INFRASTRUCTURE COST IMPLICATIONS OF URBAN FORMS IN DEVELOPING COUNTRIES: An analysis of development patterns in Ghana

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DEDICATION

This dissertation is dedicated to my family, especially my cherished wife, Abigail, and our dearest son, John Oduro Adaku.

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AMA	Accra Metropolitan Assembly
CAD	Computer-Aided Design
CBD	Central Business District
CEC	Commission of the European Communities (CEC)
CER	Cost Estimating Relationship
CNR	Connected Node Ratio
DPH	Dwellings per Hectare
EPA	Environmental Protection Agency
FDI	Foreign Direct Investment
GAMA	Greater Accra Metropolitan Area
GEMA	Ga East Municipal Assembly
GIS	Geographic Information System
GWMA	Ga West Municipal Assembly
kVA	Kilovolt Ampere
LNR	Link-Node Ratio
Mwc	Metre Water Column
NIMBY	Not In My Back Yard
PDF	Probability Distribution Function
POD	Pedestrian Oriented Development
RERC	Real Estate Research Corporation
ROW	Right of Way
SAP	Structural Adjustment Programme
TCRP	Transit Cooperative Research Program
TMA	Tema Municipal Assembly
UK	United Kingdom
US	United States
VMT	Vehicle Miles Travelled
WBS	Work Breakdown Structure

ABSTRACT

The interdependency or relationship between infrastructure costs and urban form has been an important issue in town and regional planning over the years. Debates have generated among practitioners and theorists for over three decades now as to which development is the most cost efficient. However, the conclusions are still fuzzy and not clear, partly, because both practitioners and theorists often deliberately or unintentionally gloss over the realistic impacts of alternative development patterns in their submissions. Interestingly, most planning authorities rarely know and consider the costs of alternative development patterns in their decision making process. Besides, studies on infrastructure costs efficiency of alternative developments have constantly focused on developed countries without any attention to developing countries. This study then sought to contribute to the debate from developing countries' perspective – using Ghana as the reference point – by analysing the effects of urban forms on infrastructure costs from both developing and developed countries' points of view; determining the urban form that is infrastructure costs efficient as well as recommending to planners and policy makers in developing countries, possible areas in the development process, where infrastructure costs could be reduced.

In approaching the study, both qualitative and quantitative methods were employed. The qualitative approach deals with the literature review of urban sprawl, particularly its general impacts and influence on the costs of infrastructure. Again, the phenomenon of urban sprawl is situated in the context of both developing and developed countries with differences and similarities of attributes in the different economic regions of the world ascertained. The literature review, further, focuses on how infrastructure costs relate to urban forms as well as analysing how the urban structures (with respect to social and spatial distributions) in both developing and developed countries affect infrastructure costs and financing. The conclusions of the literature review form the bedrock of the investigation and further reinforce the isolation of the effect of urban configuration on infrastructure costs. A graph theoretic tool, by means of AutoCAD, was employed for further isolation of the effect of urban configuration on infrastructure costs. Pattern classification – to delineate the primary urban patterns – coupled with agreement in literature on historical and current urban patterns gave rise to four hypothetical residential neighbourhood patterns – tributary, radial, grid and hybrid patterns.

The four hypothetical patterns held all other factors constant and isolated the effect of street patterns and density on the capital costs of roads, water and electricity distribution networks.

The study found out that, generally, the major factors that drive the current urban development patterns – urban sprawl – in developed countries have reached, relatively, higher levels of development in comparison with developing countries. Therefore, developed countries have higher urban dispersion potential and hence higher infrastructure costs vis-à-vis developing countries. The phenomenon also occasions a shift from intra-city to inter-city infrastructure costs concerns in the case of developed countries while in developing countries, emphasis is on intra-city infrastructure costs concerns with respect to urban forms. Again, the phenomenon of urban sprawl is perceived to be occasioned by market distortions and failures. The market distortions and failures leading to urban sprawl are deemed to be anchored in the cost-sharing scheme of infrastructure financing. Hence, the externalities and market failures associated with the cost-sharing scheme (which induces urban sprawl) could be dealt with so as to ensure more efficient urban forms through marginal costs pricing of infrastructure. The phenomenon of urban sprawl albeit evident in developing counties (particularly Ghana), does not fit exactly into the developed countries' scheme of urban sprawl – both in causes and impacts. Besides, the urban structures of both developing and developed countries are different and have different implications on the costs of infrastructure development and financing. The study also found out that there is a relationship between urban forms and infrastructure costs. However, the relationship is not a single relationship but rather a multiple one. The intrinsic purpose of these relationships, as claimed by studies in developed countries, is independent of the socio-economic situation of any particular region. Hence, this relationship is presumably applicable in developing countries as well. It has also been shown in this study that apart from density, lot size, lot shape, location and dispersion of developments, street pattern or configuration relates to and has influence on infrastructure costs, particularly network infrastructure.

In isolating the effect of street patterns on urban forms, the total capital costs of three infrastructure (roads, water and electricity distribution networks) revealed the tributary pattern as the most economical pattern in terms of the capital costs of linear infrastructure while the grid pattern is the least economical. The tributary pattern showed a 27% costs savings per dwelling over the costs of the grid pattern. The radial and hybrid patterns also indicated 9%

and 3% savings per dwelling, respectively, in comparison with the grid pattern. Clearly, the savings in capital costs of linear infrastructure by the tributary, radial and hybrid patterns in comparison with the grid pattern, largely, resulted from savings in water distribution and road networks. The study showed that – it appears – other factors such as demand, density and type of distribution system other than the configuration of the street pattern influence the costs of electricity distribution network significantly. The capital costs per dwelling showed a gradual rise in infrastructure cost as one moved from the pure tributary pattern towards the pure grid pattern. Besides, in isolating the effect of density on linear infrastructure costs, it was revealed that the capital costs per dwelling of linear infrastructure reduce sharply, initially, with increasing density and later reduce, marginally, with further increments in density. Again, a density from 13 DPH to 53 DPH means approximately a 300% increment in density. However, the corresponding decrease in capital costs per dwelling for linear infrastructure was about 68% across the alternative hypothetical residential patterns.

The general street pattern in Ghana is the cellular or grid type which is expensive in terms of linear infrastructure. Thus, since most developing countries (including Ghana) have fiscal challenges, urban configurations which reduce infrastructure costs and enhance revenues would be more appropriate. Thus, as shown by this study, the tributary pattern appears to fulfil this goal. However, the shortfall in accessibility – a key planning goal – could be augmented by a carefully designed network of footpaths. This measure fits well into Ghana or developing countries' scheme of transportation – slow mode or walking. Again, geometry seems to provide a tool to optimise the values of infrastructure costs minimisation and accessibility enhancement. The fused grid, a new residential neighbourhood layout, is a good example. See Grammenos et al. (2008) for more discussions on the fused grid model. Besides, the price of infrastructure comprises costs and profits. Hence, an approach like urban configuration which seeks to reduce the costs is not enough. Other factors or areas which also influence the price of infrastructure to the user should also be considered and their effects – preferably – minimised. Such areas are developer or client's costs, risks and contingencies related to the infrastructure development and profit margin of the construction contractor or developer.

Keywords: urban forms; infrastructure cost; street patterns; density; urban sprawl; developing countries; Ghana

ZUSAMMENFASSUNG

Die Interdependenzen zwischen Infrastrukturkosten und Stadtform sind seit Jahren ein wichtiges Thema in der Stadt- und Regionalplanung. Es wird seit über drei Dekaden darüber gestritten, welche Entwicklungformen die größte Kosteneffizienz aufweisen. Allerdings sind die Schlussfolgerungen noch unklar, weil Praktiker und Theoretiker oft dazu neigen, die realistischen Auswirkungen alternativer Entwicklungsmodelle absichtlich oder auch unabsichtlich nicht hinreichend zu berücksichtigen. Interessanterweise können nur wenige Planungsbehörden die Kosten alternativer Planungsmodelle einschätzen und diese bei ihrem Entscheidungsprozess abwägen. Darüber hinaus haben sich Studien über Infrastrukturkosteneffizienz von alternativen Entwicklungen von Städten hauptsächlich auf die Industrieländer bezogen und somit die Entwicklungsländer vernachlässigt. Diese Studie versucht, einen Beitrag zur Debatte aus der Perspektive der Entwicklungsländer zu leisten. Dabei wird das Land Ghana als Bezugsraum verwendet. Der Beitrag beinhaltet folgende Punkte:

- Analyse der Auswirkungen der Stadtform auf Infrastrukturkosten aus der Perspektive der Industrie- und Entwicklungsländer.
- Bestimmung der Stadtform, die infrastrukturkosteneffizient ist.
- Empfehlung an Planer und Entscheidungsträger in Entwicklungsländern über mögliche Bereiche, wo Infrastrukturkosten im Entwicklungsprozess reduziert werden könnten.

