<th>Elements</th>
<th>Quantity</th>
<th>Unit</th>
<th>Rate</th>
<th>GH¢</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>100mm Hollow concrete blockwork wall</td>
<td>32.0</td>
<td>m²</td>
<td>20.87</td>
<td>667.84</td>
</tr>
<tr>
<td>2.</td>
<td>150mm Hollow concrete blockwork wall</td>
<td>22.5</td>
<td>m²</td>
<td>24.96</td>
<td>561.60</td>
</tr>
<tr>
<td>5.</td>
<td>Masonry paint for concrete blockwork, 3 times</td>
<td>286.8</td>
<td>m²</td>
<td>3.02</td>
<td>866.14</td>
</tr>
</tbody>
</table>

Cost per compartment: 2095.58 GH¢

**Image 3.43:** Surface of non-load bearing walls and lifecycle costs when these walls are realised in hollow sand-cement or concrete blocks

**150mm Hollow concrete blockwork wall dry stacked with an interlocking system**

Current rate is 13 blocks of 400 x 200mm / m²

Current mortar use is 0.026m³ for 13 blocks, which mean 0.002m³ / block

Surface of mortar bed and joint of 1 blocks is (0.4 + 0.2) * 0.15 = 0.09m²

Mortar use divided by joint surface gives the average joint thickness 0.002 / 0.09 = 0.022m = 22mm

Surface of one block without mortar joint (dry-stacked) 0.4 * 0.2 = 0.08m²

Surface of one block with mortar joint 0.422 * 0.222 = 0.094m²

Current rate with mortar joints is 13 blocks / m² gives a surface of 0.094 * 13 = 1.22m²

Necessary number of blocks by dry-stacking is 1.22 / 0.08 = 15.25 blocks of 400 x 200mm / m²

<table>
<thead>
<tr>
<th>Item</th>
<th>Elements</th>
<th>Quantity</th>
<th>Unit</th>
<th>Rate</th>
<th>GH¢</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>MATERIAL</td>
<td>15.25</td>
<td>No.</td>
<td>1.51</td>
<td>23.03</td>
</tr>
<tr>
<td>B</td>
<td>Labour</td>
<td>0.65</td>
<td>Hrs</td>
<td>1.15</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>1 Mason</td>
<td>0.65</td>
<td>Hrs</td>
<td>0.90</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td>1 Labourer</td>
<td>0.65</td>
<td>Hrs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Add Profit and Overheads</td>
<td>0</td>
<td>%</td>
<td></td>
<td>0.00</td>
</tr>
</tbody>
</table>

Cost per square meter: 24.37 GH¢

**Image 3.44:** Unit rate analysis of purchase 150mm hollow concrete blocks with an interlocking system which are dry stacked
3.5.2.5  Sand-cement blockwork wall

The space between two concrete columns and strip foundation and window frames must be filled with a blockwork wall. None of these walls have to carry any loads and they can be made with hollow blocks instead of solid ones to save materials and weight. The high external and middle walls should be 150mm thick and for the partition walls a thickness of 100mm satisfactory. These partition walls must be well linked with the external walls by a bonding.

According to presented specifications of sand-cement blocks in the database must all blockwork walls be protected and covered with a smooth plaster finish of sand-cement mortar. Principle hereby is that, by improved construction works, all blocks are laid so straight that a 12mm thick plaster finish is sufficient. For the outside is a mixture of cement - sand mortar (1:4) used and for the inside mortar proportion (1:6). To protect and decorate the smooth cement and sand rendering are all wall surfaces above ground level coated with masonry paint for plaster finish and concrete. Lifecycle costs for all non-load bearing walls, constructed with sand-cement blockwork is 2004.78 GH¢ / compartment. Image 3.43 on the left page shows calculations of the wall surface and lifecycle costs for realising these non-load bearing bearing walls which costs 2004.78 GH¢ / compartment.

3.5.2.6  Concrete blockwork wall

For these blockwork walls can also be used hollow concrete blocks with a thickness of 100 and 150mm. Concrete blocks are stronger and have a harder surface than sand-cement blocks, making a smooth plaster rendering redundant. Only a masonry paint finish for concrete blockwork, applied above the surface level, is required to give the construction a nice and attractive appearance which is cleanable. The costs for realising all walls with concrete blockwork is also presented in image 3.43 and costs 2095.58 GH¢ / compartment.

The use of an interlocking system causes that the production rate will be reduced from 1.66 hours / m² for 100mm hollow blocks and from 1.83 hours / m² for 150mm hollow blocks to 1.30 hours / m². Hereby is assumed that length and height of concrete blocks, 400 x 200mm keeps the same. This has a marginal effect on the unit rate, which changes slightly from 20.87 to 20.47 GH¢ / m² for 100mm thick hollow blocks and respectively 24.96 to 24.39 GH¢ / m² for 150mm thick hollow blocks. And it doesn’t bring any alteration to the total costs for all walls of a compartment. Differences are so little because reduction of the production rates is little and labour part of the unit rate is just around 6 to 7%. Advantages of an interlocking system become more obvious by large walls without too much joining walls and that is different from the compartments with so much partition walls. From this findings can be concluded that the advantage of an interlocking system in this case is limited to the simplified laying of concrete blocks.

One last possible improvisation can be an interlocking concrete block which is dry stacked on each other. Hereby must be noticed that space which remains by omitting mortar should be filled with blocks. A unit rate analysis based on the current rate for 150mm hollow concrete blockwork wall is given by image 3.44 and shows that in case of interlocking dry stacked blocks there are 15.25 blocks needed for every square meter. This gives a unit rate analyse of 24.37 GH¢ / m² which is equal to interlocking concrete blocks and just 0.59 GH¢ / m² cheaper than ordinary stacked blocks in sand cement mortar. From these calculations can be said that the financial profit of an interlocking system, stacked dry or with mortar, is minimal. Hereby are costs for development of an interlocking dry-stacked block not even calculated and is assumed that costs for purchasing hollow concrete blocks are constantly the same.
Image 3.45: Laid sand-cement blockwork wall before applying a smooth sand-cement plaster finish
3.5.2.7 Appropriate non-load bearing walls

With the applying criteria of paragraph 2.3 are sand-cement and concrete blockwork walls compared which each other. This is done to decide which of the two construction materials are most suitable to fill the non-load bearing walls in a framed structure.

The scorings of sand-cement and concrete blockwork walls for the criteria image building, social acceptance, fit building services and usability and energy are at least sufficient and similar. All walls are from the in- and outside painted to make them cleanable, making this criterion not relevant.

Walls of both alternatives are made of the basic materials cement, sand, paint and in case of concrete blocks quarry dust. This makes the impact on the Ghanaian environment equal for sand-cement and concrete blockwork walls.

Structural quality of concrete blocks is much better than sand-cement blocks. But when they are accurate rendered with a smooth plaster finish, shall their durability little less to concrete blocks. Concrete blockwork doesn’t require any maintenance except repainting every 8 years making it more usable than sand-cement blockwork with a plaster finish. It’s likely that after 6 to 10 years some small places of sand-cement plaster must be repaired what can be done together with repainting.

Labour circumstances are for sand-cement and concrete blocks equal, and provisions must be taken to prevent workers for carrying too much weight of blocks or mortar. Technical acceptance of sand-cement blocks is excellent and no high qualified workers are required. This is much better than concrete blocks wherefore above-average skilled workers are needed. Because there isn’t a thick plaster finish applied, must all blocks be laid very straight in horizontal and vertical direction.

The criteria adjustment of plans and realizable in slums is equal for both alternatives of non-load bearing walls. A sand-cement blockwork wall supports, due its plaster finish, more the local employment. In case of concrete blocks is more money spent to purchasing blocks which are more expensive per piece than sand-cement blocks. There can be generally said that supporting of local employment and economy is equal for both alternatives.

Lifecycle costs for realising all non-load bearing walls of a compartment is for sand-cement blockwork 2004.78 GH¢ and for concrete blockwork 2095.58 GH¢. This is 5% more expensive than sand-cement blockwork walls. An interlocking system and dry-stacking concrete block holds the costs similar and doesn’t really support making concrete blocks cheaper. None of the alternatives shall need extremely much time and delay construction proceedings. Total required construction time for realising walls isn’t specific calculated and depends strongly on the number of workers.

In most of the criteria are sand-cement and concrete blockwork comparable to each other. Sand-cement blockwork walls are much easier to realise and cheaper, it scores therefore much better on technical acceptance and lifecycle costs. Disadvantage is that the smooth plaster finish needs some little reparations around every 8 years, something what doesn’t apply to concrete blocks. Concrete blocks are around 5% more expensive than sand-cement blocks. And above all must concrete blocks be laid very accurate which doesn’t really fit in the local building culture. It needs more preparation and supervision on site and higher skilled masons than normally. The little advantage of no maintenance doesn’t compensate to the higher costs and risk of low technical acceptance. Using an interlocking concrete block can partially solve the technical acceptance but doesn’t make it cheaper. This makes sand-cement blocks with a smooth plaster finish the most appropriate construction material for the non-load bearing walls in a frame structure.
Appropriate design and work plan for Safi Sana service blocks in Accra, Ghana

**Image 3.46:** Interlocking and dry stacked column and wall blocks, image from Parry associates [55]

**Image 3.47:** Concrete hollow block walls, image from Appropriate building materials [16]

**Image 3.48:** LOK BILD SYSTEM, interlocking blocks with cavities, image from Appropriate building materials [16]

**Image 3.49 & 3.50:** Sketch design of an undeveloped hollow interlocking block (left) and schematically presented in one course of a compartment (above)
3.5.3 Massive, load bearing walls

The objective of massive, load bearing walls is to realise all walls with one material, this mean all external and internal, also the non-load bearing walls. The only appropriate and affordable material to use for these walls is concrete blocks. Into the blocks should standardised openings be created to fasten the laying of blocks. These cavities can be filled with reinforcement bars and concrete to guarantee the load bearing and anchoring capacity of the structure, making concrete columns unnecessary. [53] [55]

Examples of these load bearing walls made of hollow, interlocking and dry stacked, concrete blocks are largely available in literature and internet but aren't be seen in Accra, Ghana, image 3.46, 3.47 and 3.48. It's therefore likely that wanted blocks must be produced yourself with a simple steel mould or a more expensive block making press. Hereby must directly be mentioned that producing blocks on site shall not be possible everywhere. In most part of the cases are available construction sites in slum areas so small and enclosed by other structures that there is no space left to produce any blocks. Then it's better to produce blocks somewhere else and transport them to site or to purchase them from a professional block factory. An intern block production on site is therefore not considered, and should than also be done for hollow sand-cement blocks as described in paragraph 3.5.2.5.

To create interlocking blocks in all surfaces must a block making press be used, for an interlocking system in only the length direction is a steel mould sufficient. Investment of buying such a mould or press can be earned back by producing blocks instead of purchasing them and probably by selling own produced blocks. For example the costs for a Hydraform block making machine varies from $11,000 to $16,500 per machine, costs for a simple steel mould is unknown but can locally be made with by a smith or welder.

With given examples is a concrete hollow block designed which forms the starting point for a cost calculation and comparison with a framed structure of concrete columns filled with sand-cement blockwork walls. Dimensions are equal to current used hollow concrete blocks, 400 x 150 x 200mm (l x b x h). Every block contains two cavities of 100 x 100mm with in the middle a smaller opening, which makes it easy for workers to divide a block into two halves. There should be noticed that presented hollow block is a sketch design which isn't further developed. Designed block and one course of a wall between two grids are presented on the left page by image 3.49 and 3.50.

To limit costs are all interlocking, hollow concrete blocks produced with one steel mould and not with a press. This causes that with one type of hollow block all walls must be realised. The blocks are only interlocking in one direction but should also be dry stacked because there is no bottom in the blocks. When cavities are regularly filled with concrete have blocks enough bonding with each other to form a solid structure. The rate for dry stacked blocks is already calculated in paragraph 3.5.2.6 and is 24.37 GH¢ / m². Differences in rates with ordinary hollow concrete blocks that are stacked in mortar, with or without interlocking are minimal.

Costs for purchasing a hollow concrete block is assumed to be equal with investigated hollow blocks as described in the database. Using one block for all walls means that partition walls are also made in 150mm thick hollow concrete blocks, this to match block cavities for filling with reinforced concrete and provide a structural bonding with the external walls, see image 3.49 and 3.50. To support the roof construction is a small retaining wall made and are blocks around the window opening stacked till a height of 3.30m above the strip foundation. On these columns should a short wall plate be fixed for the connection joint with roof construction, these plates aren't calculated. Around every second cavity must be filled with in-situ casted concrete (1:2:4) and one reinforcement bar ø12mm.
### Massive, load bearing walls

<table>
<thead>
<tr>
<th>Item</th>
<th>Walls</th>
<th>L</th>
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<th>m²</th>
</tr>
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<td>1.</td>
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<td>3.</td>
<td>Middle wall</td>
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<td>3.00</td>
<td>1</td>
<td>9.00</td>
</tr>
<tr>
<td>4.</td>
<td>Partition walls</td>
<td>1.60</td>
<td>2.00</td>
<td>1</td>
<td>3.20</td>
</tr>
</tbody>
</table>

Total wall surface: 66.20 m²

**150mm Hollow concrete blockwork wall dry stacked with an interlocking system**

<table>
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<tr>
<th>Item</th>
<th>Elements</th>
<th>Quantity</th>
<th>Unit</th>
<th>Rate</th>
<th>GH₵</th>
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<tr>
<td>1.</td>
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<td>m²</td>
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<td>2.</td>
<td>Reinforced in-situ vibrated concrete (1:2:4)</td>
<td>1.7</td>
<td>m³</td>
<td>@ 152.91</td>
<td>259.95</td>
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<tr>
<td>3.</td>
<td>Mild steel round bar reinforcement</td>
<td>152.0</td>
<td>kg</td>
<td>@ 1.36</td>
<td>206.72</td>
</tr>
<tr>
<td>4.</td>
<td>Masonry paint for concrete blockwork, 3 times</td>
<td>359.4</td>
<td>m²</td>
<td>@ 3.02</td>
<td>1085.39</td>
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</tbody>
</table>

Cost per compartment: 3165.35 GH₵

*Image 3.51: Surface of load bearing walls and lifecycle costs when these walls are realised with dry stacked hollow concrete blocks with an interlocking system in one direction*
Concrete blocks don't need a smooth plaster finish, only a masonry paint finish for concrete blocks is sufficient to decorative, protect and make all walls cleanable. Only the uppermost 2.70m, above the surrounding soil, of all walls and columns is coated. Painting is counted for 3 times to define the lifecycle costs of a compartment. These costs for all (non-)load bearing walls made of hollow concrete blocks and partially filled with reinforced concrete are 3165.35 GH¢ / compartment. On the left page are all calculations for the wall surface and lifecycle costs presented by image 3.51.

