# Lifecycle Engineering of Infrastructure: An Essential Approach to Engineering for a Sustainable Africa

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**Abstract.** Looking at African Development in comparison with other continents, it can be concluded that there are still so much to do to achieve comfortable standard of living for the majority of the inhabitants. While a lot of steps has been taken and appreciable progress has been made in many places, majority are yet to have access to stable and affordable basic necessities of life such as potable water, stable electricity and comfortable accommodation. This study examined various engineering approaches being used and those that could be used to make the enumerated basic necessities of life accessible to majority of Africans at affordable price. Our evaluation revealed appropriate lifecycle engineering as a feasible approach to achieving the desired goal. This research and its findings will assist Africans and other nations in understanding African infrastructure problems and how best to address the technical problems in a sustainable manner.

**Keywords**: Lifecycle Design, Lifecycle Management, Sustainable Africa, Sustainable Engineering, Sustainable Infrastructure, System's Lifecycle Extension

## 1. Introduction

The quest for improved standard of living in the African continent is enormous. The challenge is formidable and concerted effort being made to achieve the fit is strong and consistent. Progress has been made in various sectors of the economy, but the goal is yet to be achieved. A number of successes attained has been short lived by unexpected failure in some realms. The standard of living of a population is largely dependent on the strength/capacity of infrastructure asset that is in the place, effectiveness of its utilization and its maintenance [1], [2]. The infrastructural development in Africa has been heavily dependent on foreign help. The foreign help has been in terms of technology importation funded by loans and foreign aids. While foreign technology and its international diffusion is a well-recognized factor in the rapid industrialization of newly industrialized countries, it doesn't seem to yield similar result in Africa [3]. There are evidences that significant number of infrastructure technologies shipped to Africa were either based on outdated engineering technologies or technologies considered inferior to acceptable standard at the source. Many of the technologies are foreign to African culture and way of life. Consequently, they failed to achieve their intended purpose or the performances are short lived. There is therefore a need for a new approach to engineering African infrastructure in order to achieve sustainable development.

### 1.1 Objective of the study

The main goal of this study is the identification of viable solutions to the long standing infrastructure engineering problem in the Sub-Saharan Africa. It involves looking for the sustainable solution that would guarantee continuous growth and prosperity of the continent Africa.

### 1.2 Research Questions

The research addresses the following questions:

- What are the technical issues affecting African infrastructure?
- What are the available engineering approaches for infrastructure development?
- Which engineering approach is considered appropriate for solving African infrastructure problem and why?

## 2. Research Methodology

The methodology of the study involved thorough examination of the causes of the longstanding infrastructure problems in Africa as identified by notable scholars, policy makers and technocrats. The study of the causes of African infrastructure problems also involved personal experiences and observations over a long period of time. This was followed by the study of various infrastructure development approaches in the developed and other developing countries, identifying those that worked well and those that did not. It also involved a study of the current progression in engineering on approaches for sustainable infrastructure development. With these knowledges of causes of African infrastructure predicament and the best practices in infrastructure engineering, an engineering approach considered suitable for African infrastructure development now and into the future was proposed.

## 3. Findings on African Infrastructure Problems

Our study revealed that there are quite a number of technical and socio-economic issues affecting the development, availability, smooth operation and longevity of African infrastructure [4-9]. Quoting a number of UN reports, [5] gave a vivid picture of the state of African infrastructure and how it is affecting its economic development. He stated that "Africa's poor infrastructure is slowing its economic development. African countries need to promote industrial development to spur economic progress and reduce poverty. Africa's share of global manufacturing is drastically disproportionate to its population. While 15 percent of the world's population lives in Africa, only about one percent of global manufacturing takes place there. That is largely due to poor transport, communications and energy infrastructures." The following are some of the techno-economic issues identified in the course of the study.

### 3.1 Restricted customer access to service

Infrastructure is a capital intensive investment. Limitation in locally generated revenue by many African governments has made many of them to depend on loans and subsidies to fund currently available infrastructure. Most of the infrastructure for energy and water supplies and transportation in many African countries are only available to urban dwellers. Majority of the rural populace does not have access to them. This problem is affecting productivity and affecting standard of living of people. This problem would have to be overcome in order for Africans to achieve the sustainable development goals on eradication of poverty, clean water and economic growth [7].