In dieser Studie werden sowohl qualitative als auch quantitative Methoden eingesetzt. Die qualitative Annäherung erfolgt über eine Auswertung der Literatur zu Urban Sprawl, insbesondere dessen allgemeine Auswirkung auf Infrastrukturkosten. Das Phänomen des Urban Sprawl wird hier auch im Kontext der Industrie- und Entwicklungsländer diskutiert. Dabei werden Gemeinsamkeiten und Unterschiede zwischen den unterschiedlichen wirtschaftlichen Regionen der Welt festgestellt. Des Weiteren verfolgt die Literaturauswertung das Verhältnis zwischen Infrastrukturkosten und Stadtformen und analysiert die Auswirkung von urbanen Strukturen und räumlichen Konfigurationen auf Infrastrukturkosten und deren Finanzierung in Industrie- und Entwicklungsländern. Die Schlussfolgerungen aus den Ergebnissen der Literaturauswertung bilden die Grundlage für die weiteren Arbeitsschritte und grenzen der Auswirkung von urbanen Konfigurationen auf Infrastrukturkosten ein. Das Hauptkonzept für die Abgrenzung der Auswirkung von urbanen Konfiguration auf Infrastrukturkosten wird mit einem graphentheoretischen Tool mit Hilfe

von AutoCAD umgesetzt. In Anlehnung an die Literatur wurden auf der Grundlage von historischen und gegenwärtigen Stadtmodellen modellhafte Siedlungsstrukturmuster bzw. Stadtgrundrisse klassifiziert. Es wurden vier hypothetische Modelle von Wohnsiedlungen erarbeitet: tributary (dt. Sackgassengrundriss), radial (dt. radialer Grundriss), grid (dt. Schachbrettmuster), und hybrid. Für diese vier hypothetischen Grundrissmodelle werden zunächst alle anderen Faktoren als konstant angenommen und die Auswirkung von Straßenmustern und Straßendichte auf die Kapitalkosten der Straßen-, und der Wasser- und Stromverteilungsnetzwerke isoliert.

Die Studie zeigt, dass -im Allgemeinen- die Faktoren, welche die gegenwärtigen Muster der urbanen Entwicklung beeinflussen, in den entwickelten Ländern eine relativ höhere Intensität erreicht haben als in den Entwicklungsländern. Daher haben Industrieländer im Vergleich zu Entwicklungsländern ein höheres Potential der Siedlungsdispersion und somit höhere Infrastrukturkosten. Dieses Phänomen verursacht in den Industrieländern eine Verschiebung von intra-städtischer zu inter-städtischer Infrastrukturkosten, während in Entwicklungsländern mehr Wert auf intra-städtische Infrastrukturkosten mit Bezug auf die Stadtform gelegt wird. Es wird vermutet, dass das Phänomen des Urban Sprawls durch Marktverzerrungen- und -versäumnisse verursacht wird. Zudem scheinen die Marktverzerrungen und -versäumnisse, die zum Urban Sprawl führen, im Kostenverteilungsschema der Infrastrukturfinanzierung verankert zu sein. Die externen Faktoren und die Marktversäumnisse, die mit dem Kostenverteilungsschema, das Urban Sprawl auslöst, verbunden sind, könnten beeinflusst werden, um effizientere Stadtgrundrisse durch eine Grenzkostenkalkulation von Infrastruktureinrichtungen sicherzustellen. Das Urban Sprawl Phänomen, in Entwicklungsländern, insbesondere Ghana, passt nicht genau in das Urbanisierungsschema der Industrieländer und zwar weder in den Ursachen noch in den Wirkungen. Außerdem unterscheiden sich die Stadtstrukturen in Industrie- und Entwicklungsländern und haben unterschiedliche Folgen für die Kosten der Infrastrukturentwicklung und deren Finanzierung. Die Studie zeigt auch, dass es einen Zusammenhang zwischen Stadtform und Infrastrukturkosten gibt. Jedoch ist dieser Zusammenhang keine einfache, sondern eine vielfache Relation. Studien in Industrieländern behaupten, dass die grundsätzlichen Zusammenhänge zwischen Einflussgrößen und Infrastrukturkosten von der sozial-wirtschaftlichen Lage einer Region unabhängig sind. Diese Aussage gilt vermutlich auch für Entwicklungsländer. In dieser Studie wird auch gezeigt, dass die Dichte, die

Grundstücksgröße, die Grundstücksform, die Lage und Ausdehnung von Entwicklungen sowie der Straßengrundriss einen Zusammenhang mit und eine Wirkung auf Infrastrukturkosten, insbesondere der Netzinfrastruktur, aufweisen.

Durch die Abgrenzung der Wirkung von Straßengrundrissen auf die Stadtform zeigt sich, dass im Hinblick auf die gesamten Kapitalkosten von drei linearen Infrastrukturarten (Straßen-, Wasser-, und Stromverteilungsnetzwerke) der Sackgassengrundriss das wirtschaftlichste und der Schachbrettgrundriss das am wenigsten wirtschaftliche Modell ist. Der Sackgassen-grundriss zeigt eine Kostenersparnis von 27% je Wohnstätte gegenüber dem Schachbrettgrundriss. Im Vergleich zum Schachbrettgrundriss weisen der radiale Grundriss und das Hybridmodell eine 9%ige bzw. 3%ige Kostenersparnis je Wohnstätte auf. Die Kapitalkostenersparnis der linearen Infrastruktur im Sackgassengrundriss, im radialen Grundriss und im Hybridmodell ist im Vergleich zum Schachbrettgrundriss insbesondere auf Ersparnisse bei der Wasserverteilung und im Straßennetzwerke zurückzuführen. Zudem zeigt die Studie, so scheint es, dass andere Faktoren wie beispielsweise Nachfrage, Dichte und Verteilungssystem die Kosten des Stromverteilungsnetzwerks stärker beeinflussen als der Straßengrundriss. Die Kapitalkosten je Wohnstätte zeigen eine allmähliche Kostensteigerung bei der Umstellung von reinem Sackgassengrundriss auf einen Schachbrettgrundriss. Bei der Abgrenzung der Wirkung von Dichte auf lineare Infrastrukturkosten wird festgestellt, dass sich die Kapitalkosten der linearen Infrastruktur je Wohnstätte reduzieren. Bei einer anfänglichen Erhöhung der Dichte ist die Reduktion stark und nimmt mit einer weiteren Erhöhung kontinuierlich ab. Eine Erhöhung der Dichte von 13 Wohnungen je Hektar (DPH) bis 53 DPH bedeutet ungefähr eine 300%ige Dichte-Steigerung. Jedoch beträgt die entsprechende Reduktion der Kapitalkosten je Wohnstätte für lineare Infrastruktur lediglich 68% bei den untersuchten hypothetischen Stadtgrundrissen.

Der allgemeine Stadtgrundriss in Ghana entspricht dem Schachbrettgrundriss, der mit Bezug auf lineare Infrastruktur sehr teuer ist. Da die meisten Entwicklungsländer (Ghana inklusive) finanzielle Schwierigkeiten haben, wären Stadtformen adäquater, die Infrastrukturkosten reduzieren und Einkünfte fördern. In diesem Sinne scheint der Sackgassengrundriss, wie diese Studie zeigt, dieses Ziel zu erreichen. Jedoch müssten auftretende Erreichbarkeitsdefizite – ein wichtiges Planungsziel - durch ein Netzwerk von Fußwegen ergänzt werden. Diese Maßnahme passt sehr gut zu dem Verkehrssystem von Ghana oder Entwicklungsländern, die durch langsame Verkehrsmittel oder zu Fuß gehen geprägt sind. Die Geometrie scheint ein

Werkzeug zur Optimierung der Werte von Infrastrukturkosten und Erreichbarkeit bereitzustellen. Das angepasste Schachbrettmuster, ein neues Wohnsiedlungsmodell, das den Sackgassengrundriss und den Schachbrettgrundriss kombiniert, ist ein gutes Beispiel. Eine ausgiebige Diskussion des angepassten Schachbrettgrundrisses findet man in Grammenos et al. (2008).

Der Preis von Infrastruktur umfasst sowohl Herstellungs- und Wartungskosten als auch Gewinne der Anbieter. Daher ist ein Ansatz wie die Anpassung des Straßengrundrisses, der allein die Erstellungskosten reduzieren soll, unzureichend. Andere Faktoren oder Bereiche, die den Infrastrukturpreis für den Verbraucher beeinflussen, sollten auch in Erwägung gezogen und in ihrer Wirkung verringert werden. Solche Faktoren oder Bereiche umfassen beispielsweise Entwicklerkosten, Risiko und Reserveaufschläge, sowie die Gewinnspanne der Auftragnehmer oder Projektentwickler.

Schlüsselwörter: Stadtform; Infrastrukturkosten; Straßengrundriss; Dichte; Urban Sprawl; Entwicklungsländer; Ghana.