3.5.4 Appropriate structure type and wall construction

Both structure types, frame structure and load bearing walls, are now elaborated and calculated. Results are two alternatives with their most suitable materials to apply for the wall construction of a compartment. This is firstly a framed structure with concrete columns and a hollow sand-cement blockwork wall and secondly a hollow concrete blockwork wall. In this final paragraph shall be defined which of these two structure types with their materials are most appropriate to use for the wall construction of Safi Sana service blocks. To compare alternatives and assess them are the criteria used which are described in paragraph 2.3 together with all information that already is given in previous paragraphs and completed with the database of appendix 1. An assessment diagram is presented by image 3.52 on the next page.

All walls and columns shall finally be painted as protective and decorative finish. The original materials shall not be visible anymore making the image building and social acceptance equally.

Building services must be placed in trenches in the wall to make them vandalism proof. When possible should cavities of the hollow concrete blockwork wall be used to fix some service pipes inside. Usability and energy of both options is the same and cleaning isn’t a relevant criterion because all surfaces will finally have a paint finish.

Materials used for the two alternatives shows much similarity and exist mainly of cement, sand, quarry dust, stones, reinforcement and paint. This makes the effect on the Ghanaian environment equally, only for the concrete columns is timber formwork used which has a low classified effect on the local forests.

Long term quality and maintenance of concrete blocks is little better than sand-cement blocks with a smooth plaster finish. Very best are the reinforced concrete columns which are structural strong enough to carry and anchor the roof construction itself and don’t need any maintenance. Plaster finish on sand-cement blockwork wall requires every 6 to 10 years some little repair. All surfaces of the two optional structures must be repainted around every 8 years.

For both alternatives should labour circumstances be safe, and when necessary special provisions be taken, on such a way that construction works doesn't affect the health of workers. Largest health risk is carrying too much weight for a longer period by workers.

Technical acceptance of a concrete blockwork wall with reinforcement and concrete is low. Firstly needs dry-stacking of hollow concrete blocks, with only an interlocking system in one direction, above-average skills. Secondly is this building method with filled cavities not very common in Ghana and shall it require much time and energy to convict and instruct local people about it. A sand-cement blockwork wall with concrete columns is very common in Ghana, requires not high qualified workmanship and is totally accepted by local people. It’s also known as the ‘post and beam method of construction’, the mostly used construction method in southern Ghana.
<table>
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<th>Criteria:</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Construction time (hours / unity)</td>
<td>14</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Lifecycle costs (GĦ / unity)</td>
<td>13</td>
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<td>Local employment and economy</td>
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<td>Realizable in slums</td>
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<td></td>
<td>3</td>
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<tr>
<td>Adjustment of plans</td>
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<td>2</td>
</tr>
<tr>
<td>Technical acceptance</td>
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<td></td>
<td>2</td>
</tr>
<tr>
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</tr>
<tr>
<td>Long term quality, maintenance and reliability</td>
<td>7</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Environmental sustainability</td>
<td>6</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Cleaning</td>
<td>5</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Usability and energy</td>
<td>4</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Fit building services</td>
<td>3</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Social acceptance</td>
<td>2</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Image building</td>
<td>1</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

* Not relevant aspect

Image 3.52: Assessment diagram of two different structure types with their wall construction
Starting point for the two solutions is the concrete strip foundation and column base where reinforcement bars stick out. For both options it's not a real problem when bars aren't on their exact location, they have the same margin of around 50mm. Connection of column and wall to the roof construction comes very accurate and must be realised with a simple steel joint by concrete columns and a more complex wall plate by concrete blockwork wall. Due to the large sectional area is the adjustment of concrete columns better. When they aren't completely vertical constructed is the sectional area of 300 x 300mm large enough to place the roof construction on. This margin for a wall plate is much smaller and more difficult to realise with dry stacked blocks without an interlocking system in the height direction. When the load bearing walls aren't realised vertically shall fixing of the roof construction give measurement problems.

Both alternatives can be realised in a slum environment and there aren't much differences between the two solutions. The same applies for supporting the local employment and economy which is almost equal for the frame structure and load bearing walls because the used (basic) materials are very similar.

Costs for four concrete columns and sand-cement blockwork walls of a framed structure are 2670.62 GH¢ / compartment. This is much cheaper, around 19%, than a structure of massive, load bearing walls with hollow concrete blockwork that costs 3165.35 GH¢ / compartment. Only the blockwork and painting of load bearing walls is already more expensive than a complete framed structure. This makes reducing the number of filled cavities needless.

Duration of the different construction activities are comparable to each other and shall not make a real difference in the required time for realising the structure of a compartment.

Advantages of load bearing walls made with hollow concrete blockwork are little and are reduced to the fitting of building services, environmental sustainability and the long term quality and maintenance. This structural quality and maintenance of a framed structure is just little less and doesn't make a substantial difference between both alternatives. But the adjustment of plans and especially the technical acceptance of constructing a framework are much better. Together with a significant lower price, makes this a framed structure much more appropriate for realising a compartment than with load bearing walls. Structure type and wall construction shall thus be made of concrete columns and non-load bearing, hollow sand-cement blockwork walls.

Above the middle wall in a compartment is one course of design blocks proposed, see also image 3.36 and 3.37. With a height of 0.30m are costs around 38.52 GH¢ / compartment. This causes that steel roof trusses must span a compartment at once instead of with a supporting point in the middle. Costs for such a roof construction are little higher but increases the freedom in placing walls and order of construction activities.
Image 3.53: Complete view of one compartment, these can be linked to create a service block

Image 3.54 & 3.55: To prevent that space remains at the top side of a wall which must be filled with mortar or concrete, should the height of walls be adapted to the dimensions of sand-cement blocks

Image 3.56: Position of all 10 purlins at one side of the roof construction, with a ridge detail and an overhang at eaves
3.6 Final design of a compartment

In previous paragraphs is for a generic designed compartment defined which construction materials and methods are most appropriate to use, a 3-D model is presented by image 3.53. This appropriateness is based on the vision of the Safi Sana project and local conditions and needs. All results of the paragraphs 3.1 till 3.5 are summarized and repeated below, besides this is the final design adapted to dimensions of the used materials in this paragraph.

3.6.1 Appropriate materials and methods

The roof shall be covered with cellulose bitumen corrugated sheets and be fixed on a steel roof construction that exists of angle bars for purlins and square pipes for the roof trusses. In every grid is only one truss foreseen which span a compartment at once and is fixed and anchored to concrete columns with dimensions of 300 x 300mm.

Columns are placed on a column base, which is a local widening of the strip foundation. Both column base and strip foundation are made of reinforced concrete. The concrete columns create a frame structure and are on their top part kept together by steel frames with burglar proofing. These frames form also directly the wall openings in side elevations. In facade of the service blocks, front and back elevations, are painted design blocks more advisable.

The space between two columns, steel window frame and strip foundation is filled with 150mm thick sand-cement blockwork walls made smooth with a 12mm thick plaster finish. Above the concrete slab must hollow blocks be used and below the slab solid blocks because this substructure wall supports the slab. The middle wall, which separates the male and female side, is also constructed by these blocks and rendered with a plaster finish, with on top one course of design blocks. All partition walls are made of 100mm thick hollow sand-cement blocks and completely finished with a 12mm thick smooth plaster finish.

The area between substructure of two external and the middle wall is filled and rammed with laterite and all together support the reinforced concrete slab. A sand-cement or granolithic screed can be used to level and give the slab a smooth surface. Partition walls, that form the cubicles, are placed directly on this slab and don’t have a strip foundation. All slab and wall surfaces, in- and outside, are finished with a Safi Sana specific coloured paint coating to decorate, protect and make them cleanable. The same applies for all surfaces of the steel roof construction, design blocks and steel window frames with burglar proofing.

The design and graduation project is demarked by one compartment as shown by image 3.53 and is including building services and wall openings. The front and back elevation, further finishing and furnishing than painting and sanitary and all external works and (underground) holding tanks aren’t part of the design. It should be orientated on the East-West axis to reduce sun radiation on building surfaces and to increase wind ventilation in the service block.
Image 3.57: Final design, cross section and top view, of one Safi Sana compartment
3.6.2 Adaptation of generic design to used materials

The dimensions of applied construction materials are in this paragraph considered to adapt the measurements of different building elements and to make the final design of a compartment definitive. Total length 3.00m of a compartment isn't changed to keep the possibility of creating cubicles on logical centre to centre distances like 0.75m and 1.00m.

Produced and used sand-cement blocks have a length of 450mm, a height of 225mm and a width of 100 or 150mm. A mortar thickness of 15mm is sufficient and advisable. For establishing the definitive height and length of blockwork walls should be used a block length of 465mm and a block height of 240mm. This occurs that large gaps and joints remains in the different walls and too much blocks must be broken to get closer blocks, see images 2.2 and 2.3 on the previous left page. By using a certain number of blocks are the height and length of all walls defined.

<table>
<thead>
<tr>
<th>Wall</th>
<th>No. of blocks</th>
<th>Height or length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substructure</td>
<td>2</td>
<td>0.48m high</td>
</tr>
<tr>
<td>Superstructure - external</td>
<td>7</td>
<td>1.68m high</td>
</tr>
<tr>
<td>Superstructure - middle</td>
<td>9</td>
<td>2.16m high</td>
</tr>
<tr>
<td>Superstructure - internal</td>
<td>8</td>
<td>1.92m high</td>
</tr>
<tr>
<td>Superstructure - internal</td>
<td>3.5</td>
<td>1.63m long</td>
</tr>
</tbody>
</table>

Height of steel window frames is now 0.82m and one course of design blocks, with a height of 240mm, is sufficient on top of the middle blockwork wall. Cross section of the reinforced concrete columns, 300 x 300mm, causes that steel roof trusses on one side become 3.00m long with a 1.00m overhang. This gives a roof pitch of exactly 1:3 which is around 18.5° and has a length of 4.22m. For every roof side are still 10 purlins needed as shown by image 2.4 on the previous left page.

The length of internal walls and extended roof truss result into a 1.07m wide corridor and makes the concrete ground floor slab 5.85m wide. Width of column base and strip foundation is 0.90m respectively 0.50m wide and based on block work wall and concrete columns.

By using the dimensions of sand-cement blocks is the design of a compartment adapted. This simplifies construction works and shall decrease the wastage of materials and thus building costs. Final design of one Safi Sana compartment with all construction elements is shown on the left page by image 3.57 and also presented in appendix 2. Used materials for this final design are already mentioned in paragraph 3.6.1. This final design shall be used for further development into a work plan in chapter 4.
Image 4.1: Framework of chapter 4, development of a work plan for realisation of the Safi Sana compartments
4.  Work plan

The final design of a compartment as presented in paragraph 3.6 forms the base for this chapter, where it shall be developed into a work plan. This is a manual that step by step describes on which way a service block can be constructed locally in a slum environment. First is the designed compartment with its most appropriate materials and methods, completely analysed to determine what must be constructed and which problems can arise during realisation of a Safi Sana compartment. To solve these problems must the applying criteria be fulfilled which lead to a concept work plan for all construction works. After defining the most suitable way of communicating and reporting are plans for the concept further developed into a final work plan, with for every activity a separate sheet. On the left page is by image 4.1 the framework for this chapter presented.

With a qualitative and quantitative analyse techniques like the 5WH questions and counting is the final design of a compartment and the slum environment extensively analysed. Besides this design are also the “Analysis of construction works in Accra, Ghana, Final report Master project ‘Participatory observation’ by J.J.J. Hulsen” and the local conditions and needs as described in paragraph 2.2 used as input for the analysis. This is accomplished for functionality, environment, structure, services, earthworks, concrete works, blockwork walls, steel works, roof finishing and paint finishing. The analysis is accomplished for general construction works instead of the different building elements, because most of the problems that can take place are in a strong relation with the specific activities. Result is to understand what must be constructed and why, and which problems and remarks can arise during realisation of the final design of a Safi Sana compartment.

To solve all noticed problems and remarks that can arise during realisation of a Safi Sana compartment are criteria formulated. These originate from the developed criteria in paragraph 2.3 and only those, who are relevant for the construction works are applied. With the criteria are different plans and choices for the construction works made and assessed. All applied criteria are fulfilled as much as possible to meet wishes of the client, and used to solve the problems with an integral approach, from a higher abstract level. This lead to some main, important plans for the construction works with (time) schedules and budget estimations, which is presented in a concept work plan. It makes in general clear how a compartment should be constructed and is described for the construction technology aspects: construction site and transport, method of construction, organisation and time, measurements, structural quality, safety and construction costs.