### 3.2 Affordability issues

Majority of the agencies providing vital services such as energy, water, telecommunication and transportation are state owned. They are usually monopolies. Many of them are so large that their operations are sub-optimal. At the advent of privatization campaign, most of them were dismembered and privatized as independent organizations with public-private participation. As a result of their arms-length operation, their service rate was jacked up but unfortunately such increase has made them become unaffordability for the ordinary citizens.

### 3.3 Dissatisfactory customer service

Transportation, communication, energy and water services in many countries of Africa are characterised by what can be termed "epileptic and poor quality of service". The monopolistic nature of the various service agencies in African countries made them become very large and made many of them operate like government bureaucracy. Their services are essentially unreliable as they are "off and on" over time. For instance, some municipalities have electric power supply for 2 - 4 hours in a day while some receive such service every day, a number of the cities receive such service two or three days in a week while some other ones or part of a city may not even receive electricity service for weeks. During the period of availability, many households and businesses do experience power fluctuation between low voltage and high voltage which has caused significant damages to equipments and machinery. This has also reduced productivity and consequently affected the profitability of businesses. The same epileptic and poor service is experienced by many communities in the areas of water supply and other services.

### 3.4 Frequent breakdowns

Unavailability of services or epileptic nature of services rendered were as a result of frequent facility/equipment breakdown. Several reasons can be adduced to causing the breakdowns. The breakdowns arose from the differences in the service conditions of the technology originating country in comparison with the country of deployment. Many of the imported infrastructure technology were from Europe and North America which are essentiality temperate climate with the attendant soil and vegetation conditions compared to the mainly tropical African climate. In addition, cultural behaviour and attitude of the technology originating country are totally different from the recipient African countries. As a result, the normal care of the system which is a given in the originating country is totally absent in the recipient country.

In addition, the frequent breakdowns arose from inadequate maintenance of the facilities either because of the replacement parts unavailability, non-availability of needed fund to procure necessary parts or negligence on the part of facility management. Significant number of the infrastructure is in a state of disrepair and breakdown. Other reason for the frequent breakdown is lack of foresight on the part of the planners and other stakeholders in ensuring the localisation of repair and maintenance capacity building into the system development strategy.

## 4. Some of the utilizable engineering approaches to solving African systemic infrastructure problems

Over the years, engineers have developed various design approaches to engineering systems development. Most of the modern design approaches has many things in common except few differences that attempt to eliminate the lapses of the earlier ones and to incorporate new knowledge and developments in the field [10-12]. Many of them are called different names, probably due to differences in the sources of idea and premises from where they emerge. The following are some of the modern design approaches that could be adapted to solve the longstanding African infrastructure problems:

### 4.1 Concurrent Engineering

According to [13], “Concurrent engineering (CE) is an engineering management philosophy and a set of operating principles that guide a product development process through an accelerated successful completion.” It is also known as simultaneous engineering. It is an effective method for managing the development of complex systems; but it requires a set of analytic tools and procedures to operationalize its concepts. It involves the completion of all aspects of design process simultaneously. It promotes the incorporation of downstream concerns into the upstream phases of a development process. This would lead to shorter development times, improved product quality, and lower development– production costs. Concurrent engineering is accomplished through integration of people, processes, standards and tools. It involves bringing together cross-functional and multi-disciplinary teams representing various functional areas. These professionals are brought together to discuss integrating issues of functional design, manufacturing, quality control, customer service, and so other relevant matters [14].

### 4.2 Systems Engineering

According to [15], “System engineering is an interdisciplinary approach and means to enable the realization of successful systems that satisfies the customer and stakeholder's needs in a high quality, trustworthy, cost efficient and schedule compliant manner throughout a system's entire life cycle. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem.” A system is defined as a construct or collection of different elements that together produce results not obtainable by the elements alone. The elements, or parts, can include people, hardware, software, facilities, policies, and documents; that is, all things required to produce systems-level results. The results are defined in terms of system level qualities, properties, characteristics, functions, behavior and performance [16], [17].