1. INTRODUCTION

1.1 Motivation

The interdependency or relationship between infrastructure costs and urban form has been an important issue in town and regional planning over the years. Infrastructure are deemed to be the backbone of urban areas (Mitchel & Campbell, 2004). Clearly, the interdependency between infrastructure costs and urban forms warrants an influence of infrastructure demand, supply and costs by urban forms. Paraphrasing Winston Churchill, first we shape our cities; thereafter they shape us. Alluding to this assertion, as we shape our human settlements, they shape the associated infrastructure costs to our countries, regions, municipalities and neighbourhoods. All kinds of urban forms and neighbourhoods, whether planned as in developed countries or unplanned as it pertains in most developing countries, have significant infrastructure costs implications which have to be looked at critically, especially in most developing countries. The concerns of the influence of urban forms on infrastructure costs is usually captured under a broad study area termed *costs-of-sprawl*. The costs-of-sprawl debate intensified, in developed countries, after the seminal work of Real Estate Research Corporation (RERC) in the U.S. in 1974 under the title "The Costs of Sprawl". The study attempted to unveil the excessive costs associated with urban sprawl by summarising what is known about the various costs as they apply to different neighbourhood types and to different community development patterns. Again, in New Jersey and other locations in the U.S., Robert Burchell (See Burchell et al., 1998) related development density and housing types to the demand of local/state roads and sewer/water infrastructure. The study revealed that development density is inversely related to the lane-miles of the local and state roads and their attendant infrastructure costs. On the issue of density and infrastructure costs, Ladd (1992) argued that except within the range of very low densities, the per capita public services costs of infrastructure increase with higher densities. Ladd's research did not consider the quality and quantity of public services delivered in jurisdictions of varying densities, but the findings indicate that it appears public services costs per capita of infrastructure are less in low densities than in high densities.

The world's population is currently about 6.5 billion and it is predicted to hit 9.2 billion by 2050 with about 2.7 billion persons expected to be accommodated by developing countries

(United Nations' Department of Economic and Social Affairs, 2007). The expected population boom would be coupled with increased urbanisation. Therefore, developing countries, currently, planning new urban centres or yet to plan ones in the future to deal with this inevitable growth need to find ways of minimising infrastructure costs to development patterns.

Incidentally, the dynamics of urban forms in developing countries – currently – appear to be different from the dynamics in developed countries. The former is usually dense and centralised, normally expanding outwards from already established urban areas while the latter is normally more fragmented and sparse (Leao, Bishop, & Evans, 2004). According to Chin (2002), there are four patterns with regard to urban transition or development. The first phase is the fastest growing of the core city, termed urbanisation. The second phase is suburbanisation with fastest growth just outside the city core. The third phase is counter urbanisation with population at the city core and the suburbs moving out to more rural areas. The final and fourth phase is re-urbanisation with an increase in population at the core of the city. Chin (2002) and Leao, Bishop, & Evans (2004) indicate that the phenomenon of urban sprawl experienced in developed countries would better fit into the third phase of urban transition or development. Furthermore, Leao, Bishop, & Evans (2004) posit that the current urban processes in urban areas in developing countries, however, would better fit into the second phase of the urban transition or development due to their limited mobility and lower standard of living.

In addition to the limited mobility and lower standard of living as posited by Leao, Bishop, & Evans (2004), one of the reasons why the urban development in developing countries would fit into the second phase of the urban transition is the primate city phenomenon. The historical and current reinforcements of primate city phenomenon in developing countries discourage developments that are fragmented and very remote from already consolidated urban areas. This leads to urban growth or developments just spilling over to areas close to already consolidated areas in an accretion manner. The consequence is an unlimited outward expansion of cities and towns in developing countries, a major characteristic of urban sprawl. Major cities in Ghana like many other cities in developing countries are fast spreading out in a sprawl-like manner with emphasis on low density continuous development, warranting great concerns for infrastructure costs. Unlike some developing countries in Asia with high density developments, the outward expansion of developments in Ghana is relatively low density and residential based. For instance, from 1990 to 2005, the population density of Accra – administrative capital of Ghana – declined from 14,000 persons per square kilometre to 8,000 persons per square kilometre (World Bank, 2007). The relatively low density residential developments are, partly, informed by a mixture of growth in economic welfare of households and cultural values. The growth in the economic welfare of households provides the catalyst for households to leave the smaller traditional compound houses for bigger owner-occupied homes. This phenomenon feeding into the relative aversion of high rise buildings by Ghanaians – partly – leads to low density developments.

A consideration of the nature of current urban developments in developing countries vis-a-vis developments in developed countries, particularly urban sprawl, weakens the emphasis on location, remoteness and homogeneity in the case of developing countries and accentuates the concerns for configuration with regard to infrastructure costs efficiency. Hence, in analysing the influence of urban forms on infrastructure costs in the context of developing countries, there is therefore a need to shift from inter-city infrastructure costs concerns to intra-city infrastructure costs concerns. In that vein, the relevance of urban configuration in ensuring infrastructure costs efficiency cannot be discounted. Conventionally, urban configuration with respect to street patterns indicates an association between urban sprawl and tributary or cul-de-sac street networks. However, it could be argued that there is no scientific relationship between urban sprawl and anyone particular street pattern. A development configured to have a grid or radial street pattern could still assume the status of urban sprawl, depending on the density level. In reality, urban sprawl as related to density is relative as what is perceived as an acceptable density level varies from place to place around the world. Hence, at a local or regional level, urban sprawl is incident when a development achieves a density level below the locally or regionally prescribed or acceptable density level (Burchell et al., 1998). Therefore, in confronting the negative impacts of urban sprawl (particularly its infrastructure cost burden) in a more objective way, density alone may not provide the best solution. Another urban feature such as street pattern or configuration also provides a useful tool in dealing with the infrastructure costs concerns of urban sprawl.

The general phenomenon with respect to the development process necessitates an optimisation between urban forms and infrastructure costs, particularly for developing countries. Infrastructure involves the formation and improvements of capital which is usually necessitated by growth encompassing roads, sewers, water supply among other facilities (Burchell & Mukherji, 2003) and by their nature are cost intensive which should warrant an inclusion into the main criteria for determining urban forms by all planners and policy makers. However, a research conducted for the Department of the Environment in U.K. by Breheny, Gent, & Lock (1993), revealed that most planning authorities, in general, have no information about the relative cost of alternative developments, and have been found to be almost uninterested in that matter. Furthermore, the research in determining criteria for assessing the most cost effective development pattern omitted the costs of infrastructure. This was because, with the exception of highways and railways, usually the providers are private developers and their charges are reflected in the prices of their products which are recovered through the prices the customers pay for the land. This situation may not be different in most developed countries but, more often than not, in developing countries infrastructure are provided by parastatals which make them necessary to be considered in alternative development patterns by planning authorities and policy makers. In Ghana, the government through the Lands Commission Secretariat regulates the functions of state, stool/skin (traditional authorities) and family lands. However, the responsibility of servicing the land with infrastructure lies with the parastatals involved in infrastructure provision. Unfortunately, there is no proper collaboration between the state agency in charge of land regulation and the parastatals involved in infrastructure provision. The consequences are development patterns which are inefficient in infrastructure costs.

The infrastructure costs implications of urban forms which are usually relegated to the background by planners and policy makers, especially in most developing countries, have not only realised developments with no or adequate infrastructure, but also realised very expensive infrastructure in most urban areas. In most developing countries, where poverty is a bane, these expensive infrastructure have stifled the supply of infrastructure and reduced the infrastructure accessibility of most households thereby reducing their welfare generally. This study premising on the peculiarity of the urban development in developing countries (urban accretion), considers urban configuration in ensuring infrastructure costs efficiency to development patterns. By configuration, the study emphasises street patterns and density as the cost drivers. Street pattern as a main cost driver is with the backdrop that, generally, linear infrastructure which are the focus of this study are related to the street pattern. Clearly, efforts targeted at the spatial configuration of the urbanscape in developing countries to reduce the infrastructure costs will not only alleviate the infrastructure accessibility problem, but will also enhance the welfare of the people. Modelling hypothetical patterns and using data from Ghana isolate the influence of street patterns and density on infrastructure costs.

1.3 Aim and objectives

The aim of this research is to analyse the effects of urban forms on infrastructure costs as a decision support for planners and policy makers in developing countries. In achieving the aim, the following objectives are required;

- To review the general characteristics and impacts of urban sprawl as a development pattern: Focus is put on the introduction and detail discussion of the phenomenon of urban sprawl which characterises current developments globally.
- To determine the relationship between urban forms and infrastructure costs: Attention is given to specific urban features that influence or relate to infrastructure costs by reviewing literature while identifying differences or similarities of the relationship from the points of view of both developing and developed countries.
- To ascertain the least cost development pattern: Emphasis with this objective is on modelling hypothetical development patterns with street patterns and density as costs drivers to reveal infrastructure costs efficiency vis-à-vis urban forms.
- To recommend areas where developing countries can reduce infrastructure costs in the development process: This objective seeks to point out elements which influence the price of infrastructure to consumers and how to ensure a systemic minimisation of the overall price of infrastructure.