During stay in Ghana is by supporting the Safi Sana project and observations on different construction sites seen how important communicating and reporting is, especially to realise a construction. Therefore is defined who of the local people must receive the information from the final work plan and which way of communicating to workers is most appropriate. To be sure that all information is reported on a suitable way for who it is purposed and that is can be used by them.

Finally is the information from the concept work plan made usable and more specific by developing and transferring it into the final work plan. For every construction activity is a separate work plan sheet made, which step by step describes how a service block should be constructed locally in a slum environment. Given information must solve all founded problems and remarks and fulfil the applied criteria. It follows from the accomplished analyses added with (locally found) practical examples, literature and described materials and methods in the database of appendix 1.
Appropriate design and work plan for Safi Sana service blocks in Accra, Ghana

Image 4.2 & 4.3: Current public sanitation facilities in Accra forms the motivation for the Safi Sana project
4.1 Analysis of a compartment

The word analysis means literally: “dissection into components to study them in detail”. Before starting an analysis should be defined why, for whom and on which way information will be collected. Objective of this analysis is to understand what is really asked for and desired by the design and client and why. How a construction and environment is composed functional and technical. Thereby must be found out what the most important and complex parts of a compartment are, or better said the largest, most difficult and dependent building elements and construction activities. Second objective is to find out which problems and remarks can arise during realisation of those parts and activities. These together give requirements for development of the work plan.

To reach these objectives are ten analyses accomplished: functionality of design, location and situation, structure, building services, earthworks, concrete works, blockwork walls, steel works, roof finishing and paint finishing. This will be done by a qualitative and quantitative analyse techniques like the 5WH questions and counting, it leads to the following research questions:

1. **What** must be constructed and what are the effort, shape, dimensions and quantities and weight?
2. **Why** must that be constructed and what is the meaning?
3. **Where** is it proposed in the construction, what is the situation and environment?
4. **When** should it be constructed, when must it start, how often, how long will it take and what is the relation with other activities?
5. **How** must it be realised generally, on which way is it processed or fixed, which level of quality should be achieved and what are the maximum measurement deviations?
6. **Who** are involved, workers, materials, equipment and what are the costs?
7. **Which** problems and remarks can arise, what are the risks?

Of a single compartment are all quantities, number and dimensions, of the different main construction works together with their output presented in one overview by appendix 3. These quantities are based on the final design as presented in paragraph 3.6. [10] [14] [16] [17]

4.1.1 Analysis of function and usage

The complete design of one compartment for a service block is explained and repeated and made definitive in paragraph 3.6. This design is used to execute a functional analysis to understand why and how the building with services is formed.

**What must be constructed?**
Compartment(s), main effort is to create a public service block that exists of two separate spaces and entrances for male and female sexes. On both sides are a corridor and cubicles foreseen for various functions like toilets, wash hand basins, bucket wash and showers. Therefore must building services in the walls, slab and roof construction incorporated. Length of one compartment is 3.00m, width 8.00m and the height is around 4.50m, see image 3.57. The shape is rectangular and the roof construction is a double pitch roof.

**Why must that be constructed?**
To improve and increase the poor quality and low quantity of current available public sanitation facilities like toilets and showers in slums, see images 4.2 and 4.3. The company Safi Sana (Ghana) Limited wants to improve this current situation by realising linked compartments to a service block.
Image 4.4 & 4.5: Acquired construction site in a slum can be very small with many adjoining properties and difficult to reach, especially during rainy season, as here in July 2009.

Image 4.6: Most of the time is water to the construction sites supplied by water tankers and stored in poly tanks, like here on a on-site concrete plant.
Where is it proposed?
The compartments and thus public service blocks are foreseen in different slum areas of Accra, the capital of Ghana or in its outskirts, because sanitation problems occur in those places.

When should it be constructed?
Total time for construction works must be in proportion with the expected time and the change on delay must be restricted. To start the realisation of a compartment should the construction site be clear. All construction works aren’t directly dependent to other, surrounding activities. Building activities should be adaptable to changed, delayed or incorrect measured results of previous construction works.

How must it be realised?
Compartment must be constructed with help of the local building culture and labour mentality. It shall not affect the safety and health of workers negative. Realisation should create more local employment and stimulate the local economy and all final results should achieve a prescribed long term, structural and aesthetic quality.

Who are involved?
Project is an initiative of the Aqua for All foundation together with the established company Safi Sana (Ghana) Ltd. Further design and construction works shall be done by Ghanaian architects, engineers and workers. Direct costs for construction works must be kept as low as possible.

Which problems and remarks can arise?
- Compartments must be realised in slum areas, see also next paragraph 4.1.2.
- Different activities take more time than expected and construction works delay.
- Consecutive works doesn’t fit or can’t be established due to incorrect constructed previous works.
- For construction works are above-average knowledge and skills from workers required.
- Construction activities are done unsafe and affect the health of workers negative.
- Use of local workers, materials and equipment should be stimulated.
- Results don’t fulfil the required aesthetic and structural quality.
- Final costs for construction works are higher than estimated before.

4.1.2 Analysis of environment

Local conditions in slum areas are imported factors for the realisation of a compartment and are therefore analysed in this paragraph. Objective is to find out relevant aspects and possibilities of the environment for construction works. Construction works for the Safi Sana service blocks takes place in slum areas but constantly on different locations. The current situation in slums is already generally explained in paragraph 2.2 and this result into the following problems and remarks:

- Available land is scarce and access roads are small and bumpy, which limits the area for transport, construction works and storage and makes large transportation even more difficult, images 4.4 and 4.5.
- On most of the locations are adjoining properties structures present very close to the construction site.
- Limitation of nuisance from noise and dust and pollution from waste to the direct environment in a slum area and indirect to the nature.
- There is a change on stealing of materials and equipment from the construction site.
Image 4.7 & 4.8: Two cross section of a compartment with mentioned above all top loads caused by the own weight of the construction and below the pressure and tensile forces caused by wind loads, the action forces are green coloured, the reaction ones red

Image 4.9: Stability in the construction will be created by different wind bracings, steel window frames and external walls
- Ground conditions and slopes changes for the different locations which cause that the depth of a foundation should be adapted to each location. In all the cases shall the soil be strong enough and suitable for a reinforced concrete strip foundation with column bases.
- Water table and salt water are low enough and doesn't have any influence on construction works.
- An (underground) sewer system isn't everywhere present.
- Sometimes there is a water grid available in Accra's slums, but there isn't always enough water free to serve all grids, see image 4.6 on the previous left page.
- On most location are electricity service lines present but there isn't always electricity on it caused by under capacity of the service lines.
- Rain mainly affect construction works of the substructure, falling rain can flood excavations and foundation trenches. It's advisable to build underground construction not during the rainy seasons. Besides this shall workers hide when it is raining.
- Used and produced materials must be protected to and not be damaged or lose quality by rain, heat and direct sunshine.
- Doing intensive labour in a mostly sunny and constantly hot climate makes workers quickly tired.
- Insects like termites and sea salt from the nearby Atlantic Ocean damage the different construction materials.

### 4.1.3 Analysis of structure

Intension of analysing the structure type of a compartment is to understand how all pressure and tensile forces will be transferred through the construction. And to find out which building elements are part of the main construction for transmitting all loads. In paragraph 3.5 is already determined that a framed construction with columns and non-load bearing walls is most suitable for a service block, hereby aren't any structural calculations accomplished to optimize material dimensions. Most important loads are own weight of the construction and its finishing, users, super imposed loads of construction and repair works and wind loads, especially during rainy season can strong winds and rainstorms take place. Due to the large wall openings can strong winds also cause suction forces on the roof construction and therefore tensile loads on the construction. Transferring of the different loads through the structure is presented by images 4.7 and 4.8.

**What must be constructed?**

For the main structure of one compartment is a reinforced concrete foundation, slab and four columns required with anchored on these columns a steel roof construction. To create stability in the construction, by connecting columns and roof trusses, must also steel windows frames, external blockwork walls and wind bracings be fixed, see image 4.9. The different elements of a construction are presented in the images on the left page and will be further analysed in the following paragraphs.

**Why must that be constructed?**

A structure is required to carry and transmit all pressure and tensile loads and to guarantee a construction which is safe to use, even by seismic activity. For every single compartment is it possible to stand on itself.

**Where is it proposed?**

In every grid, centre to centre 3.00m as mentioned by image 3.57, is one roof truss and are two columns with column bases foreseen. Connection between grids is made by steel roof purlins, wind bracings and steel window frames. By linking compartments are wind bracings in only one compartment sufficient.
Image 4.10: Different sanitation services in a compartment, every cubicle needs a sewerage pipe and water provision.

Image 4.11: Detail of the external wall, with from every cubicle one sewerage pipe which went into a pipe with larger diameter to the (underground) holding tank. Inspection chambers can be placed to solve congestions.
When should it be constructed?
Directly when excavation works are finished can workers start with realisation of the reinforced concrete strip foundation and column bases. Works for foundation, columns and roof construction must follow each other chronologic. Before applying the roof finishing should at least the wind braces be fixed, steel window frames can be placed shortly after that.

How must it be realised?
Those construction elements that are of significant importance for the load bearing capacity of a compartment must have an excellent long term, structural quality. The same applies for the different connections between these elements, especially the detail the joint between steel roof truss and reinforced concrete column to occur blowing off the roof construction. Final required qualities and dimensions should be prescribed by a structural engineer. These connections must transfer pressure and tensile forces and should join each other well.

Who are involved?
Client, engineers, a foreman and workers are preparing, realising and supervising the load bearing structure of a compartment.

Which problems and remarks can arise?
- All different elements and connection between those elements must fulfil prescribed long term, structural quality and should be calculated and detailed to transmit pressure and tensile loads. This applies especially on the joint between the roof truss and concrete column.
- Measurements of construction works must be done accurate enough that different construction elements can easily join each other.
- All activities must be done correctly by the contractor and supervision by contractor and client should take care that all building elements are present in the final construction.

4.1.4 Analysis of building services
Main function of to realise compartments is to form a public sanitation block with various services like toilets, wash hand basins, bucket wash / showers and selling of drink water. Obviously require all these function some service pipes, sanitary and electricity. In this paragraph shall by analysing be defined which services are needed inside a compartment and what their relation and dependence with other construction elements is. This is demarcated to only the building services needed for a compartment and not the external works like an outside holding tank, rain and drink water storage and necessities for selling drink water.

What must be constructed?
Every cubicle needs one sewerage pipe with a trap outlet and bents. Its diameters can be different and depends on the proposed function of a cubicle, for soil drains is the minimum diameter 100mm. In most cubicles is sanitary equipment like a wash hand basin or squat mix toilet with cistern required as presented by image 4.10. Water provisions are needed for people to wash their hands and fill their buckets. Electricity pipes and cables for lighting must be fixed in the roof construction. Specification of required building services must be defined and further designed by a mechanical engineer.
Image 4.12: It often happens that pipes are forgotten and new trenches must be cut
Why must that be constructed?
Sanitary, water and sewerage pipes are present to provide different sanitation services for the local inhabitants. To made adequate lighting during the night are electricity pipes and cables needed.

Where is it proposed?
All sewerage pipes are laid through the external substructure wall and flows into a larger diameter pipe, a detail is shown by image 4.11. Squat mix toilets must be placed or casted in the concrete ground floor slab, wash hand basins shall be anchored to the walls. Water pipes and cisterns are fixed in trenches or on the external and internal walls. Electricity pipes and lighting shall be tied up to the steel roof construction. All pipes that can be reached by users, which are lower than 2.5m, must be processed and covered in trenches in the walls to make them vandalism proof.

When should it be constructed?
All sewerage pipes should be laid at the same time as realisation of the substructure walls and shall partially be covered with backfilled laterite. Exact moment of placing the squat mix toilets depends on the definitive composition of the ground floor slab. It’s for sure this sanitary equipment must be casted in the slab to fix it. When all sand-cement blockwork walls are ready, and before the sand-cement plaster finish is applied must trenches be cut to place and fix all water and electricity pipes. Other electricity pipes and lighting can be fixed afterwards to the roof construction. All sanitary equipment that is visible must be covered before painting works start.

How must it be realised?
All pipes and sanitary must be well fixed to a supporting material or in a cut trench with concrete or a sand-cement mortar. Important is that all used materials are reliable, have a long life quality and that pipes are watertight. This must be well tested before the complete plaster finish is added. Diameter of pipes and corners must be large enough to occur that congestion takes place. A fall of around 1:40 is recommended.

Who are involved?
Water and electricity services are realised by plumbers and electricians who are sometimes assisted by labourers. They are mainly using hand tools. Position of pipes and measurements must be set out by foreman.

Which problems and remarks can arise?
- Used water and sewerages pipes must be of a strong quality and be very durable, they must be checked before if they are water tight.
- Cutting trenches must be done carefully and damaging of other works and pipes mustn’t be taken place during construction works.
- Pipes and sanitary should be set out and fixed accurate and strongly on their correct positions.
- Service pipes lower than 2.5m above ground level aren’t covered in trenches and therefore not vandalism proof.
- In building process should the moments that pipes, sanitary equipment and cables are fixed and placed accurately be organised and planned. It’s important to order and control these activities by a time schedule to occur that pipes are to late or forgotten and new trenches must be cut in already plastered or painted walls, see image 4.12. And to take care that all works for building services are completely and correctly finished on time.
- Sanitary equipment and lighting should be protected to filthy of construction works like paint or sand-cement mortar.
Appropriate design and work plan for Safi Sana service blocks in Accra, Ghana

Image 4.13: Backfilling around foundation columns and walls with earlier excavated laterite soil

Image 4.14: A manual compactor to ram the backfilled soil as used in Accra, Ghana
4.1.5 Analysis of earthworks

To realise the foundation and ground floor slab should the soil firstly be excavated and later on filled back around the foundation to make up a levelled bed, like image 4.13. These excavations works are analysed in this paragraph to know for one compartment all earthwork activities and what the risky aspects are.