### 4.3 Lifecycle engineering

Lifecycle engineering refers to the consideration of the entire lifecycle of a system right from the point of conception of the idea to the end-of-life management of the system. The necessity for lifecycle engineering of a system arose from the realization that a new industrial culture has to be developed [18]. The new industrial culture has to drastically reduce the amount of wastes generated, reduce environmental damage and occupational health damages. Furthermore, the new industrial culture would need to increasingly reduce its dependence on non-renewable resources while adding to the overall effective utilization of invested resources. Sustainable industrial production is the new industrial culture that is environmentally conscious, economically sound and socio-culturally compatible to the community of its utilization/deployment. According to [19], Lifecycle engineering seeks to maximize a product's contribution to society while minimizing its cost to the manufacturer, the user, and the environment.

Lifecycle Engineering involves project definition, project planning, project plan implementation, monitoring process, evaluation and adjustment, closing process, and commissioning/celebration. Lifecycle engineering is based on determining all aspects of the design for the entire life of the system. All the stages of the system's lifecycle are evaluated at the beginning of the design process. Lifecycle engineering takes start-up cost and ongoing cost into account. It also takes into account the market trend, reliability, system replacement timeline, and the system's end-of-life management.

## 5. The Future of African Infrastructure System

Paraphrasing Lord Henley's perception on the characteristics of today's infrastructure in [20], the current nature of our transport, communication and energy and water supplies infrastructure makes them vulnerable to the effects of climate change. The reason for the vulnerability arose from two fronts. Firstly, they were not designed with the consideration of potential impacts of these facilities on climate change. Secondly, they were not also designed with the consideration of possible impacts of climate change on their functionality/operations and longevity in mind. To mitigate the potential risk and to build a sustainable future for Africa infrastructural development, indigenous engineers and stakeholders in African development would need to come up with or adopt a customized collaborative engineering approach to infrastructure development. Considering all the aforementioned engineering design approaches, customized collaborative systemic lifecycle engineering approach to infrastructure development is recommended/proposed. It is adjudged the best approach to infrastructure development that could be adapted to African culture to ensure the sustainability of African infrastructure development. Adopting the approach would facilitate resource use optimization, capacity building, reduced cost of ownership, and result in minimal contribution to climate change [21].