1.4 Scope of research

The study is geared towards developing countries with particular reference to Ghana, a West African country. This study considers only infrastructure at the neighbourhood or subdivision level. A residential land use type is considered for the analysis. Due to lack of data of sufficient quality in Ghana, a hypothetical approach is used in this study. The infrastructure considered under this study are the network infrastructure - water, electricity and road - as their costs are deemed to be spatial development pattern sensitive. In the cases of water and electricity infrastructure, only the conveyance aspects are considered, excluding the supply components. The supply components are deemed to be point infrastructure and are not influenced by street pattern which is considered as the main cost driver in this study. It is noted that only the capital costs of infrastructure, without the maintenance costs, are being considered in this study as the capital costs of the infrastructure under consideration (linear infrastructure) connote the maintenance costs. Again, the costs of externalities for the alternative development patterns are omitted since the maintenance costs are already not considered in this study. However, a discussion on externalities as they relate to existing development patterns and their attendant infrastructure provision schemes is made and a possible internalisation measure proffered to ensure a relatively balanced submission on the costs-of-sprawl debate.

The water infrastructure excludes water storage tanks since its cost is less sensitive to street patterns. The water usage per capita in Ghana is considered to be 50 litres per person per day (Adombire, 2007). Overhead lines distribution system is considered for electricity distribution due to its relative cheapness. Again, it is selected with the background that most developing countries, mainly, employ this system for electricity distribution. The electricity load demand of each household is estimated to be 4.0kVA. See Appendix B for load demand details. The roads are, typically, residential roads. The quality of the road is a bituminous surface treatment (surface dressed) type. A 13m right of way is assumed with 1.5m walkways on both sides of an 8m width carriageway within the residential neighbourhoods.

1.5 Methodology

The approach to this study is mixed – qualitative and quantitative methods. See the framework of the study in Figure 1.1. The qualitative approach deals with the literature review of urban sprawl, particularly its characteristics, general impacts and influence on the costs of infrastructure. Again, the phenomenon of urban sprawl is situated in the context of both developing and developed countries with differences and similarities of attributes in both economic regions of the world ascertained. The literature review, further, focuses on how infrastructure costs relate to urban forms as well as analysing how the urban structures or spatial configurations in both developing and developed countries affect infrastructure costs and financing. The conclusions of the literature review form the bedrock of the investigation and further reinforce the isolation of the effect of street pattern and density on infrastructure costs.

The quantitative approach employs a graph theoretic tool in isolating the effect of urban configuration on infrastructure costs. In employing the graph theoretic tool, pattern classification was done to delineate the primary patterns of urban development. The pattern classification coupled with agreement in literature on historical and current urban patterns led to four hypothetical neighbourhood patterns. Besides, quantitative and presentational devices were employed to characterise the urban patterns in Ghana to ascertain their appropriateness with regard to infrastructure costs in order to recommend policy direction. Due to lack or incomplete data in Ghana, the Greater Accra Metropolitan Area (GAMA) was chosen as representative of Ghana. The isolation of the effect of urban forms on infrastructure costs was carried out by estimating and analysing the capital costs of providing water, electricity and road infrastructure to the four hypothetical neighbourhood patterns. Each hypothetical neighbourhood pattern with a total area of $1.1km^2$ settles at least 5,000 inhabitants, the minimum threshold for a community to be considered urban in Ghana. A household size of 5 persons, an average household size in Ghana (Ghana Statistical Service, 2001), was assumed. The lot size was assumed to be 30m x 25m (100ft x 80ft), reflecting an average lot size in Ghana. The four hypothetical patterns were considered on flat topographies and static in development for simplicity of analysis.

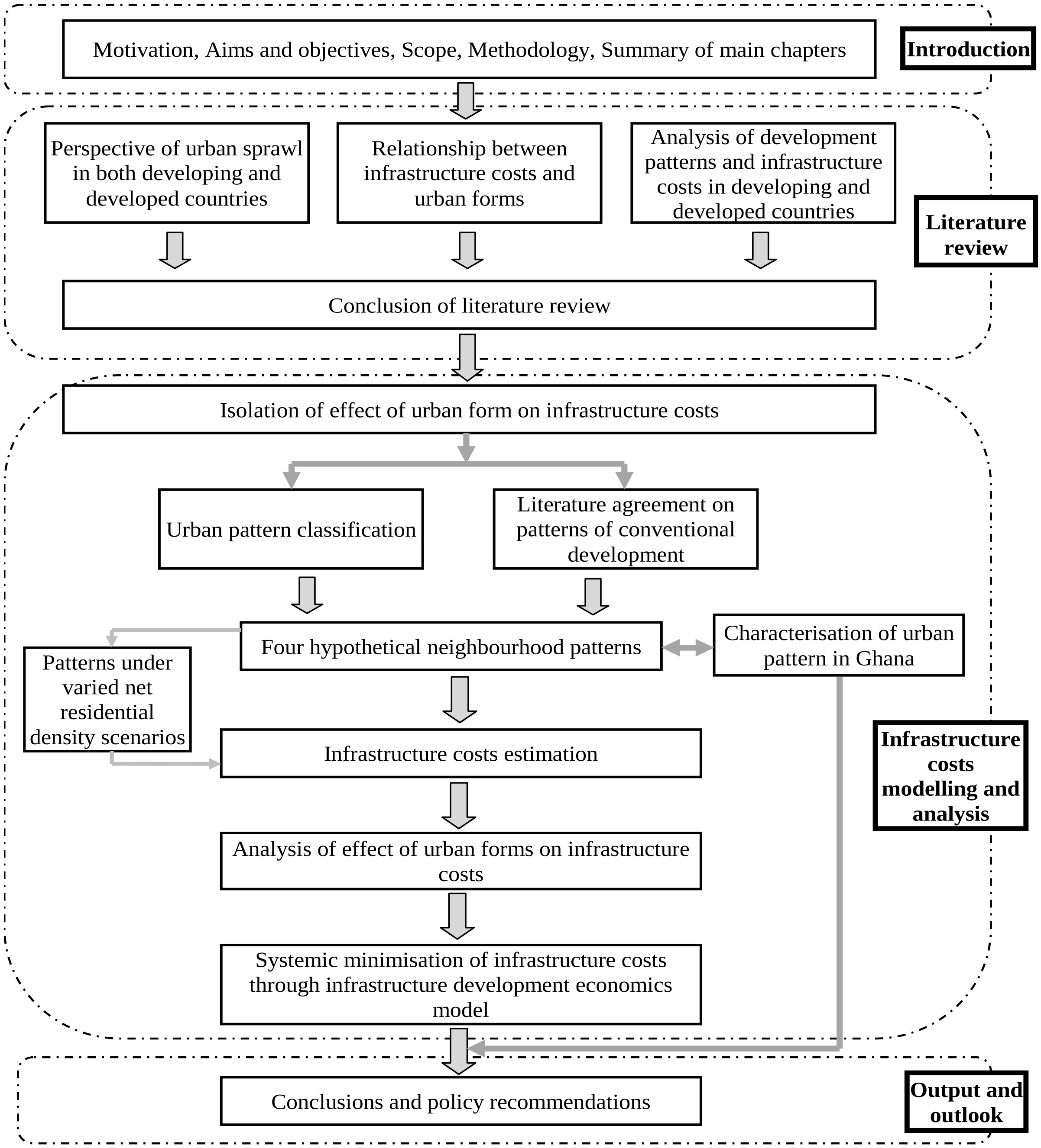


Figure 1.1 Framework of Study

The four hypothetical neighbourhood patterns holds all other factors constant and isolate the effect of street patterns and density on infrastructure costs. The capital costs of water, electricity and roads for each hypothetical development pattern were estimated using EPANET 2.0 and a spread sheet cost model, respectively. Unit costs data of water, electricity and road infrastructure in Ghana were obtained from state institutions in charge of the provision of the respective infrastructure under consideration. The unit costs data were based on 2011 construction cost in Ghana. The quantities of deliverables of each infrastructure type together with the respective unit costs were computed for each hypothetical neighbourhood pattern to determine the total direct costs. Indirect costs, client's costs and other price escalation factors were estimated to determine the total project costs for each infrastructure under consideration. See Figure 6.18 for the costs estimation structure. In ensuring, a systemic minimisation of infrastructure costs to developments patterns in Ghana and other developing countries, an infrastructure development economics model is being proposed, recommendation are made and policy directions given.

1.6 Summary of main chapters

The study is divided into seven main chapters as follows;

- *Chapter one:* The chapter one of this study deals with the introduction of the study, spelling out the motivation, the aim and objectives, the scope and methodology of the study.
- *Chapter two:* Chapter two deals with urban sprawl in perspective: This chapter commences with definitions and discussions of some terms as they relate to this study. Again, this section discusses the general characteristics, geometric patterns and drivers of urban sprawl which, currently, dominates development patterns in both developing and developed countries. The impacts of urban sprawl, with special emphasis on its benefits to households and general costs to infrastructure, are presented in this chapter. Furthermore, the externalities of alternative urban forms, which are perceived to be anchored in the current scheme of urban infrastructure financing, are discussed.
- *Chapter three:* Chapter three looks at urban sprawl: A view from developing and developed countries: By this chapter, an analysis is made of the dynamics of the phenomenon of urban sprawl as it pertains in developing and developed countries. The focus is on the Ghanaian and the United States versions of urban sprawl with an assessment of the level of departure of the Ghanaian version of urban sprawl from the version in the United States. Besides, since most costs-of-sprawl studies are done in developed countries, this section attempts to probe into the transferability of the results of costs-of-sprawl studies to developing countries.