What must be constructed?
Remove vegetable soil and excavate foundation trenches and column bases to 0.70m below ground level. All soil must be stored temporarily. Excavated trenches and bases must be well rammed and levelled. Later on must the same soil be filled back, rammed and levelled to form a smooth bed 0.05m above the ground level. Remaining soil may be spread out on site.

Why must that be constructed?
Earthworks must be done to create a work space and strong bed for the concrete foundation and slab.

Where is it proposed?
Excavation and backfilling works takes place under the whole ground floor slab between 0.05m above and 0.70m below the ground level.

When should it be constructed?
Removing top soil and excavating and ramming foundation trenches and column bases is the first activity that must be done by realising a compartment. Directly when blockwork walls and concrete columns of the substructure are ready must laterite soil be filled back and levelled.

How must it be realised?
Slope of a foundation trench and column base can be excavated almost vertically, slope around 5:1, due to the hard laterite soil. Both sides of the excavated trenches and pits must be kept unimpaired to use them as formwork for casting the foundation. It’s advisable to excavate to 0.70m below ground level and then to backfill the excavated soil for 0.07m and ram and level it well. Measurement deviation of the height should be maximum 10mm. Excavated laterite should be stored on or very close to the construction site because it’s all needed for the backfilling. The backfilling around foundation to 0.05m above ground level should be done with the excavated soil and well rammed into layers of maximum 0.20m. Top side of this backfilling is downside of the concrete ground floor slab and this measurement deviation is also maximum 10mm. Backfilled soil must finally be at the same level as top site of the substructure walls. Remaining soil must be spread and levelled on the construction site but outside the building, to raise surrounding land.

Who are involved?
Earthwork is normally only done by labourers with help of a spade and wheelbarrows. To ram the backfilling well is a manual, timber compactor used, see image 4.14.

Which problems and remarks can arise?
- Laterite soil can be hard, making excavation works difficult.
- Measurement height of the backfilled soil isn’t according to the drawing and requirements.
- Levels of backfilling are too thick making the compressive strength of rammed backfilling not strong enough to serve as foundation.
- Laterite is a heavy material and maximum weight carried by workers at once must be limited to around 20 till 25kg.
Image 4.15: A plastic sheet should divide the laterite from casted concrete, all reinforcement and mesh must be laid on concrete spacer blocks to achieve a concrete covering.

Image 4.16 & 4.17: Deviation and deformation of realised concrete elements must be limited to prescribed requirements.
4.1.6 Analysis of concrete works

The main structure of a compartment exists mainly of reinforced concrete foundation, slab and four columns. Objective of this paragraph is to find out the quantities and qualities of the different concrete works that must be realised and which problems can arise.

What must be constructed?
A concrete strip foundation and four column bases forms the foundation for one compartment. Furthermore are four columns required and one smooth concrete slab with a top side on 0.20m above ground level. All concrete elements must contain reinforcement bars or B.R.C. mesh and are mentioned by image 4.7 and 4.19.

Why must that be constructed?
Concrete works are needed to get a structure for transferring all loads and providing an area for all consumers to reach and use the sanitary facilities.

Where is it proposed?
The concrete strip foundation and column bases must be realised on the rammed soil at 0.63m below ground level. On every column base is one reinforced concrete column purposed to 2.70m above ground level. Between these columns and on the substructure walls and levelled soil must the smooth concrete slab be realised.

When should it be constructed?
Directly when backfilled soil in foundation trenches and column boxes is levelled must the concrete foundation be realised, immediately followed by the concrete columns. Concrete columns can be realised at once or casted in two times. Before realising the slab must backfilled soil be rammed and levelled to 0.05m above ground level. Formwork must be stand at least 2 days after casting before removing it. All building services should be fixed into the formwork before casting the concrete elements.

How must it be realised?
Plastic sheets must be laid on the rammed soil to divide laterite from the concrete foundation and slab and to prevent moisture for penetrating into the slab, see also image 3.14. Due to this plastic sheets and hard rammed and levelled earthwork is a concrete blinding bed unnecessary. When sides of excavated trenches and pits are kept unimpaired they can be used as formwork to cast the complete foundation. Height deviation of foundation should be maximal 10mm and for columns maximal 5mm. The topside of a column may be deviate maximal 20mm from its verticality. Some deformations are presented by images 4.16 and 4.17. Surface of columns must be smooth and closed, so that a plaster finish isn’t required. Acceptable difference in height of the concrete slab is 5mm / m1. The reinforced concrete slab can be casted smooth in one time or it can be advisable to realise it in two times, with a reinforced concrete bed and later on a screed bed as smooth finishing. All realised concrete works must fulfil a certain long term quality and prescribed requirements like concrete covering on reinforcement, a closed non deformable formwork, vibrating of concrete and a careful on site production, transport, processing and curing. Correct proportions of materials must be added to the mixture and should achieve a low water cement ratio and satisfactory workability. Curing of concrete is important to prevent occurring of cracks in hot dry conditions due to the rapid setting or temperature.
Image 4.18: The water cement ratio of concrete and quality of the different aggregates is of significant importance for the long term, structural quality of the concrete mixture.

Image 4.19: 3-D model of a compartment, the concrete elements of a compartment are coloured dark blue, the blockwork walls with a smooth plaster finish are coloured light blue.
Who are involved?
Concrete works must be produced and processed safely by carpenters, steel binders, masons and labourers with locally extracted, produced and imported materials. As main equipment is formwork, a concrete mixer and poker vibrator needed.

Which problems and remarks can arise?
- Amount of required and used reinforcement in concrete works is reduced to save costs.
- Not all building services are present in the formwork during casting of concrete.
- Measurements of realised concrete elements aren’t according to the drawings, are deformed and exceed deviations.
- Ground floor slab must possibly be realised in two times to get a smooth surface.
- Long term, structural quality of realised concrete works isn’t conform requirements.
- Construction works aren’t done safely by workers.
- Distribution over the several diameters of stones, used as coarse aggregate isn’t equal, see image 4.18.
- Sand, used as fine aggregate, is polluted with grass and roots.
- Reinforcement bars are polluted and covered with dust, laterite and loose rust.
- See for a complete overview of all problems and remarks that can arise during the realisation of concrete works, activities A1, A2, A3 and A4 in “Analysis of construction works in Accra, Ghana, final report Master project: ‘Participatory observation’ by J.J.J. Hulsen”. [10]

4.1.7 Analysis of blockwork walls and smooth plaster finish works
All walls of sub- and superstructure are made of sand-cement blocks and smooth finished with sand-cement plaster. In these paragraph are these blockwork and smooth plasterer works analysed and is defined what the quantities and qualities are and which problems and remarks can arise.

What must be constructed?
Substructure walls of 150mm solid sand-cement blocks, on the outside finished with a 20mm thick cement-sand (1:4) plastering. The external and middle walls of the superstructure must be constructed with 150mm hollow sand-cement blockwork walls and the internal walls should be made with 100mm hollow sand-cement blocks. All external, middle and internal walls are smooth finished with a 12mm thick cement-sand (1:4) plastering. On the middle wall is one course of design blocks foreseen which doesn’t require a plaster finish. Length of all blocks is 450mm and height is 225mm. Different walls are visible in the top view and cross section of a compartment presented by image 3.57 and by 3-D image 4.19.

Why must that be constructed?
Substructure walls are primarily needed to support the concrete ground floor slab. The walls of the superstructure are required to create cubicles and to offer privacy and protection against various influences.

Where is it proposed?
On the concrete strip foundation must the substructure walls be realised to 0.05m above ground level which is equal to top side of levelled soil and thus downside of the to realise concrete ground floor slab. All other external, middle and internal walls are made on this slab to 1.88m, 2.36m and respectively 2.12m above ground level. Length and height of blockwork walls is adapted to dimensions of the used sand-cement blocks including a 15mm joint.
Image 4.20 & 4.21: If walls aren’t correctly finished plenty of cracks appear by curing of the plastering (left). Less cracks occur when plaster finish is scoured smooth one more time (right).

Image 4.22: Using a short leveller by realising blockwork walls causes that small measurement deviations are made consecutively.
When should it be constructed?
The substructure walls must be realised directly when concrete columns of the substructure are ready. Other walls can be made when ground floor slab and columns of the superstructure are realised. But this depends also on which way and when the roof construction will be realised, probably it’s better to wait for it until the (complete) roof is finished. When building services must be placed through walls, should this be done at the same time as realising those walls. For smaller pipes can later trenches be cut in the different walls, what must be done before the smooth plaster finish is applied. Adding the smooth plaster finish may only start when all building services are fixed and all other previous activities are completely finished. Curing time of the plaster finish is around 4 weeks before painting activities may start.

How must it be realised?
Cement content of blocks should be at least 20% to prevent that produced blocks are weak and brittle. It’s advisable to produce sand-cement blocks under own supervision to guarantee strength and durability and to cure them well. Measurements of the blocks should be very constant with a maximum deviation of 2mm to all directions, this to simplify the laying of blocks. All blocks are stacked and laid in a cement-sand (1:4) mortar produced on site. A mortar thickness of 15mm for all joints is sufficient. The before realised concrete columns can be used as frame to set out and control measurements of the walls. All walls of the superstructure must be realised so smooth that a 12mm plaster rendering is sufficient. Maximal deviation is 5mm / m1 and 10mm for a single wall. Plaster finish is applied to walls with a so called ‘throwing-on’ method. That must be done from down till top whereby finished surfaces of walls and slab must be protected to fallen mortar. Plaster finish must be scourd enough times to occur that cracks arise in just finished surfaces, see images 4.20 and 4.21. Long term quality of produced sand-cement mortar for joints and plaster finish must be very well and consistent by adding qualitative and correct proportions of materials with a low water cement ratio, also must transport, processing and curing be done very careful.

Who are involved?
Blocks must be laid safely by masons who are assisted by labourers. For materials are especially cement and sand needed, main equipment is a concrete mixer, steel mould and a long leveller to guide and measure a correct laying of blocks, see image 4.22.

Which problems and remarks can arise?
- By applying the smooth plaster finish aren’t all building services fixed into the walls.
- Laying blocks, plaster works and its joints for a wall aren’t done completely and finished in one time.
- Used sand contains some soil and clay and is polluted with grass and roots.
- Deviations of produced blocks are more than the prescribed 2mm.
- Realised walls show measurements deviations that exceed the maximum allowed deviations.
- Thickness of mortar beds and joints is much more than the prescribed 15mm.
- Already smooth finished walls and slab is polluted by fallen mortar from applying the plaster finish.
- Realised smooth plaster finish surfaces show cracks after curing.
- Long term, structural quality of produced sand-cement blocks and mortar for joints and plaster finish isn’t conforming prescribed requirements.
- Workers carry too much weight of mortar and blocks which affects their health and safety.
- See for a complete overview of all problems and remarks that can arise during the realisation of a blockwork wall with smooth plaster finish, activities A5, A6 and B4 of “Analysis of construction works in Accra, Ghana, final report Master project: ‘Participatory observation’ by J.J.J. Hulsen”. [10]
Image 4.23: Steel roof trusses and purlins are coloured red, the steel window frame with burglar proofing yellow and the wind bracings green.

4.1.8  Analysis of steel works

Steel works exist of steel window frames and steel trusses with purlins and wind bracings for the roof construction. These steel works are analysed in this paragraph of define what must be realised and which problems and remarks can take place.

What must be constructed?
Steel works with burglar proofing has a length of 2.70m and a height of 0.82m and are made of square pipes 20 x 20 x 1.5mm and reinforcement bars ø14mm centre to centre 140mm. The steel roof construction spans a compartment at once and exists of 2 trusses, 20 purlins and 3 wind bracings and is made of square pipes 1.25” x 1.25” (30 x 30 x 1.5mm) and angle bars 1” x 1” (25 x 25 x 3mm), see also image 4.23.

Why must that be constructed?
To close wall openings for unwanted entries and to connect the columns structural are steel frames with burglar proofing required. The steel roof trusses, purlins and wind bracings are necessary to provide a stable roof construction for fixing the roof finishing.

Where is it proposed?
Steel window frames are foreseen between the concrete columns and above external blockwork walls of the superstructure which is 1.88m above ground level. The roof trusses must be placed on two concrete columns at 2.70m above ground level, rectangular on the window frames. Purlins and wind bracings should be fixed on and between these trusses.

When should it be constructed?
The whole roof construction should be made immediately when concrete columns of the superstructure are finished, because most workplace is than available on the ground floor slab. First the trusses and then all wind bracings and purlins. When welders and a welding machine are present on site it's advisable to fix the steel frames directly too. If wanted, this can be done before the external walls of the superstructure are made. All steel bars and pipes must be well painted with a primer and finishing coat before processing them in the work.

How must it be realised?
Steel window frames and especially the roof trusses should be structural connected and anchored to the reinforced concrete columns, to prevent blowing of the roof construction. Connection between steel elements can be done by welding and with bolts and nuts and should be specified by a structural engineer. Thickness and fullness of the welding joints is very important for the final quality of the structure. In case of a restricted work space on site it can be more practical to prefabricate the steel window frames and roof trusses completely somewhere else on ground level. And later on transport them to the construction site and process them into the work. Weight of one roof truss is around 33.0 kg which makes transportation and lifting by hand well possible, see image 4.24. Purlins and wind bracings are almost always directly fixed into the work and connected to the roof trusses by small cleats of steel angle bars welded on the roof trusses. Maximal deviation is around 15mm into all directions for every steel bar and pipe of the roof construction. Outside dimension of window frame is dependant of the space between the realised concrete columns. Design of a roof truss should be expressed with round numbers and in simple relations between height and span.