## 6. Implementation Process for Collaborative Lifecycle Engineering of Infrastructure System

Figure 1 is an illustration of the proposed collaborative lifecycle engineering approach that could be customized to facilitate the achievement of the desired sustainable African infrastructure development goals. It is an improvement on/adaptation of collaborative lifecycle design-based rural technology development process model developed by [22]. The application of the lifecycle design based technology development model starts with the assemblage of coalition partners to identify needs. The coalition partners may include product developers, policy makers, voluntary organizations, members of rural community groups and other stakeholders. Needs identification could be in the form of new infrastructure needs in the area. The need could also be for re-designing or retrofitting of an existing infrastructure to improve its performance or to address specific problem of the system. The next step involves making arrangement for how the needs will be addressed. This could be achieved through policy formulation, and the consideration and assemblage/incorporation of various design components and features. This step is followed by generating conceptual designs and applying various environmentally friendly design concepts (DFXs) on the conceptual designs. DFX refers to design for X where X could be material (DFMt), modularity (DFMd), assembly (DFMA), manufacturability (DFMf), disassembly (DFD), maintainability (DFS), use and reuse (DFUR), upgradeability (DFUG), remanufacturability (DFRm), recyclability (DFR), energy efficiency (DFEE), packaging (DFP), multi-lifecycle (DFML), multi-purpose (DFMP), or minimum residue (DFMR) and so on. Each conceptual design is then evaluated in turn for environmental friendliness by using E-LCA and by doing enabling infrastructural availability analysis (EIAA). They are also subjected to socio-cultural compatibility assessment (SCA), risk assessment (RA) and economic assessments (LCC). Environmental lifecycle assessment method (E-LCA) is used to screen each conceptual design in terms of the technology's potential resource requirements, emissions and their possible impacts at each stage of the technology's lifecycle and over its entire lifecycle. The potential impacts considered include global warming, ozone depletion, eutrophication, eco-toxicology and human toxicology. The best conceptual design is the one that has the lowest overall environmental impact potential. Lifecycle costing (LCC) is similar to the E-LCA, except that it is used to analyze the technology cost at each stage of its lifecycle. This helps us to account for the true and total cost of the technology. Social lifecycle assessment (S-LCA) is also a lifecycle analysis approach. It is used to determine the socio-cultural impacts of the technology at each stage of its lifecycle. Here we account for how it will affect the way of life of people who develop, use and live/work in the neighbourhood where the technology is developed and deployed. Risk Assessment: This is the determination of the potential impact of an individual risk associated with each stage of the lifecycle. The focus of this assessment is on the development and utilization of the technology. The assessment is done by measuring the likelihood of occurrence and the potential magnitude of the impact if it occurs. Cost–Benefit Analysis is used to compare the net present values expected to be derived from development or retrofitting of the infrastructure. Furthermore, before the evaluation of each option of the infrastructure system being considered for development, a minimum acceptable performance level has to be set for each of the evaluations described above. Any or all options that fail to reach such performance threshold is discarded. Those that survive the screening process are ranked according to their overall performance at each stage and throughout their entire lifecycle. For instance, assuming the conceptual design option A, C and G (out of options A, B, ... , K) satisfied the minimum requirements, the three of them will be ranked. A computer model or prototype of the highest ranking conceptual design option (say Option A) will be developed. The computer model will be simulated and evaluated using the lifecycle evaluation tools earlier discussed. If the results obtained from the computer simulation evaluation are acceptable, a scaled-down size of the infrastructure prototype would be to assess the real-life performance of the system. If /when the performance model is deemed satisfactory and there is confidence that it would adequately serve the need of the consumers, the appropriate community scaled size of the model then built, tested and chargehands from the community of deployment are then trained on the system. The skills development for the chargehands would involve training for complete know-how in the areas of operation and maintenance; managerial skills and knowledge for generating and managing technical change. The capacity building on the infrastructure system would be best achieved not only through the training of local technicians in each of the aforementioned areas, but also by continuous monitoring of the system on site and interactions with the operators of the system throughout the system's lifecycle. Doing so would enable the developer to step in whenever necessary. It would also afford the developer and the users to learn crucial lessons for further development of the system. Furthermore, it would prevent the breakdown or inadequate performance of the system. Consequently, it will assure the longevity of the system's lifecycle thereby ensuring the sustainability of the infrastructure. Thus, collaborative lifecycle engineering would deliver a consistent standard of living that can be maintained indefinitely for the present and future generations. This would be achieved by its helping to reduce negative impacts on human health and the environment, and by reducing costs to business and the entire community. Another way by which the approach would provide benefits to businesses and the community at large is through infrastructure system's lifecycle extension as it provides opportunity for continuous innovation and improvements [23].