- *Chapter four:* Chapter four looks at infrastructure costs of urban forms: An analysis of developing and developed countries: This chapter presents a picture of the urban structures, especially the socio-spatial structures, in both developing and developed countries and how they influence infrastructure costs and financing in the different economics regions of the world.
- *Chapter five:* Chapter five deals with capital and services costs of infrastructure and urban forms: This section describes the variability of infrastructure costs vis-a-vis urban forms. Major determinants of infrastructure costs are discussed. An evaluation of prominent costs-of-sprawl studies to ascertain the stand of the previous studies concludes this chapter.
- *Chapter six:* Chapter six deals with the search for an efficient urban form in Ghana: Premising on configuration to ensure infrastructure costs efficiency to development patterns, this chapter undertakes urban pattern classification to reveal the basic urban patterns with regard to street pattern as a basis for infrastructure costs modelling. Again, the chapter ascertains the appropriateness of the urban patterns in Ghana with regard to infrastructure costs efficiency by characterising the street patterns through the demonstration of simple quantitative parameters and presentational devices. A modelling of infrastructure costs to four hypothetical alternative development patterns with main assumptions situated in the Ghanaian context and an efficiency analysis of the development process with particular reference to developing countries end this chapter.
- *Chapter seven:* Chapter seven considers the conclusions and outlook of the study: This chapter gives an overview of the findings of the impacts of urban forms and their implications on infrastructure costs. Again, how the study contributes to knowledge, the limitations of the study, recommendations for future research and finally the relevance of the study to policy are presented in this section.

2. URBAN SPRAWL IN PERSPECTIVE

The study under consideration deals with the influence of infrastructure costs by urban forms. The recent urban transitions or developments in both developing and developed countries reveal the phenomenon of urban sprawl, particularly Ghana. Though the dynamics of this phenomenon (urban sprawl) indicate some points of departure in both developing and developed countries, which is the main focus of the next chapter, its influence on infrastructure costs is significant. This chapter then provides definitions of some terms as they relate to this study. Again, the phenomenon of urban sprawl, as it is perceived internationally, is widely discussed by looking at its characteristics, geometric patterns, drivers or catalysts and impacts with emphasis on benefits to households and costs to infrastructure. A discussion on the externalities of alternative urban forms, which are perceived to be anchored in the current scheme of urban infrastructure financing, concludes this chapter. The discussion of the phenomenon of urban sprawl and associated externalities, in addition to costs-of-sprawl studies, will better inform policy and decision makers in coming out with policies and measures to deal with its negative impacts – especially – in developing countries.

2.1 Definitions and introduction

2.1.1 Urban

The definition of the term urban in town and regional planning is somehow fuzzy and varies across many regions and cultures. However, in basic terms, an urban area is a geographical area constituting a town or a city. To understand better what is termed urban and to deal with the complexities associated with its interpretation in different parts of the world, a general approach is required. Pacione (2009) points out that the term urban should be seen as a physical entity as well as a quality. The urban as physical entity, which is the objective aspect of defining what is urban, is characterised or measured by the population size, economic base, administrative criteria and functional definition. The measurement of these criteria varies from country to country. On the other hand, the quality dimension of what is urban deals with cognitive or subjective aspect of people. Different groups of people have different conceptions or perceptions about what is an urban area.

2.1.2 Urban structure

Urban structure deals with the characterisation of the configuration of spatial distributions. It is the two-dimensional organisation of the ground plan of an urban area reflecting in the street patterns or the structure of the land parcels (Marshall, 2005a). Urban structure has both physical and socio-economic dimensions. However, with regard to the physical dimension which is the focus of discussion, urban structure considers the arrangement of urban public and private spaces and how they ensure accessibility and promote urban activities.

2.1.3 Settlement form

A settlement form is usually more specific than urban form in connoting the form of discrete units of settlement such as cities, towns and villages. In contrast, urban form could refer to any portion of urbanity, whether constituting part of a city, town or other urban accretion (Marshall, 2005a).

2.1.4 Built form

The built form refers more to the artificial features or environment of the urban area. It implies the three dimensional description of the urban area.

2.1.5 Development pattern

A development pattern refers to the layout of an urban area in conscious formations (Marshall, 2005a). Furthermore, a development pattern implies a pre-meditation or a conception of spatial development. In this case accretions (in terms of housing, transportation extensions and all other physical developments) to already established urban areas are borne out of a normative plan. This notion is in contrast with unplanned developments, which over time aggregate to form settlement units.

2.1.6 Urban form

The term urban form is the most all-encompassing of the terms related to spatial configurations, implying both the two and three dimensional aspects of an urban area from a courtyard to a conurbation (Marshall, 2005a). However, Marshall (2005a) further argues that on a much wider scale, an urban area approximates to a two-dimensional surface, akin to an image on a map. Hence, an urban form generally refers to the layout and design of physical features, influencing the overall size or shape of a city or a town. What defines the physical features as referred to in the definition of urban form are natural features, transportation corridors, open spaces, public and private facilities, landmarks and activity centres. Decisions on the provisions of these physical features, especially the built ones, influence the urban form significantly.

2.1.7 Density

Density in spatial development is the ratio of a unit to a given land area. The variability of what is considered under both the numerator and denominator makes density a versatile and a confusing term in spatial development. The numerator could be a population or dwelling units leading to population or dwelling units densities respectively. What is usually the source of confusion is the value or land area considered for the denominator - whether net or gross value. The net density, for example a residential density, only considers the residential area and excludes other areas or land-uses such as schools, opens spaces, roads and other facilities while the gross density considers all areas and land-uses. Gross densities provide values that are merely reduced and meaningless as there is no way of measuring the other uses (Jenks & Dempsey, 2005). Admitting the difficulties in standardising densities, it is still obvious that densities influence the intensity of land-uses, determine the townscape and affect the size and shape of an urban area. Again, appropriateness of the social, economic and environmental diversities in urban areas is measured by density.

2.2 Urban sprawl

2.2.1 Characteristics of urban sprawl

The term *urban sprawl* is quite not straight forward to define as most researchers attempt to give certain characteristics of it. Urban sprawl is more often than not discussed without any associated definition (Bhatta, 2010; Malpezzi & Guo, 2001). Jaeger et al. (2010) assert that there is considerable debate and confusion about the exact definition of urban sprawl which, eventually, hinders agreement on its measurement. They believe the confusion about the definition of urban sprawl is as a result of mixing causes and consequences of urban sprawl in its description. Most researchers, especially opponents of sprawl, usually use it pejoratively to describe urban development patterns which are seen as undesirable (Knaap, Talen, & Olshansky, 2000). In literature, sprawl is often defined by some researchers as a kind of low density, spatially extensive pattern of development that has become dominant in current development patterns for at least four decades now (Fulton, et al., 2001; Glaeser & Kahn, 2004; Bruegmann, 2005; Úlfarsson & Carruthers, 2006). Excessive spatial growth of cities, sometimes, can be taken as sprawl (Brueckner, 2000). This reference of sprawl still boils down to low density, rate of spatial growth far exceeding rate of population growth, as a feature of sprawl. While some researchers attempt to define sprawl in simple terms and statements, others try to define sprawl by giving some general attributes of it. For instance Ewing et al. (2002) define sprawl as low density development with residential, shopping and office areas that are strictly fragmented; a lack of thriving activity centres; and limited choices in travel routes. Furthermore, Burchell & Mukherji, (2003) define sprawl as low density, leapfrog development attributed with strip form along major thoroughfares and tributaries at the periphery of a metropolitan area. Again they see sprawl as any development, residential or non-residential, that takes place in a relatively pristine environment.

In an attempt to decouple the causes and consequences of urban sprawl from its definition as seen from some of the definitions above, Jaeger et al. (2010) focusing on the landscape pattern define urban sprawl as:

"*Urban sprawl is a phenomenon that can be visually perceived in the landscape. The more heavily permeated a landscape by buildings, the more sprawled the landscape. Urban sprawl therefore denotes the extent of the area that is built up and its dispersion in the landscape. The more area built over and the more dispersed the buildings, the higher the degree of urban sprawl. The term ''urban sprawl'' can be used to describe both a state (the degree of sprawl in a landscape) as well as a process (increasing sprawl in a landscape).*"

An overview of the characteristics used to identify sprawl (See Table 2.1) could be categorised into three major aspects: configuration, land-use composition and governance and economy.

Table 2.1 Aspects and Characteristics of Urban Sprawl

Sprawl Aspects	Sprawl Characteristics
Configuration	Low density development
	Striped development
	Scattered or leapfrog development
	Unlimited outward expansion
Land-use composition and governance	Fragmented and homogeneous land use pattern
	Fragmentation and multiple governance over land-use
	Automobile dependent transportation
Economy	Resource-consumptive development
	Significant variances in fiscal capacities of local governments

There have been attempts by some researchers (Torrens & Alberti, 2000; Frenkel & Ashkenazi, 2008; Torrens, 2008; Wissen Hayek, Jaeger, Schwick, Jarne, & Schuler, 2010; Jaeger, Bertiller, Schwick, & Kienast, 2010; Siedentop & Fina, 2010) to measure urban sprawl. The authors proposed various dimensions in the measurement of sprawl. The differences in the choice of dimensions among the different authors are partly due to the unclear opinions and disagreements on how sprawl manifests. Torrens (2008) puts forward some common dimensions of urban sprawl (See Table 2.2) which are representative of all descriptions given about sprawl in literature. These form the bedrock for sprawl to be identified and described qualitatively or measured quantitatively.