Who are involved?
Only used material is steel which must safely be processed by skilled welders who are assisted by labourers. Required equipment is a welding machine and an electrical cutter or steel hand saw.
Image 4.25 & 4.26: Detail of a side trim and top and down side of bitumen corrugated roofing sheets fixed on a steel roof structure with hook bolts and washers at a project of the Foundation to Build

Image 4.27: A safer spreading board must be used when roofers lean on fixed sheets
"Which problems and remarks can arise?"
- Welding and/or bold and nuts joints between the different steel pipes, bars and elements aren't constructed structural strong enough according to prescribed requirements.
- Measurement deviation of different prefabricated steel elements or finally the construction is more than allowed.
- Steel window frames doesn't fit between the concrete columns or the opening is too wide.
- Prefabricated steel trusses and window frames must be transported to the site.
- Processing and welding all steel bars and pipes to (prefabricated) construction elements doesn't take place safely. Especially reaching the work space can be dangerous with a risk on falling off the roof.
- Workmanship of the welders and their equipment isn't sufficient.

4.1.9 Analysis of roof finishing works

Corrugated sheets made of organic bitumen with cellulose fibres are most appropriate to use for the roof covering. Application of these sheets is in this paragraph analysed to find out what must be done, on which way and what the risks are by placing these sheets.

What must be constructed?
Fixing cellulose bitumen corrugated sheets, with a length of 2.00m, a width of 1.00m and a corrugation depth of 31mm, on the steel roof construction. Placing ridge capping and gutters with downpipes. By using a roof overhang at the facade shall a side trip not be necessary, like image 4.26.

Why must that be constructed?
The corrugated sheets are fixed to cover the roof and to protect all users and the service block itself from environmental influences like sunshine and rain and to give them a feeling of safety and comfort. To make the roof water proof and to collect rainwater is a ridge cap and gutter necessary.

Where is it proposed?
The roof finishing must be placed on the steel roof construction. The ridge of roofing sheets should be covered with a ridge cap and on both ends must a gutter be fixed.

When should it be constructed?
Placing corrugated sheets can start when the complete steel roof construction is finished. Order in which the sheets must be fixed should be adapted to the most prevailing wind direction. After all sheets are laid can the ridge cap and gutter be placed.

How must it be realised?
Centre to centre distance of purlins shouldn't exceed 0.45m to prevent sagging of sheets. Processing corrugated sheets to the steel roof construction with end overlap, overhang and overlap must be done according to the prescriptions as mentioned in the material handbook. The same applies for the number of bolts and order in which all sheets must be laid with an overlap. This all should be well prepared. For fixing the roof sheets are (self made) hook bolts and bituminous washers needed which must be placed at the top of a corrugation. When roofers leaning on fixed sheets they should use a safe spreading board as shown by image 4.27. Deviation to fix roofing sheets is maximum 15mm. Gutters must be fixed on the lowest purlin at every 0.50m and requires a slope of 3mm / m1 to the downpipe. [30]
NEW MASONRY

Surface Preparation:

Fresh masonry is likely to contain lime, which is very alkaline. Until the lime has had time to react with carbon dioxide from the air, the alkalinity remains high, which can attack the potency of the paint.

1. Allow masonry surfaces to cure for 30 days before painting.
2. Apply 1 coat of SHIELD CONCRETE SEALER.
3. Apply 2 coats of SHIELD ACRYLIC PAINT.

Image 4.28: Fixing of sheets must start at the opposite end of prevailing winds and be laid from down till top. Image from Technical Book of Onduline Roofing system [30]

Image 4.29: Instruction for painting new masonry surfaces. Image from Painter’s guide of Azar Chemical Industries Ltd.
Who are involved?
Used materials are cellulose bitumen roofing sheets, hook bolts with bituminous washers, ridge caps and gutters that are processed by roofers who are assisted by labourers. As equipment is a hammer and hand saw sufficient.

Which problems and remarks can arise?
- Centre to centre distance of purlins will be increased to save materials.
- End overlap, overlap at eaves and overhang aren't according to the requirements.
- Order in which roofing sheets are fixed isn't conform the prescribed order as indicated by image 4.28.
- Nails aren't placed on their correct position or not at the top of a corrugation.
- Realising the roof finishing doesn't take place safely and cause a change on falling off the roof.
- Roofing sheets will be damaged by workers during the fixing of sheets and ridge cap.
- Slope of placed gutter is too steep or too flat.

4.1.10 Analysis of paint finishing works

All surfaces are finished with a paint coating added by painters. In this paragraph are these works analysed to find out what must be painted, how it should be done and what the risky aspects are.

What must be constructed?
Applying a paint covering, which exist of one undercoat and two topcoats, on steel and masonry surfaces of walls, slab, columns, window frames and roof construction of a compartment.

Why must that be constructed?
To cover, protect and to provide neat surfaces that are easy to clean, damp proof and keeps the usability of service blocks high, and to create a decorative effect at the in- and outside of a service block.

Where is it proposed?
Only those masonry and steel surfaces that are above ground level and visible must be painted.

When should it be constructed?
Applying under- and topcoats of the paint finish on masonry surfaces may only begin when all other construction activities are completely finished, especially the smooth plaster finish on blockwork walls. These masonry surfaces must cure for around 30 days and moisture level should be 16% or lower. All steel (prefabricated) elements like window frames, trusses, purlins and wind bracings should be painted completely before fixing them into the work.

How must it be realised?
The slab must be brushed and washed before adding the coating. All other surfaces must be sandpapered smooth, all pollution be removed and gaps be filled before applying the paint coatings. Every paint finish exists at least of one undercoat, the primer, and two top coats which all require a certain thickness. All coats must dry for around 24 to 48 hours before recoating it. Sanitary and already finished surfaces of walls and slab should be covered to protect them against spilled and spattered paint. Applying the different paint finishing coats to the separate building elements must be organised in a logical order, one by one. How to process and apply paint exactly is more specific described in guide lines and product specifications, an example is given by image 4.29.
Image 4.30: Before applying the paint finish must all previous construction activities be finished
Who are involved?
Painters assisted by labourers apply acrylic emulsion paint on masonry and oil-based paint on steel surfaces with brushes and rollers. Used paint must be qualitative and of a professional, industrial level to keep its quality and decrease the number of repainting during its lifetime. Paint may not be stored in a temperature exceeding 40°C. For applying all paint coatings must prescribed safety provisions be taken like sufficient ventilation and prevent eye and skin contact.

Which problems and remarks can arise?
- Previous construction works, like the smooth plaster finish, isn't completely finished during application of paint coatings on walls and slab, see image 4.30.
- Moisture level of masonry is too high and hasn't cured for 4 weeks.
- Surfaces aren't free of pollution, not well sand papered and gaps aren't filled before applying the first undercoat.
- The different added paint coatings are too thick or thin.
- Surfaces and sanitary are spoiled with spilled and spattered paint.
- Applying one coat to a single construction element, for example a wall, isn't finished completely in one time and elements aren't painted one by one.
- Too save construction costs is cheaper paint be used with a lower quality level.
- Safety provisions aren't taken and paint activities affect the safety and health of workers.
Image 4.31 & 4.32: Structural quality of building elements, especially the load bearing ones, is absolutely important for the lifetime of a service block.

Image 4.33: Construction works may not affect the safety and health of construction workers.
4.2 Concept work plan

During the analysis of paragraph 4.1 is determined what exactly must be constructed, why and which problems and remarks can arise during realisation of a Safi Sana compartment. For constructing a complete Safi Sana compartment locally is a usable work plan needed and very helpful. To achieve such a work plan should the analysed problems and remarks be solved, which will be reached by applying and fulfilling the described criteria of paragraph 2.3. [17]

From all fourteen criteria, apply only the criteria 7, 8, 9, 10, 11, 12, 13 and 14 on the construction works for a Safi Sana compartment. These criteria are used to make choices and assess plans for construction works that can solve the problems and remarks in the building process of new Safi Sana service blocks, some examples are given by image 4.31, 4.32 and 4.33. Besides this, gives the criteria also a direction for development of the building process.

All above mentioned criteria apply on the complete realisation of a Safi Sana service block. For setting relationships and order between different construction activities as well for solving problems of the specific construction works itself. It makes an integral approach, of the building process and its expected problems, well possible to finally develop a suitable work plan for a compartment.

During the analysis of construction works are many problems and remarks indicated for the specific construction activities. These are most of the time in relation, causes or results, with above mentioned criteria. By fulfilling these criteria for the construction works are those problems solved too. This goal forms also directly the principal theme of the work plan and is the concept for a well controlled realisation of all construction works. It's not one but a combination of requirements, necessary to solve all problems from a higher abstract level and fulfil all wishes of the client.

This paragraph presents a concept work plan with most important plans, a time schedule and budget estimation for all construction works of one Safi Sana compartment. It makes clear how a compartment should be constructed. All plans must already fulfil the applying criteria and form the principle for further development of the activities and building process into the final work plan. The concept work plan is described by the following construction technology aspects: construction site and transport, method of construction, organisation of the building process, time schedule, measurements, structural long term quality, safety and health and construction costs.

4.2.1 Construction site and transport

Circumstances in a slum environment, and especially the small and bumpy access roads, have a great influence on the building process of a compartment, it makes transportation by (large) trucks difficult. There can only raw materials and light weight building elements and materials be transported by a small pick-up truck or by hand, see also image 4.34 and 4.35 on the next page. Using labour for transportation must be stimulated to create more jobs, at least when it's done safely as described by paragraph 4.2.7. Large prefabrication and cranes are already unwanted due to their high costs and the non-stimulation of local employment. This result that only some equipment and light weight building elements like steel frames and sand-cement blocks can be prefabricated. All other (raw) materials must be transported to the site and there be produced and/or processed into the work.
Image 4.34 & 4.35: Transport to the construction site can only take place by a small pick-up truck or by hand.
It's advisable that contractors have another fenced work place or hangar to store materials and equipment and prefabricate those light weight building elements. Thereby should the contractor take along the everyday required expensive materials and equipment with a small pick-up truck to the construction site. This shall reduce the required work place on site and limit the change on stealing from equipment and materials. Another opportunity is to hire a security service or work together with people from the local community to protect the construction site, a suitable security service is presented in image 4.36.

The horizontal and vertical transport of materials on site must mainly take place by hand to create local employment. They can use hereby a head pan or (wheel) barrow. To store water on site is a poly tank needed which can also be filled by a pick-up truck instead of large water tankers. The need of an electrical generator depends on the availability of electricity in the slum and how often electricity is wanted. On construction sites should be a place where workers can sit, prepare and eat their food. Regularly must the site be cleaned by workers to remove all waste of construction activities.

Image 4.36: Matching security service at a construction site in Accra, Ghana
Image 4.37: After excavation works are first the concrete foundation and substructure columns be realised

Image 4.38: Realisation of the superstructure columns takes place directly after the concrete ground floor slab
4.2.2 Method of construction

Following the design with most appropriate materials are the building activities of the method of construction also kept simple and individual. All materials are, as much as possible, manual processed into the work by the local present workers. How to construct the different, grouped activities is already general explained by the different research questions in the analyses of paragraph 4.1. This shall be shortly repeated in these paragraphs added with the most important plans and choices for construction works of those grouped activities.

4.2.2.1 Earthworks

Trenches and column bases are excavated by hand with use of a spade and pickaxe. Horizontal transport of soil takes place by a wheel barrow and must be stored at different sides on the construction site. Due to the hardness of the laterite soil can excavations be done almost vertically with a slope of around 5:1. The sides of excavations and pits should be kept unimpaired and can be used as formwork for casting the foundation. For backfilling is the earlier excavated soil used which must be well rammed, into layers of maximum 0.20m with a manual compactor, to a hardcore filling. Measurements of this hardcore filling can be checked from placed profile boards and from the top side of substructure blockwork walls.

4.2.2.2 Concrete works

All concrete elements are casted into the work with on site produced concrete from qualitative raw materials, therefore is a small concrete plant with concrete mixer required on-site. Adding exactly the correct proportions of materials to the mixture is very important. Control especially the amount of water in relation with the amount of cement and the water-cement ratio. During production, transportation and processing may the concrete mixture not be put down on polluted surfaces like a slab. Produced concrete must be casted and vibrated in a timber formwork where reinforcement, with 30mm concrete covering at the outside, already is placed in. These timber formwork and reinforcement cages are made by carpenters and steel binders from beams, sheets and bars and can already be prefabricated on site or somewhere else. Timber formwork can be reused for around 5 times and it depends on the number of concrete works and available construction time how much formwork is needed. Use plastic sheets to divide concrete from laterite surfaces and to cover the top side of concrete directly after casting to improve the curing of it. The formwork must be stand till at least 2 days after casting.

For the concrete ground floor slab is it better to cast it in two times. First a steel mesh reinforced, rough finished slab with sewerage pipes. On this slab and pipes must the squat mix toilet pans be fixed, and finally can the top slab be casted. This last slab exists of a relatively dry concrete mixture with higher cement content and must be finished very smooth. The concrete columns of the substructure are casted to 10cm above the concrete ground floor slab to form a starter for the superstructure columns.
Image 4.39: The whole roof construction and finishing should be placed before realisation of all superstructure walls, because than is more work space available and are walls protected from environmental influences.