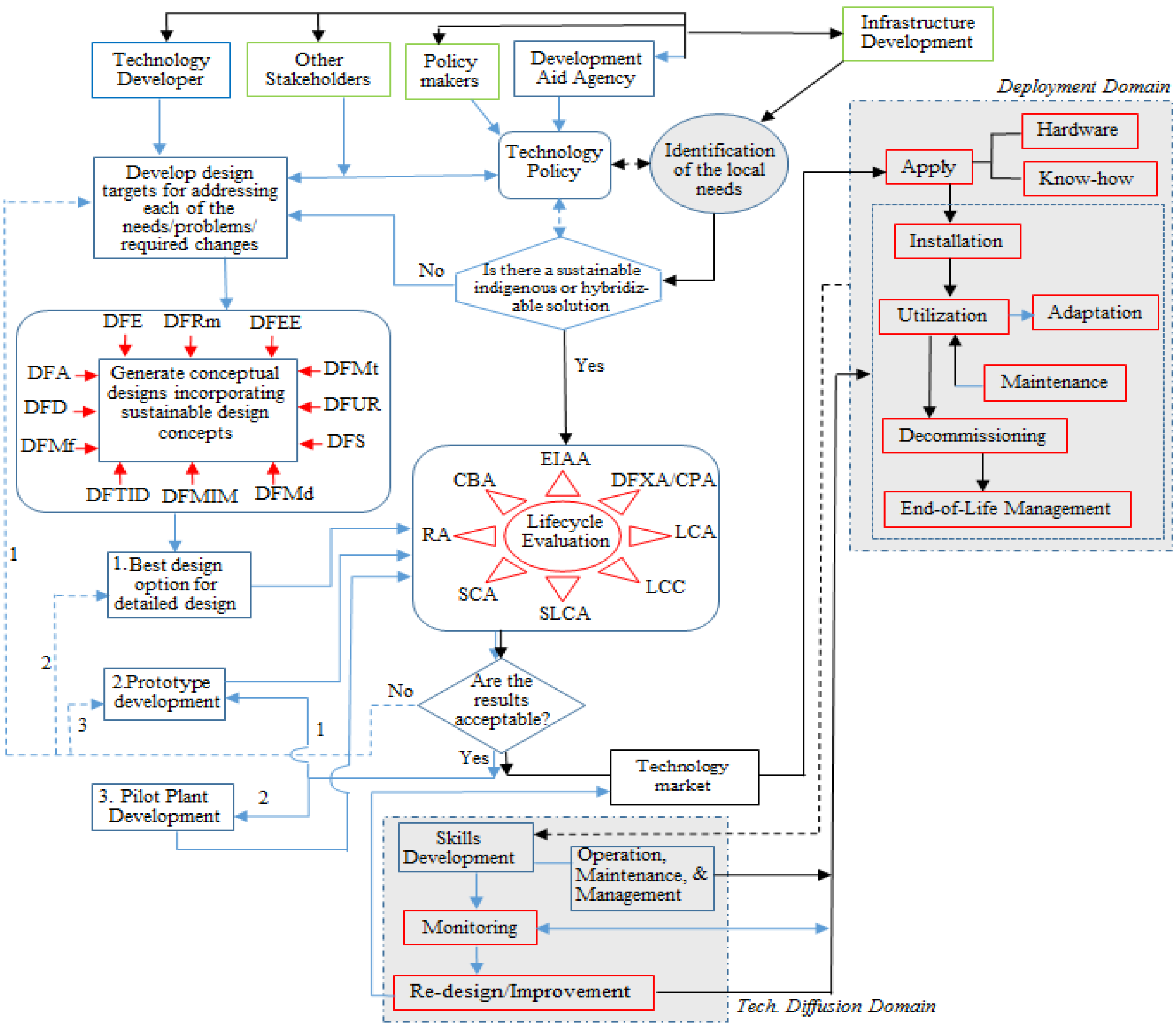


Figure 1 An Illustration of Collaborative Lifecycle Engineering Design Process for Sustainable Infrastructure Development

## 7. Conclusion

The current challenges being faced in the operational effectiveness of many infrastructures in Africa are attributable to a number of issues, some of which includes differences in climate and culture of the developers and the users of the technologies. The problem is expected to be exacerbated as the climate change due to incessant emission of greenhouse gases kicks in. There is therefore a need to prepare and implement design changes that would enable our infrastructures to adapt to the expected changes in our climatic conditions. African Engineers would need to come together and proactively meet the challenge of creating a climate resilient infrastructure system for Africa. This will reduce the risk of economic disruption to the continent and enable the opportunities from well-adapted infrastructure to be maximised. There is therefore a need for African engineers to rise up to our peculiar challenges by hybridizing the foreign infrastructure technology with our indigenous technology in designing, building and maintaining suitable infrastructure that are able to meet our current needs , consider future changes in our needs and that are able adapt to our culture and potential climate change in Africa. Collaborative lifecycle engineering is the engineering platform that would ensure sustainable development of African Infrastructure and assure their effective operation and utilization for our posterity.

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