One of the fundamental defining characteristics of sprawl is low density (Burchell et al., 1998). However, density is perceived differently with regard to cultural, religious and geographical backgrounds across the globe. For instance, urban densities are known to be highest in Asia, high in Europe, North Africa and Middle East, low in Latin America and Sub-Saharan Africa and lowest in North America and Australia (Acioly & Davidson, 1996).

Table 2.2 The Dimensions of Urban Sprawl in Urban Studies Literature

Source	Dimensions									
	Growth	**Social**	**Aesthetic**	**Decentralisation**	**Accessibility**	**Density**	**Open Space**	**Dynamics**	**Costs**	**Benefits**
Audirac et al. (1990)	X									
Bae and Richardson (1994)						X				
Benfield et al. (1999)									X	
Burchell et al. (1998)	X		X		X	X			X	
Calthorpe et al.(2001)			X							
Clapham Jr. (2003)							X			
Duany et al. (2000)			X							
El Nasser and Overburg (2001)										
Ewing (1997)		X		X	X	X	X	X	X	
Ewing et al. (2002)		X		X	X	X	X	X	X	
Farley and Frey (1994)		X								
Galster (1991)		X				X				
Galster et al. (2001)	X			X						
Gordon and Richardson (1997a)						X		X		X
Gordon and Richardson (1997b)						X		X		X
Hasse and Lathrop (2003a)							X			
Hasse and Lathrop (2003b)			X	X	X					
Hasse (2004)				X						
HUD (1999)				X						
James Duncan et al (1989)									X	
Lang (2003)						X				
Ledermann (1967)						X				
Lessinger (1962)				X						
Malpezzi (1999)					X					
OTA (1995)				X						
Peiser (1989)						X				
Pendall (1999)						X				
Real Estate Research Corporation (1973)						X			X	
Sierra Club (1998)					X					
Sudhira et al. (2003)							X			
Ding (2009)				X						
Jaeger et al. (2010)				X		X	X	X		

Source: Adapted from Torrens (2008)

The TCRP report by Burchell et al. in 1998 on "the costs of sprawl – revisited", indicates that sprawl is not necessarily a development at less-than maximum density as the notion has always been; rather, it is a development that, given national and regional framework, is at a low relative density, and moreover somehow costly to maintain.

Low density developments are synonymous with sprawl, globally. Again, coupled with the phenomenon of low density is the dimension of location in characterising or defining sprawl. Most previous works, in their attempts to define sprawl, put much emphasis on its low density and outlying characteristics. However, some outlying or fringe developments on some continents have taken place in high densities because of high-rise housing blocks that are close to each other (Neuman, 2005). In general, where one draws a line between sprawl and other related forms of development may be contended unless the specification is firstly quantifiable and secondly related to impacts. It is widely acceptable that, it is the impacts of a particular development that render it undesirable and not necessarily the patterns themselves (Ewing, 1997). Many a time sprawl is maligned by some academics, planners and policymakers but the truth is, sprawl is directly associated with urban growth (Batty, Besussi, & Chin, 2003) and as cities grow, especially in population, which is a major challenge for most developing countries now, it will be impossible and difficult to accommodate all the growth in the inner city. The question then is, should sprawl be seen as a pejorative development pattern as perceived by many stakeholders? The key emphasis should be on the impacts of sprawl and how they could be mitigated rather than calling for a complete ban on it.

2.2.2 Geometric patterns of sprawl

There has always been the temptation among planners, policy makers and academics to consider various urban forms under sprawl. This has made the understanding of the term somehow fuzzy. A proper distinction between the various types of sprawl is very necessary as each type has its own drivers, characteristics and impacts (Chin, 2002). The current stage of knowledge as to which development pattern is more desirable appears still to be inconclusive, partly because of the lack of proper distinction which eventually manifests in improper costs and benefits analysis of the various urban forms. Furthermore, policies to arrest sprawl as discussed in literature extensively may not prove to be useful, if what underline sprawl - drivers, characteristics and impacts - are not well distinguished. Compact growths surrounding a few smaller centres which are located a distance from the downtown is sometimes classified as sprawl (Clawson & Hall, 1973). This is somehow confusing as superficially, it is similar to the poly-nucleated development pattern otherwise called concentrated decentralisation, usually not referred to as sprawl where the downtown serves the few distant centres (Chin, 2002).

Some researchers consider time as a very important component in the identification of whether or not a development is sprawl as sprawl is a moment of time (Harvey & Clark, 1965; Schmid, 1968; Ohls & Pines, 1975; Ottensmann, 1977; Peiser, 1989; Ewing, 1994; U.S EPA , 2000). A development that may be perceived scattered and sparse currently may evolve into a completely compact one in the future, if the right policies are ensured. This implies that sprawl is a matter of degree, a continuum of development from a sparse to a compact one, and not an absolute form (Chin, 2002). This hypothesis is supported by an empirical study conducted by Frenkel & Ashkenazi (2008). They considered multi-dimensional measurement of urban sprawl at a town scale level, covering seventy-eight Israeli settlements, over two decades (1980-2002) and realised a reduction in leapfrog index by 20%.

In classifying sprawl, urban density, configuration and land-use composition are instrumental although other features may be important for the categorisation (Batty, Besussi, & Chin, 2003; Frenkel & Ashkenazi, 2008). Generally, sprawl occurs in the following geometric patterns as indicated by some researchers in Table 2.3: low density continuous development, ribbon or strip development and scattered or leapfrog development.

Low density continuous development

The low density continuous development is perceived as the lowest order of sprawl and the least offensive (Harvey & Clark, 1965; McKee & Smith, 1972). One main feature of it is its aggressive usage of land (See Figure 2.1). The single family homes built on lots of two to five acres or even more are somehow aesthetically pleasing as they preserve the natural qualities of the urban fringes (McKee & Smith, 1972). Mckee & Smith (1972) further indicate that some will argue that the population densities should be increased in such circumstances in order to ensure that conventional municipal services are provided at reasonable rates. However, the concern of unreasonable rates for conventional municipal services under such circumstances appears not to be a major issue as under such low density conditions, households – by choice – shelve most of the costs by meeting their services needs privately. This claim is supported by a study done in South Kingstown, Rhode Island in the United States by Mohamed (2009). In examining public records for costs of constructing twenty eight sub-divisions, it was realised that on-site costs for water and sewer services as well as roads decreased with increasing lot size. What accounted for this, seemingly, disagreement to conclusions in literature is the satisficing strategies employed by small developers.

Table 2.3 Patterns of Urban Sprawl

Source	Low Density Continuous Development	Ribbon/Strip Development	Scattered/Leapfrog Development
Whyte (1957)			X
Clawson (1962)			X
Lessinger (1962)	X		X
Harvey and Clark (1965)	X	X	X
Bahl (1968)			X
Mckee and Smith (1972)	X	X	X
Acher (1973)			X
RERC (1974)			X
Ottensmann (1977)			X
Popenoe (1979)	X	X	X
Mills (1981)			X
Heikkila and Peiser (1992)	X		X
Beaumont (1994)	X	X	X
Downs (1994)	X		
Barnett (1995)	X	X	
Fulton (1995)	X		X
Moe (1995)	X	X	X
Ewing (1997)	X	X	X
Burchell et al. (1998)	X	X	X
Galster et al. (2001)	X	X	X
Burchell and Mukherji (2003)	X	X	X
Nechyba and Walsh (2004)	X		X
Schneider and Woodcock (2008)			X
Fina and Siedentop (2008)	X		X
Ding (2009)			X
Jaeger et al. (2010)	X		X
Chadchan et al. (2010)	X	X	

Source: Adapted from Ewing, (1997)

Small developers preferring the advantage of larger lots installed private septic tanks and water wells and later passed on the costs to residents or home buyers. The installation of private septic tanks and water wells, invariably, reduces the costs of trunk infrastructure for these services to zero. Again, wider roads with lower standards were provided so as to reduce costs.

Ribbon or strip development

The ribbon or strip development consists forms that are compact in themselves, but extend axially along major transportation routes leaving some lands undeveloped in between (Harvey & Clark, 1965). This type of development is very common in most urban centres especially in developing countries where accessibility and road development are quite low (See Figure 2.1). Harvey & Clark (1965) claim that this type of development may be more expensive than the low density continuous sprawl at the time of development. This may be partly due to the segments of higher densities which may be requiring full scale conventional municipal services and the problem of location as development takes place axially with undeveloped interstices.

Scattered or leapfrog development

Scattered or leapfrog development is perceived as a development which is completely separated from the periphery of the urbanised area by unused or vacant lands (Bahl, 1968). In other words, this type of development comes in relatively compact agglomerations springing up with substantial amounts of undeveloped lands surrendering them (McKee & Smith, 1972).