Image 4.40: All blockwork walls can be painted when they are completely smooth plastered and have a low moisture level.
4.2.2.3  Blockwork walls and smooth plaster finish works

Sand-cement blocks are prefabricated from qualitative raw materials, under own supervision of the contractor to guarantee strength, durability and measurements. It’s important that correct proportions are exactly added to the mixture with a moderate use of water. For laying the blocks and the smooth plaster finish is sand-cement mortar needed, which can be produced with the already on site present concrete mixer. Provisions for the production of sand-cement blocks must also be considered by producing sand-cement mortar. On site transportation of the blocks and mortar, and to lay them with a smooth plaster finish will completely be done by masons and labourers. Different superstructure walls can be realised at one time, course by course, which makes it possible to link walls together with a bond. Block must be laid in a 15mm mortar bed one by one. Only when all blockwork walls are realised and building services are fixed, may the smooth sand-cement plaster finish be added. Cover the smooth plaster finish with a plastic sheet when it’s finished.

4.2.2.4  Steel works

All steel frames are completely prefabricated elsewhere and transported to the construction site when they are needed. The maximum weight of the heaviest, single steel element is 33.0kg which makes partially walking even possible for transportation. For production of the steel frames should the measurements be set out with ropes on a levelled bed of laterite. Cut by hand the required length of steel bars and pipes and place them correctly at the measurements on laterite bed. Weld these bars and pipes together to a steel frame. Produce the second and following frames on this first steel frame. The dimension between superstructure columns must be measured to get the width of the steel window frames. At the construction site must the steel frames be lifted and fixed manual by a welder assisted by different labourers, hereby is the joint with the columns very important. The wind bracings and purlins must directly be fixed after the roof trusses to create a stabile roof construction.

4.2.2.5  Roof finishing works

Fix the bituminous corrugated roofing sheets one by one, starting at a corner, opposite the prevailing winds. Order in which the sheets must be fixed is against the prevailing winds and to complete first the lowest course of sheets and after this the higher courses. This order should be well prepared and must really be followed during fixing of the roof finishing. All sheets, ridge caps and gutters are completely purchased in Accra. The hook bolts with bituminous washers are maybe sold on the open market in the centre of Accra, but can always be self produced. These must be placed at the top of a corrugation in a prescribed position. The complete roof construction and finishing shall be made before the superstructure walls to protect workers, materials and realised works from environmental influences, see also paragraph 4.2.4.

4.2.2.6  Paint finishing works

The steel frames, purlins and wind bracings must completely be coated with a steel paint before processing them into a roof construction. Probably that after fixing some small surfaces requires a little repainting, for example the welding joints. Masonry paint may only be added into the work when all wall and slab surfaces are completely clean, smooth finished and moisture level is low enough by curing. The purchased coatings are added by painters who only need some hand tools and perhaps a stepladder. Cover the already finished surfaces and sanitary well to spilled and spattered paint.
List with 30 most important construction works to realise a Safi Sana compartment:

**A  Substructure**
A1 Remove vegetable soil and excavate soil from trenches and column bases  
A2 Realise reinforced concrete strip foundation and column bases  
A3 Realise reinforced concrete columns of substructure  
A4 Place sewerage pipes  
A5 Make sand-cement blockwork walls of substructure  
A6 Backfill and ram the excavated soil in trenches and below ground floor slab  

**B  Superstructure**
B1 Realise 1st bed of reinforced concrete ground floor slab  
B2 Realise reinforced concrete columns of superstructure  

**C  Roof**
C1 Prefabricate steel construction elements  
C2 Paint steel surfaces of construction elements  
C3 Place steel roof trusses  
C4 Place steel roof purlins  
C5 Place steel roof wind bracings  
C6 Place steel window framework with burglar proofing  
C7 Fix cellulose bitumen corrugated roofing sheets  
C8 Fix cellulose bitumen corrugated ridge capping  
C9 Fix gutter  

**D  Walls**
D1 Make external sand-cement blockwork walls  
D2 Make middle sand-cement blockwork wall  
D3 Make design blocks on top of middle blockwork wall  
D4 Make internal sand-cement blockwork walls  
D5 Fix all building services in trenches in walls  
D6 Apply smooth plaster finish to superstructure walls  

**E  Finishing**
E1 Fix squat mix toilets in ground floor slab  
E2 Realise 2nd bed of reinforced concrete ground floor slab  
E3 Paint vertical masonry surfaces of columns and walls  
E4 Paint horizontal masonry surfaces of ground floor slab  
E5 Fix all remaining building services on walls and roof construction  

**F  Construction materials**
F1 Produce concrete mixture on-site  
F2 Produce sand-cement blocks  

*Image 4.41: Overview of appendix 4, order and relations of the main construction works to realise a compartment*
4.2.3 Organisation of the building process

All construction activities must be finished as much as possible before other works may start. With this can easily be defined when labour, materials and equipment must be present. It gives the opportunity to create an optimum order and to control and check the complete building process for realising a compartment within the defined criteria. And to be sure that every activity can be done at once and correctly, without to forget anything. Consecutive works may only and must start directly when previously work is completely finishing.

By creating an order of consecutive construction works it is also possible to protect and cover already finished surfaces to other materials like sand-cement mortar or paint. These and other finished building elements may not be damaged by workers, materials or equipment.

Workers should frequently and correctly be instructed by a foreman, he must be demonstrating how to produce materials and to execute construction works. It’s here that workmanship and labour mentality of workers can be increased and capacity building originates. Profits of it can directly be used during the realisation of following service blocks.

When the building project is tendered should already all architectural, structural and mechanical drawings with details be completed and supplied. In the contract between client and contractor must be agreed how long the construction time may take. It’s advisable to make only the contractor responsible for purchasing and delivering of all needed construction materials to occur a mix of responsibilities.

4.2.4 Time schedule

With help of all construction works and their quantities and numbers as presented by appendix 3 has a list been made with the most important activities to realise a complete compartment. This list exists of 30 main construction works and is presented on the left page. What must be constructed and the relation between different construction works is already defined by the analyses of paragraph 4.1.

Earlier in paragraph 4.2.3 is defined that all these construction works should be planned serial as much as possible. To make that order clear, in which all these activities must be taken place, are all activities transferred into one diagram. Beside this order makes the diagram also all relations visible between the several construction works. The schedule is attached to this report by appendix 4, there is no time scale added.

Works to the substructure shouldn’t be done during the rainy season to occur flooding of the foundation. The schedule of appendix 4 shows that realisation of the roof is completely independent from the superstructure walls and finishing works. Both can be done parallel or serial whereby the roof as well as the walls can be constructed first. An overview of appendix 4 is presented by image 4.41. It’s advisable to realise the complete roof construction with its finishing first. Because than is much more work space available on site and can workers more easily reach their work place with a ladder or scaffold. When the complete roof construction is realised should workers start with the walls and its finishing. Then they are also protected to rain, heat and direct sunshine and there is no danger of falling items anymore.
Image 4.42: Measurement deviations increase the use of materials and finally the construction time and costs

Image 4.43: Setting out and checking measurements of a foundation trench at a project of the Foundation to Build in Klikor
For every of the 30 most important construction works are specifications for the building process defined. These are the quantity and duration of a building activity, how many workers are involved and which equipment is required. The duration is given in hours and is for completing that specific construction activity with the mentioned number of workers. An overview of these specifications is given by appendix 5. With help of the information from appendix 4 and 5 is finally a time schedule made which is presented by appendix 6. The time schedule gives an overall construction time of 90 days to realise a single compartment, which is equal to around 4 months. All remaining finishing works for the in- and outside can be done during the curing time of smooth plaster finish. Four chronologically moments of the building process are visualised with 3-D models on the previous left pages by image 4.37, 4.38, 4.39 and 4.40.

To shorten the construction time are there three main possibilities of which all can be used. The first one is to speed up building activities by hiring more construction workers. This is more advisable than the second possibility to order construction works parallel. Because this will make the building process less clarifying, more complex and increases the change on mistakes by joints and connection between different building elements. Third opportunity is to realise the complete roof construction during the curing time of smooth plaster finish. This will shorten the overall construction time with only 13 days but makes realisation of the roof construction much more difficult and is therefore not recommended.

4.2.5 Measurements

Dimensions of the realised construction elements should be according to the drawings and requirements and mustn’t exceed the maximum measurement deviations as described in the analysis. Measurements must be controlled to limit the use of materials and spilled working hours and thus construction costs, see also image 4.42. And beside this to make sure that consecutive works does fit on previous accomplished works and to achieve some aesthetic quality. To reach this accurateness must a foreman set out and check regularly the measurements together with some capable and skilled workers. Important here is awareness by the contractor that measurements must be done accurately and lay within the maximum allowed deviations to save construction time and costs. This should be underlined by the contractor and client who must check the measurements frequently, before and direct after construction works.

For every single construction activity must in the work plan be defined which simple measurement tools and tricks are most suitable. Some available simple tools are a leveller, oil bowl, building square, profile board, rope and tape measure, see image 4.43. Also can other building elements be used to link measurements, like backfilling to top side of the substructure walls. By using these single tools or a combination of tools should it be possible to realise measurements of construction works within the maximum deviations.
Image 4.44: Instruct this posture to all workers for a safely lifting and carrying of materials, image from http://www.topinzet.nl/arbeidsfysiotherapie/

Image 4.45: An unsafe work situation during removing of formwork while a scaffold is present
4.2.6 **Structural long term quality**

For a long life time of the construction is a good structural quality very important. To achieve this should the correct (basic) building materials be purchased and used. These materials must be produced, transported, processed and sometimes even cured, according to (structural) drawings with details and requirements from the developed work plan. All prescribed labour, equipment and instructions should be present and followed to get construction elements and joints that are structural strong enough. Requirements must be checked regularly by the client and all guidelines must be well instructed to all workers by the foreman of the contractor.

Some examples are the use of sand and reinforcement bars which are cleaned and free from pollution. Stones for coarse aggregate must be mixed with quarry dust to distribute the diameters of stones better. Formwork for concrete columns needs more softwood timber members to prevent deformations. Also must be checked by the client if the amount and proportions of materials like cement, steel purlins and paint is according to the prescriptions, and if it's not be decreased to save construction costs. Finally must the structural joint between different building elements be sufficiently strong, especially the connection of roof trusses on the superstructure concrete columns.

4.2.7 **Safety and health**

The mostly unsafe work conditions on construction sites affect the health risk for workers negative. Aim is to minimize these risks and to take care that all workers don't encounter any negative consequences of realising a Safi Sana service block. By development of the final work plan must for every activity be defined, which safety provisions should be taken. Some few important ones are already presented here.

To carry weight by workers must be limited to maximum 20kg. When workers have to transport materials over a larger distance and more frequently during a day should be equipment like a (wheel) barrow used. When carrying by hand is required and it must be done for a longer period, should the maximum to carry weight be reduced to around 10 – 15kg. Thereby must be instructed how workers keep their posture to carry materials safely, as presented by image 4.44.

Change on falling down of the roofers, who are working at the columns, roof construction and finishing, must be limited with a scaffold or with some fall protection, see also image 4.45. During the welding of steel and the application of paint must necessary safety provisions be taken. Workers should wear safety shoes all the time and also a helmet when they are making the roof construction and finishing. There must be a possibility for workers to visit a toilet near the construction site during working hours.

These safety provisions must not only be told to the workers but also instructed and explained. On such a way that workers become more aware of their and others safety risk and create a safety feeling.
### Sanitary facility

<table>
<thead>
<tr>
<th></th>
<th>Costs (GH¢)</th>
<th>Percentage (%)</th>
<th>Costs / cubicle (GH¢)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single compartment by JJJ Hulsen with 6 cubicles</td>
<td>11400,-</td>
<td>100</td>
<td>1900,-</td>
</tr>
<tr>
<td>Two linked compartments by JJJ Hulsen with 12 cubicles</td>
<td>19800,-</td>
<td>174</td>
<td>48</td>
</tr>
<tr>
<td>Service block by Safi Sana (Gh.) Limited with 12 cubicles</td>
<td>41500,-</td>
<td>100</td>
<td>3460,-</td>
</tr>
</tbody>
</table>

**Image 4.46: Comparison of construction costs between designs of service blocks by JJJ Hulsen and Safi Sana (Ghana) Limited**

<table>
<thead>
<tr>
<th>Item</th>
<th>Two linked compartments by JJJ Hulsen</th>
<th>Service block by Safi Sana (Gh.) Ltd</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof surface (m2)</td>
<td>67,5</td>
<td>82,0</td>
<td>+121</td>
</tr>
<tr>
<td>Concrete for columns and beams excluding formwork and reinforcement (m³)</td>
<td>1,7</td>
<td>7,1</td>
<td>+421</td>
</tr>
<tr>
<td>Blockwork excluding smooth plaster and paint finish (m²)</td>
<td>97,0</td>
<td>223,0</td>
<td>+230</td>
</tr>
<tr>
<td>Slab finishing, for linked compartments by JJJ Hulsen is an industrial floor paint used and for service blocks by Safi Sana (Ghana) Ltd. are porcelain floor tiles used (GH¢)</td>
<td>568,-</td>
<td>2455,-</td>
<td>+433</td>
</tr>
</tbody>
</table>

**Image 4.47: Differences in quantity and quality of the used materials in service blocks with 12 cubicles and 4 wash hand basins as designed by JJJ Hulsen and Safi Sana (Ghana) Limited**
4.2.8 Construction costs

To determine the construction costs for a Safi Sana service block with compartments are two different bills of quantities estimated, these are added to this report by appendix 7 and 8. In the first appendix are the construction costs for a single compartment with 6 cubicles calculated. The second bills of quantity presents the costs for a proposed service block with two individual compartments which are linked together and contain 12 cubicles for toilets and space for 4 wash hand basins. For all bills of quantities are the current unit rates used because these are more comparable and the most complete ones and includes engineering, overhead, profit and risk. The presented construction costs in this paragraph are excluding preliminaries and contingencies because both are percentages which can be added later on. [26] [31] [34]

Both bills of quantities are made for all main, internal construction works of only the building itself. This is including the finishing with all sanitary, electrical and plumbing installations and complete doors with frames and barrel bolts. All paint works are calculated for 3 times a complete coat, thus with twice a repainting for life time duration.

In the estimations is none of the external works, like overhead drink water storage, water tanks, septic tanks, inspection chambers, pipes and pavement, incorporated because they aren't designed for a compartment. These costs will be clarified later on in this paragraph. The separate toll point is also not designed and developed and therefore not calculated by these construction costs.

According to appendix 7 and 8 and with considering of above mentioned are the lifetime construction costs calculated. These are for a single compartment 11400GH¢ and for a service block with two linked compartments 19800GH¢ (1 GH¢ = 0.56 euro on 24-06-2010), see also appendix 7 and 8.

4.2.8.1 Comparison

To prove the quality and low construction costs of developed design with compartments during this graduation project are its costs compared with the most current Safi Sana service block. This block is located in the slum Ashaiman and developed by Safi Sana (Ghana) Limited. It consists also of 12 cubicles with toilets and 4 wash hand basins and its functions are identical to the linked compartments as presented by appendix 8. From this service block is already a bills of quantity available of which all items for the external works and the toll point are removed. It contains only the main, internal construction works of the building itself and matches exactly with the above mentioned and described bills of quantity, this to make a fair comparison possible. The bill of quantity of this Safi Sana service block is attached to this report by appendix 9 and its lifetime construction costs are 41500GH¢.

A comparison between these two similar service blocks is given by image 4.46 and shows that construction costs of the developed compartments are significant lower, around 48% of the current service blocks from Safi Sana (Ghana) Limited. This is also present by the costs per cubicle in the last column. Differences can be mainly clarified by quantity and quality of the used materials, see image 4.47. By linking two compartments to a service block doesn't double the overall construction costs but it increases with only 74% because two columns, roof truss and wind bracings can be used twice.

Construction costs for external works are estimated on 14800GH¢ for a complete service block according to the bills of quantity for a Safi Sana service block in Ashaiman as presented in appendix 9. These costs should be counted up the costs for main construction works of the building itself.
Image 4.48 & 4.49: Foremen don’t do any construction works by themselves but instruct only the workers, the foreman at image 4.47 (above) is wearing a pink coloured shirt.
4.3 Communicating and reporting

Result of whole graduation project is a design and work plan for a service block with the most appropriate construction materials and building process. This information should be used locally to realise Safi Sana service blocks in the slums of Accra. To implement all these information it's important that the way of communicating and reporting match with the Ghanaian situation. In this paragraph will be defined who of the local people need to receive the information, how it must be reported and which way of communicating to workers is most suitable.

4.3.1 Who must receive the information?

The company Safi Sana (Ghana) Limited has the intention to board out all construction works for realisation of a single service block to one Ghanaian contractor. This contractor should have experience with comparable building projects and preferably be based in or around Accra. On each project he must delegate at least one foreman who is continuously present at the construction site to instruct and check all workers. This foreman should receive the information from the work plan and transfer it to the workers. His level of education must be at least Technical school, but better is when he passed the Polytechnic school. Finally he must understand the English language as well as the local languages ‘Ga’ and ‘Twi’.

Some certain foreknowledge about simple construction and buildings can be expected by selecting such a contractor. It's therefore that elementary construction skills and knowledge doesn't have to be explained in the final work plan. Examples are excavating with a spade, cutting with a hand saw or using brushes and rollers during paint works. There will also be expected that foreman can 'read' construction drawings, work plan, time schedules and diagrams to understand instructions, orders and the relations between different construction works.

4.3.2 Communicating to workers

On every Safi Sana construction site is permanent a foreman present to coordinate and support the different building activities. Besides this, he must instruct all workers with information from the work plan. There are several ways to do this like giving verbal instructions, training, paper instructions, movies, singing, demonstrations and public performance.

Most suitable way to communicate and instruct the workers with information from the work plan is to demonstrate, with at the same time giving verbal instructions. This can be supported with sketches or small notes on paper. All information concerning to a specific activity should only be instructed to those workers who are involved to that activity. It's for example not relevant for a carpenter to know how sand-cement blocks must be laid. Apart from this it's not very usual that the foreman do some construction works himself, see also image 4.48 and 4.49.

Instructions to workers should be given in their local language(s), to increase the delegation of knowledge, and it must be repeated regularly to train them. The foreman and client should also check realised works frequently, for what the guide lines in the work plan also can be used. It shall work to reward correct realised construction works with some small amount of money or a meal, to support workers and make them more aware of the significance to realise construction works correctly.
11.4 Foundation Option 2 – Post in Concrete

Pros
- Stronger and more durable foundation for vertical and rotational movement
- More resistant to weather and pests

Cons
- Experience with concrete needed
- Delay in frame construction from setting time
- More expensive

Materials?
- 2 timber sheets or planks 400x500mm
- Concrete 80 litres per post
- 4 nails per post

Tools?
- Spade x 1
- Tape x 1

What to do
1. Dig a trench for the foundations 400mm wide and 500mm deep and place timber formwork. Pour concrete block 400mm wide.
2. Put 4 nails in the end of the post 150mm from the end. This is to provide some grip to the concrete. Place post in wet concrete
3. Allow 24 hours before removing post support and timber formwork

Image 4.50: One sheet from a work plan for construction a shelter, image from the shelter centre [33]

Image 4.51: Operation ‘Show your ticket’ from Metro Mass Transport Ltd. in Ghana
4.3.3 Reporting to foreman

All plans and choices of the developed building process are reported in a work plan. This is a manual that step by step describes on which way a service block should be constructed locally. Work plan for a Safi Sana compartment exist of the 30 most important activities as defined in paragraph 4.2.4. The work plan should be reported to a foreman who can use it for instructing the workers as determined in paragraph 4.3.2. Therefore must final work plan contain of clear guidelines supported with images that can directly be used on-site.

One example sheet of a usable work plan for shelters is presented on the left page by image 4.50. With images, guidelines and risks is presented what must be constructed and how. Besides this, can the required drawings, materials, tools and equipment, workers, construction time be mentioned in every work plan sheet. [33]

A combination of images with text is often used in Ghana to explain something and communicate with the local people. By images 4.29 and 4.51 are two examples given of clarification with help of images and text. First one is from a local painter’s guide and explains how to paint new masonry surfaces. The other is from operation ‘Show your ticket’ of Metro Mass Transport Ltd., a local bus company. Other famous examples of present something with text and images are cartoon strips, LEGO instructions and IKEA guidelines. Finally is below by image 4.52, an example given of a guideline to install cardboard shelters of the Red Cross. The way of using images to explain construction works can be helpful for the final work plan.

Image 4.52: Part of a guideline to install cardboard shelters of the Red Cross
Substructure: MAKE SAND-CEMENT BLOCKWORK WALLS OF SUBSTRUCTURE (A4)  

1. Two courses of 150mm solid sand-cement blocks are enough for realising a substructure wall to 0.05m above ground level. The outside of the outer walls must be finished with a 20mm thick smooth sand-cement plastering. For laying blocks and adding plaster finish must on-site produce cement-sand blocks and mortar (1:4) be used according to final work plan sheet F2. Transport and store mortar only in clean equipment like a wheel barrow or head pan, not on a dirty slab. Workers may carry maximum 15kg of mortar and blocks. Before laying the sand-cement blocks must the strip foundation and blocks be moisten with water.

2. Measure the outer side of blockwork wall on the profile board and set with a rope and leveller this measurement on the top- and downside of the column. Place on columns the height of the block courses plus joints at 24, 25.5 and 48cm. A thickness of 1.5cm is sufficient for all horizontal and vertical mortar joints and beds. In the middle trench must a vertical timber framework be placed instead of concrete columns to set out measurements.

3. Lay at both course ends one complete block in a 1.5cm mortar bed and place this block exactly at its correct position, vertical and horizontal with a leveller. Span a rope or at the middle edge between these blocks, use when necessary a supporting block. Place between these outer blocks, whole blocks to complete the course. Place these remaining blocks one by one, to the rope and exactly horizontal and vertical. Lay constant the mortar bed for only one block and not for a complete course at ones. Measure and make finally the closer block and completely fill and finish all mortar bed and joints of the first course. Check measurements of the first course well before realising the second course. Be sure that blocks are laid vertical and exactly in one straight line to the rope. The maximum deviation is 0.5cm/m and 1cm for a complete wall in length and height. Check also if all joints are completely filled with mortar.

4. Repeat step 3 to realise the second course whereby smaller blocks must be used between the sewerage pipes and to create a stretcher bond. Be aware that blocks of the second course are laid in exactly the same vertical straight line as the first course, this can be checked with a leveller. During realisation of this second course must sewerage pipes be placed as described on final work plan sheet A5.

5. Only when blockwork walls and placing of sewerage pipes are completely finished may the smooth plaster finished be add. Place around 4 setting blocks on each wall at 20mm thickness of the wall. Lay a 30cm wide timber panel on the strip foundation to collect fallen mortar, when it’s not harden it can be easily reused. Add mortar by throwing, spread it out to mentioned thickness with a screed board and scour it smooth with a wooden float or trowel. Plaster finish must be a few times moisten and screed smooth to occur cracks in just finished surfaces. When it’s finished cover the plaster finish with a plastic sheet. Realise the plaster finish for a complete wall in one time, don’t remain only plaster work to that wall for the following day.

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Equipment:
- Head pan 2x
- Wheel barrow 1x
- Spade 1x
- Trowel 1x
- Wooden float 1x
- Screed board 1x
- Plastic sheet 3x
- Hand tools
- Water tank 1x
- Bucket 10 Ltr. 1x
- Leveller 1x
- Rope 1x
- Tape measure 1x
- Setting blocks 8x

Materials:
- Solid 150mm sand-cement blocks 4x3x
- Sand-cement mortar (1:4) 0.12m3
- Water

Labour:
- 2 Workers (7 Hrs.)

Information:
- Drawing of substructure
4.4 Final work plan

To make the concept work plan more specific for the construction works and usable on the construction site should it be translated into a final work plan. The 30 most important activities, as defined in paragraph 4.2.4, forms the base for this final work plan. Every of these activities are a step that describes how a service block should be constructed locally and for each activity can a separate work plan sheet be made. [6] [9] [10] [14] [16] [17] [28] [38]

For every single activity must applying information of different construction technology aspects like transport, construction site, equipment, safety and health, measurements, materials, processing and fixing, quality, construction time and costs, be collected and divided presented in one sheet. This information follows mainly from the accomplished analyses in paragraph 4.1, the concept work plan and results of “Analysis of construction works in Accra, Ghana, final report Master project: ‘Participatory observation’ by J.J.J. Hulsen”. To solve analysed problems furthermore is literature used added with (locally found) practical examples and described materials and methods in the database of appendix 1. At the end must achieved results, the final work plan with its sheets, solve all analysed problems and remarks and fulfil the applied criteria as described in paragraph 4.2.

The final work plan can be used by the foreman on site but also by the client to check ongoing construction works and the results of it. Of the 30 most important activities are only those with code A - Substructure and F - Construction materials further developed and elaborated into this final work plan. These work plan sheets are attached to this report by appendix 10 and one example is presented on the left page by image 4.53.

4.4.1 Layout

A foreman shall read and use this final work plan to instruct and control all workers on-site and therefore he must understand it. It’s desirable that all information will be presented on such a way that foreman can use the instructions directly from the work plan sheet. Therefore should the information be presented clear, unambiguous and so detailed that it can form directly instructions for the workers. This count especially for the guidelines, what workers have to do, and this text should be supported with 3-D images to clarify this instructions and to make them recognizable into the work.

To reach this is every sheet divided into 4 parts. At the top are the activity name, code and its position in the building process presented. Directly below are the 3-D images presented with a subscript, these together clarify the chronologic numbered guidelines that are positioned left below. At the right side below are given the necessary materials, equipment and labour with their quantities and information and drawings. These quantities are only given for one complete compartment and shall increase when compartments are linked together to create a service block. All work plan sheets are made on paper size A4 because this is most simple to operate and the possibilities to print larger paper sizes are limited in Accra, Ghana.
Image 5.1: Final design, cross section and top view, of one Safi Sana compartment

Image 5.2: Complete view of one compartment
5. **Final conclusions**

Objective for this graduation project was to develop and communicate a generic design and work plan with most appropriate construction materials and building process for the realisation of Safi Sana service blocks in Accra, Ghana. This objective can be summarised to a product, design of a service block, and a process, work plan for local realisation of the service blocks. Both must solve the current problems, where a generic design with the choice of construction materials and a developed building process are missing and desired to realise Safi Sana public sanitation facilities in Accra's slums. To find out what is desired and most appropriate for design and construction works of the service blocks are criteria defined based on the vision of Safi Sana (Ghana) Limited and local conditions, circumstances and needs.

All results of accomplished research and design work during this graduation project are collected and described in this chapter. Therefore shall firstly all conclusions be given regard to developed design (product) and work plan (process). To prove that achieved results are sufficient for the Safi Sana project and local conditions and needs shall a review be done to all fourteen formulated criteria. Finally are recommendations given for further research and development of the gained results so far.