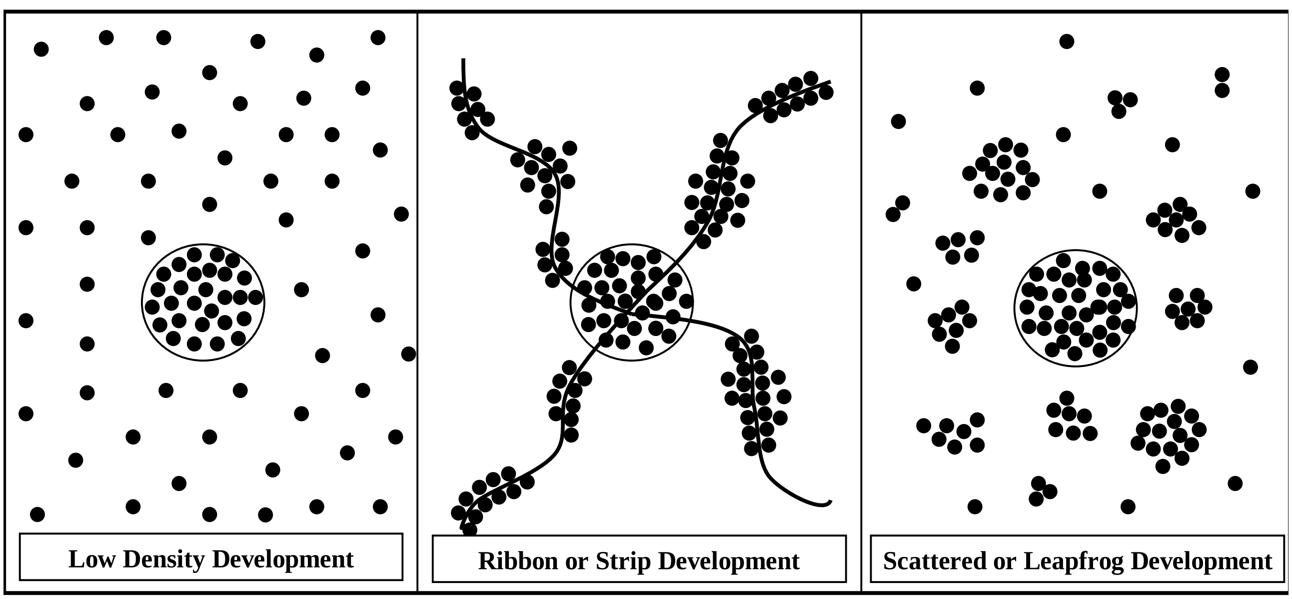


Figure 2.1 Geometric Patterns of Urban Sprawl

Figure 2.1 gives an impression of a scattered or leapfrog development pattern. Among researchers, policy makers and planners this type of sprawl is the most often attacked and considered to be the most expensive in capital and services outlays (Harvey & Clark, 1965; Bahl, 1968).

2.2.3 Drivers and catalysts of sprawl

The phenomenon of sprawl does not occur in abeyance. There are number of drivers and factors that fuel its occurrence everywhere in the world. Though in details there may be differences in factors inducing sprawl from one region to the other globally, there appear to be certain factors that are somehow general to the occurrence of sprawl across the globe. These factors act as centrifugal forces, forcing the city to break apart as both existing and new activities locate distances from the main urban core, but still remain connected to it through better transportation (Batty, Besussi, & Chin, 2003).

Perception of hazards or risks

There are two dimensions to the perception of hazards and risks – foreign aggression and natural hazards. A cursory review of literature on the causes of urban sprawl reveals that it appears history is sometimes separated from the complex mix of factors fuelling urban sprawl while blaming the occurrence of urban sprawl on current development factors. After the destruction of most European cities and Hiroshima in Japan in the World War II, a renowned planner in America, Augur (1948), in his article ‘’The Dispersal of Cities As a Defence Measure’’ called for Americans to desist from the idea of ensuring large cities, but rather small cluster towns. This he saw as a good strategy against atomic threat. He envisaged that when developments are in smaller cluster towns, it will not be attractive to enemies to bomb and also possible air strikes are likely to end up in open spaces**.** This assertion was strongly supported by Donald Monson, a planner and his wife Astrid Monson, an economist in their article “How Can We Disperse Our Large Cities?’’ in 1950. The fact that cannot be denied is that, the need to deal with atomic threat saw an immense commitment in America by ensuring collaboration between three federal agencies - the National Security Resources Board, the Department of Defence and the Federal Civil Defence Administration - with all officially recommending the acceleration of low density peripheral development to the federal government. Consequently, the government integrated this recommendation into the 1954

Housing Act; the interstate highways were planned in part to aid this decentralisation strategy and eventually, the American Institute of Planners officially endorsed decentralisation as a defence strategy (Dudley, 2001). This strategy may not have, partly, contributed to sprawl in America alone, but also in Korea. Bosworth (1997) indicated that both the mass media and the civil defence planners portrayed the city as a place of danger which affected real estate development in the early post-war years in Korea.

The perception of hazards or risks with respect to foreign aggression as a driver of urban sprawl may be peculiar to the United States and Korea, particularly as a historical driver of urban sprawl, and cannot be emphasised in other countries. Its relevance, currently as driver of urban sprawl globally, can be discounted now but cannot be completely ignored in the global urban processes. Perhaps, what is more relevant currently, as a potential driver of urban sprawl is the perception of hazards or risks with regard to natural disasters. Large cities are potentially vulnerable or hot-spots in the event of natural disasters such as tsunamis, flood, earthquakes and hurricanes among others due to the magnitude of exposure to the respective hazards. Therefore, the notion of a perceived hazard could generate policies that disperse growth or developments. Main cities may be less vulnerable in comparison to smaller cities or rural areas due to relatively higher adaptive capacities and would make sense for people to rather move to the main cities. However, there is a need to trade-off between higher adaptive capacities in main cities and minimisation of the exposure level through dispersion.

Land speculation

Land speculation appears also to be a major cause and catalyst of sprawl. Speculation takes place when land is purchased and withheld from development with the ulterior motive of making profits with the resale at a later date. Farmers and real estate developers are perceived as core players in speculation by withholding their lands from development and selling them later for higher prices (Archer, 1973). The competition for land among these players determines the spatial sizes of most cities and urbanised areas (Brueckner, 2000). What aggravates this speculation phenomenon and increases the centrifugal force, scattering the cities outward, is the fact that most of these players - real estate developers and farmers - have different judgments and perceptions about risk regarding future development trends.

Unfortunately, speculation usually occur on the basis of independent decisions of the speculators and hence their fuelling of sprawl (Harvey & Clark, 1965; McKee & Smith, 1972).

Topography

Topography or physical features sometimes are to blame for sprawling patterns of development. Topography usually determines the urban expansion pattern as growth and utilisation are more often than not towards readily available lands (Harvey & Clark, 1965; McKee & Smith, 1972). The problem of topography causing sprawl can sometimes be overcome, but that will mean unduly high development costs which may not be economically justifiable. With reference to topography, that which appears to be sprawl and perceived to be uneconomic is simply the least cost development of available development sites (Harvey & Clark, 1965).

Urban and population growth

Urban growth is also seen as a factor causing urban sprawl. Chin (2002) argues that commentators usually refuse to accept the fact that the increment in population cannot all be accommodated within the city boundaries and the consequence of such growth is urban sprawl. As population grows and density increases, there is usually congestion and overcrowding at the urban centres. This phenomenon culminates into poor quality housing, dirty neighbourhoods, crime and a host of other social vices and eventually force households, especially the richer ones, to the suburbs of main cities. Again, with increase in population within the city limits, the demand for land increases while the supply may remain constant. This leads to artificial hiking of prices of land making any development within the city expensive. This coupled with cheaper land at the suburb will definitely scatter development to the fringes as the market forces interplay to ensure equilibrium. Advocating for infill developments in the event of population growth is quite challenging and somehow expensive for households. Bragado et al. (1995) conducted a study in San Francisco area comparing infill and green space land prices. The infill areas were about 75% higher on the average. This situation drives moderate to low-income households to the urban fringes to meet their own housing needs ((Snyder & Bird, 1998). Usually, what underpins urban growth is economic growth. The economic growth has the tendency to increase the income levels of households (Carruthers & Úlfarsson, 2008; Brueckner & Fansler, 1983). As the income levels of households increase, it will bring about changes in life styles and demand for better and spacious homes which can only be located at the suburban areas. In most Sub-Saharan African countries, economic growths with consequent growths in households' incomes have triggered a lot of housing developments at the suburban areas of cities by households who are currently living in the city centres. The self-help system of housing which spans over several years to complete (Diko & Tipple, 1992) coupled with the economic growths in the cities has produced residential structures at various stages of completion at the suburban areas. This phenomenon has attracted most rural poor into the major cities who for lack of proper shelter take refuge in these uncompleted houses at the suburban areas while commuting to the city centres for work.