5.1 **Design of a compartment**

Main conclusions of this part are the generic design of an independent compartment with the most appropriate construction materials and methods. These compartments are part of a concept, whereby they must be linked together and/or placed beside and opposite each other to create a site specific service block that suits to all desired facilities. Every compartment covers a surface of 3.00 x 8.00m, has a double pitch roof and can host up to 4 male and 4 male customers at once.

The roof shall be covered with cellulose bitumen corrugated sheets and be fixed on a steel roof construction that exists of angle bars for purlins and square pipes for the roof trusses. In every grid is only one truss foreseen which span a compartment at once and is fixed and anchored well to concrete columns with dimensions of 300 x 300mm.

Columns are placed on a column base, which is a local widening of the strip foundation. Both column base and strip foundation are made of reinforced concrete. The concrete columns create a frame structure which is kept together by steel frames with burglar proofing at their top part. These frames form also directly the wall openings in side elevations. In facade of the service blocks, front and back elevations, are painted design blocks more advisable.

The space between two columns, steel window frame and strip foundation is filled with 150mm thick sand-cement blockwork walls made smooth with a 12mm thick plaster finish. Above the concrete slab must hollow blocks be used and below the slab solid blocks because these substructure walls supports the slab. The middle wall, which separates the male and female side, is also constructed by these 150mm solid and hollow blocks and rendered with a plaster finish, with on top one course of design blocks. All partition walls are made of 100mm thick hollow sand-cement blocks and completely finished with a 12mm thick smooth plaster finish.
### Substructure: REALISE REINFORCED CONCRETE STRIP FOUNDATION AND COLUMN BASES (A2)

<table>
<thead>
<tr>
<th>Remove and excavate soil</th>
<th>Realise concrete foundation</th>
<th>Realise concrete columns substructure</th>
<th>Make blockwork walls substructure</th>
<th>Place sewerage pipes</th>
<th>Backfill and ram soil</th>
</tr>
</thead>
</table>

#### 1. Set out measurements and place formwork boards. The trench is already half covered with grey coloured plastic sheets.

#### 2. Place reinforcement cages, which includes bars for substructure columns and starter bars for superstructure columns, on concrete spacers. These bars must be measured very accurately!

#### 3. Cast on-site produced concrete mixture and check its level.

---

#### Equipment:
- Timber panels 200mm
- Steel brush 1x
- Poker vibrator 1x
- Spade 2x
- Plastic sheet 3x
- Wooden float 1x
- Electric jigsaw 1x
- Leveler 1x
- Tape measure 1x
- Rope 1x
- Oil bowl 1x

#### Materials:
- Plastic sheet 25.5m2
- Mild steel reinforcement 137kg
- Concrete (1:2:0.5:1=1:3) 1.4 m³

#### Labour:
- 2 Workers (27 Hrs.) & 9 Workers (2 Hrs.)

#### Information:
- Drawing of substructure
- Structural drawing with reinforcement
Area between substructure of two external and the middle wall is filled and rammed with laterite and all together support the reinforced concrete slab. A sand-cement or granolithic screed can be used to level and give the slab a smooth surface. Partition walls, that form the cubicles, are placed directly on this slab and don’t need a strip foundation. All slab and wall surfaces, in- and outside, are finished with a Safi Sana specific coloured paint coating to decorate, protect and make them cleanable. The same applies for all surfaces of the steel roof construction, design blocks and steel window frames with burglar proofing. Hereby must a professional and industrial, qualitative paint coating be used.

Dimensions of the most appropriate materials are finally used to adapt the designed compartments. The final design of one Safi Sana compartment with all construction elements is shown on the previous left page by image 5.1 and is also presented in appendix 2. Design is demarked by one compartment as shown by image 5.2 and includes all building services and wall openings. The front and back elevation, further finishing than painting and sanitary and all external works and (underground) holding tanks aren’t part of the design.

5.2 Work plan

Conclusion of second part of this graduation project is the work plan, which is developed from the final design of a compartment. This work plan describes step by step on which way a compartment should be constructed in a slum and forms a manual that should be used locally by client and foreman of the contractor to instruct, realise, control and supervise all construction activities. Final work plan exist of sheets which describe all, only one construction activity completely with guidelines, 3-D images, its position in the building process, and together with necessary materials, equipment, labour and information. One example of a work plan sheet is presented on the left page by image 5.3, all others are shown in appendix 10.

From the concept work plan can more important conclusions be given which count for all construction works of a Safi Sana compartment, these are listed below.

- Contractors should have a fenced work place or hangar to prefabricate light weight building elements and store materials and equipment to protect them against stealing.
- Most materials should be processed directly into the work by labourers whereby prefabrication of large elements is difficult and unwanted.
- As much as possible must construction works and horizontal and vertical transport on site be taken place by hand.
- Workers should frequently and correctly be instructed by a foreman for the execution of construction works, to increase their workmanship and to create some capacity building.
- All construction activities should be completely finished before other activities may start to control and check the building process.
- It’s advisable to realise the complete roof construction with its finishing before all superstructure walls because then is much more work space available on site and are workers later on protected to rain, wind and direct sunshine.
- Construction time to realise a Safi Sana compartment is 90 days which is equal to around 4 months, there are some small possibilities to shorten the construction time. Most suitable is to speed up building activities by hiring more construction workers.
- Lifecycle costs to realise all main, internal construction works of only the building itself, are for a single compartment with 6 cubicles 11400GH¢, and for a service block with two linked compartments and 12 cubicles 19800GH¢. Costs for only the external works are estimated on 14800GH¢ for a complete service block.
Image 5.4: Roof trusses which are only supported by columns and not by the middle wall, create an open construction to promote wind ventilation and less energy usage.

Image 5.5: Wall openings are applied between the columns over the whole width of a compartment, above and at the same height as partition walls, for a maximum wind ventilation.
5.3 Review on defined criteria

In this paragraph shall be reflected if final design and work plan of a compartment, as concluded in this graduation project, are sufficient for the Safi Sana project and local conditions and needs. Therefore will all fourteen described criteria from paragraph 2.3 shortly be reviewed, to settle if achieved results are sufficient to the defined criteria. Of the generic designed compartments with its most appropriate and applied materials, as concluded in this chapter, are 3-D images of this model presented by the images 5.4, 5.5, 5.6, 5.7 and 5.8.

Image of a compartment is as simple and obviously as possible due to reasonable choices in the design and recognizable Safi Sana paint colours. Appearance can be improved and made more particular and distinguishable by applying ridge openings, a so called ‘butterfly roof’ and/or circular columns but this shall probably also increase the construction costs.

Heights of walls are accurately designed to offer enough privacy for all users. There are no materials used that aren’t accepted or unknown by local people and the final result shall be welcome and fit well in a slum environment without any expression of overdone richness.

Service pipes can be casted in the concrete slab and fixed to the steel roof trusses. In sand-cement blockwork walls should trenches be cut to place service pipes and to cover them with a plaster finish. This makes all achievable pipes vandalism proof. Sewerage pipes can directly be laid in the rammed backfilling and through the external walls, to flow into outside placed inspection chambers.

The large wall openings are sufficient enough for entering wind ventilation and natural lighting, providing a thermal comfortable facility without smell. To achieve more natural daylight can small transparent roofing sheets be used. Electricity for lighting is only needed during the nights. Bitumen roof sheets reduce the drumming noise of falling rain and rainwater can safely be harvested with help of a gutter. This all makes service blocks comfortable and healthy for all users and restricts the energy consumption.

All surfaces of a facility are finished with a paint coating making them well cleanable. It’s recommended to use a qualitative, industrial coating to keep the paint long-lasting and regular cleaning is strongly advised to keep painted surfaces health and need during the operational life time.

Effect on the Ghanaian environment is limited to the need of sand, quarry dust and stones. The use of timber is strongly restricted to only softwood formwork for foundation, slab and columns. Other materials as paint, cement, reinforcement bars and steel pipes are mainly imported or produced from imported products which don’t have a large impact on the local, Ghanaian environment.

The used and processed materials in a compartment are structural strong enough to fulfil its function for lifetime and to resist various influences from climate, ecology and the environment. Maintenance is restricted to repainting of all surfaces around every 8 years and at the same time some small reparations of the smooth plaster finish. In work plan sheets are guidelines prescribed that must be instructed and followed on-site to get construction elements and joints that are structural strong enough. These concern the production, transportation, processing and sometimes even curing of materials.
Image 5.6: All cubicles are placed in one row against the external wall to lay sewerage pipes directly through the external walls, only the columns, external and middle wall have a foundation.

Image 5.7: Linking three compartments together creates a service block which offers place for 10 male and 10 female customers and on both sides 2 wash hand basins. Front and back elevation aren't designed.
Appropriate design and work plan for Safi Sana service blocks in Accra, Ghana

All the applied materials shall not affect the health of workers and can be processed safely, at least if necessary safety provisions are taken and followed by construction workers. Labour circumstances are safe and guaranteed when described requirements in the work plan sheets are well instructed to labourers. Hereby is for every activity defined which safety provisions should be taken. Most important ones are carrying not too much weight at once and the change on falling down of the roof.

The technical acceptance of construction works is not always directly sufficient. For some materials and methods like concrete, steel works and roof covering, are above-average skilled workers required and should construction works be well prepared and instructed to achieve a qualitative and structural strong result. Therefore are these difficult construction works developed into a work plan with simple, understandable guidelines for the contractor’s foreman, to realise the construction works easily and correctly on site.

All used materials are very adaptable to changed, not correct measured and delayed construction works. For every activity is in the work plan a maximal measurement deviation described, which can easily be fulfilled. Guidelines to achieve this are also described in the work plan sheets. Almost all building activities are planned serial and must be completed before other works may start, it also makes that when one activity delays the following one should wait. This can be done easily and doesn’t mix different activities with each other.

Service blocks can be realised by workers in slum areas and doesn’t require difficult equipment, large transportation or much area for construction works. Light weight building elements like sand-cement blocks and steel elements must be prefabricated at another fence work place or hanger which decreases the change on stealing and needed space on site. Pollution to the direct environment is limited when the site is cleaned regularly by workers. When construction works doesn’t start during the rainy season are climatic influences on construction works minimal. Designed compartment requires an area of 8.00 x 3.00m and shall fit on almost all acquired construction sites in a slum. Too link them is more space required in the length of a service block. When sites are smaller can independent compartments be placed opposite, perpendicular on or beside each other.

Most of the construction works and transportation takes place by hand and these works are mostly done with locally extracted and produced materials. Large equipment like trucks and cranes is unwanted and application of imported materials is restricted to a minimum. This stimulates the local employment and economy as much as possible.

Lifecycle costs for realisation of all main, internal construction works of only the building itself are for a single compartment with 6 cubicles 11400GH¢, and for a service block which exists of two linked compartments with 12 cubicles 19800GH¢. These costs are just 48% from the current proposed service blocks from Safi Sana (Ghana) Limited, and makes the final designed and developed compartments very cost effective.

Estimated construction time to realise a Safi Sana compartment is 90 working days, which is equal to around 4 months. Comparing to other construction projects around Accra is this short and well acceptable. There are some possibilities to shorten the construction time by hiring more construction workers which speed up the building activities.

The review shows that final design of a compartment with work plan is sufficient to all criteria and makes that all found problems are or could be solved by following the prescribed guidelines. This proves the quality and suitability of developed compartments during this graduation project and makes all plans very usable for realisation of Safi Sana service blocks in the slums of Accra, Ghana.
Image 5.8: Paint colours of all walls in a service block should be adapted to recognizable Safi Sana colours.
5.4 Recommendations

After presenting all conclusions of the final designed compartment and work plan, with a checking review on the defined criteria, are the following recommendations given for further research and development to improve the achieved results until now.

The extension of the database is limited to the investigated materials during stay of the author in Ghana. More research should fill up the database with new, alternative materials and methods. This can be possible by adding new materials or by combining different (basic) materials to locally produced, man-made materials that can compete with currently applied materials. Examples are composed blocks, lightweight roof tiles or other finishing materials. With help of the criteria must these alternatives be assessed and compared with the already used materials to define their suitability for a compartment. When appropriateness of materials is doubtful it can be tested one time in one cubicle.

Partial application of pozzolana cement instead of Portland cement to concrete and mortar mixtures should be extendedly tested to define their impact on the final structural quality, before using it in a final mixture.

Further building physics research and calculations should optimize the inside comfort, usability and energy usage of a service block.

Structural research and calculations should be accomplished to optimize the material dimensions and achieve a smart and economical use of materials to guarantee both strength and cost effectiveness.

Dimensions of compartments, heights of substructure and partition walls, width and length of cubicles are adaptable to requirements and specific wishes of the client. The same applies for the roof type and colour of paint which can be mixed to every desired colour, to give the service blocks a specific and recognizable Safi Sana appearance.

Architectural attention should be given to the facade with incorporation of design blocks and Safi Sana coloured paint that match the already designed compartments. On a way that the criterion ‘image building’ is better fulfilled and a more recognizable, distinguishable service block originates. These front and back elevations must also be shaded and protected by a sufficient roof overhang. The same applies for the toll point which must be combined with water kiosk and overhead drink water storage to one attractive, small construction that is recognizable for all users.

When design of a service block is completed and made definitive for a specific construction site should a work plan be made for all most important construction works. Already developed work plan sheets must form an example for this and should be further extended. The same procedure from concept to final work plan must be practised, whereby all analysed problems are solved at the end and fulfil the applied criteria.

The accomplished method during this graduation project from analysis, concept work plan to final work plan must become a standard in the execution Safi Sana service blocks by client and contractor. This means from a completed design to finally the work plan sheets for a specific construction site, with help of different analyses, diagrams, time schedules and bills of quantities.
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