Transportation

Mobility, and for that matter transportation, has been one of the important means by which humans meet their needs. However, transportation is seen as a key catalyst of sprawl and scattering of cities. Bus lines have generated strip kind of development patterns while rapid transits lines have only extended the strips (Harvey & Clark, 1965). The versatility of the automobile allows almost every point, spatially, to be reached which then lubricates the urban sprawl phenomenon. Moreover, automobile dependency leads to more dispersed land use patterns and very often increased travelling to engage in human activities (Litman & Laube, 2002). Urban sprawl appears to be very extreme in cities that have short history of city development and have perhaps developed during the era of the automobile (Batty, Besussi, & Chin, 2003). This appears to explain why sprawl is probably alarming in North America as compared to Europe. Glaeser & Kahn (2003) indicate that it took Germany, one of the power houses of automobile industry in the world, until 1970 to reach the same level of car ownership that the United States had reached by 1920. It is agreed that in the United States, much dependence on automobile had led to suburbanisation and sprawl. However, public transportation and transit systems have their own share of contributing to urban sprawl (Chin, 2002; Glaeser & Kahn, 2003; Gordon & Richardson, 1998). In Britain, especially London, growth in suburbanisation began with the extension of the rail network to the suburbs in the1860's, producing radial patterns of developments along the transportation axes (Chin, 2002). Gordon & Richardson (1998) argue that the automobile only helped to diversify these radial patterns of development.

What are perceived as major factors fuelling urban sprawl are the falling prices and costs of transportation in favour of cars (Camagni, Gibelli, & Rigamonti, 2002). These apparent falls in transportation prices and costs are seriously contended by many researchers as the government's deliberate action to under price automobile costs (Newman & Kenworthy, 1989; Litman, 2006; Lee, 1995; Hanson, 1992; Ewing, 1997). The under pricing of the costs of automobile leading to sprawl could be justified at those places where the spatial structure depicts an extremely low density and most people depend on automobile for mobility. However, in most European countries where densities are relatively high, public transport systems are well developed and the cost of automobile ownership relatively expensive, there appears to be elements of sprawl. In view of this, Clawson (1971) claims that the economic benefits of locating to the suburban areas are far more important than the issue of transportation. However, it is important to indicate that the low fuel or energy prices cannot be guaranteed forever. In the event of higher fuel or energy prices in the future, it is likely the previous and current economic dynamics will change and subsequently a change in the urban process.

Information and Telecommunication Technology (ICT)

Information and Telecommunication Technology (ICT) though a very recent factor is contributing its fair share to the sprawl phenomenon across the globe. With world economies shifting to information and service-based, most service firms are highly volatile and have less incentives to purchase high priced properties in downtowns of urban areas (Snyder & Bird, 1998). Advanced Information and Telecommunication Technologies nowadays make working from home more convenient and preferable to employees than in conventional office environments. Public demands for community environments as promised by compact development patterns are no more important as they are being met in other ways such as the internet and teleconference (Archer, 1973). Meeting entertainment needs which were formerly possible in theatre settings and would require people to live closer to each other are now rendered irrelevant with the invention and improvement in television.

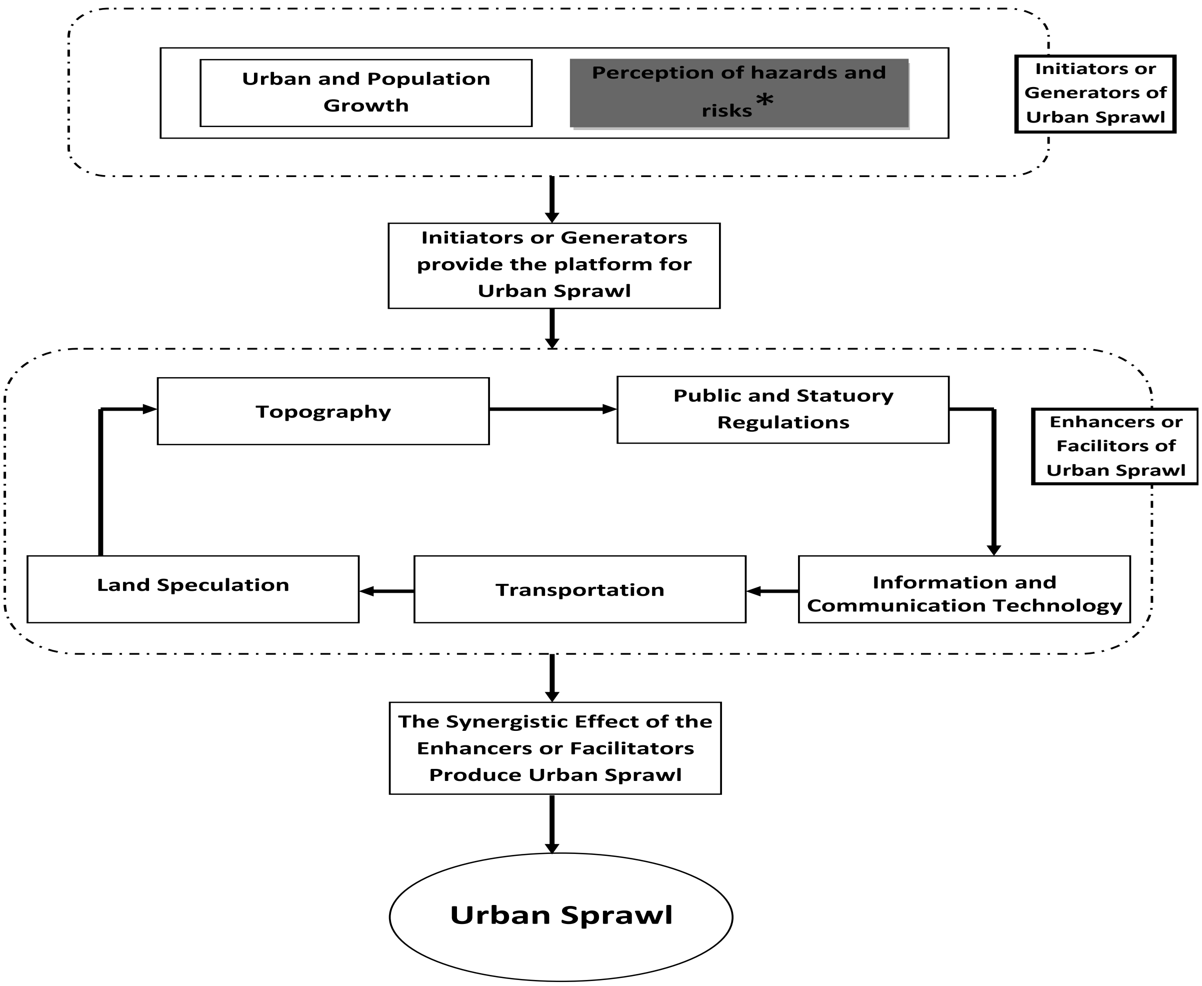
Public and statutory regulations

Public regulations ensure sprawl by imbalancing the attractiveness of competing areas (Harvey & Clark, 1965). Improper balances in regulations in a region make the lesser controlled area more attractive. The imbalances sometimes can be seen where there are too many fragmented governing bodies with uncoordinated activities in urban areas or regions which eventually lead to urban sprawl (Snyder & Bird, 1998). It is worth noting that the government's treatment of taxes, especially housing taxes, in the form of mortgage interest deductions and capital gains taxes can exacerbate the sprawl phenomenon in most countries. Persky et al. (2000) estimated that in the Chicago metropolitan area, in the United States, the federal tax code lowering the housing costs between 20% to 50% had an effect of raising land and housing consumption by about 20%.

The way and manner governments and local authorities finance infrastructure can avoid or encourage sprawl. Policies and plans to invest in transportation infrastructure without any regard to the effects on urban forms most often result in urban sprawl (Knaap, Talen, & Olshansky, 2000). Most governments in their quest to foster economic growths in certain areas offer loans and grants for the construction of sewers and water treatment plants (Freeman, 1990). The question as to whether or not they are done with a strategic development plan in mind cannot be answered, but the point is, some of these measures undoubtedly lower the cost of development and hence the incidence of sprawl.

The statutory basis for zoning is for local governments to protect the health, safety and welfare of citizens; protecting sensitive environmental resources from inappropriate development and ensuring orderly and efficient utilization of urban infrastructure (Knaap, Talen, & Olshansky, 2000; Moore, 1978). Furthermore, zoning can be used for both fiscal and discriminatory purposes (Mills, 1979; Burchell & Shad, 1998; Perin, 1977; Silver, 1991). Zoning no matter the reason for its implementation has the tendency to spread the city out. This is confirmed in researches by some planners and economists on the effects of zoning and other government regulations directly on urban forms (Pendall, 1999; Shen, 1996; Feitelson, 1993; Levine, 1999). They indicated that zoning and other land use regulations when adopted and enforced at the local level have the tendency to lower overall urban densities and induce sprawl. However, it is needful to point out that such an assertion can, only, be premised on a situation where zoning ordinances excludes high density developments, which is also a possibility.

The drivers or catalysts of urban sprawl, generally, can be categorised into initiators or generators and enhancers or facilitators. The initiators or generators hold the potential for any development to sprawl. They provide the substrate for the enhancers or facilitators to produce urban sprawl. Each of the enhancers or the facilitators could induce sprawl, however a synergistic effect of them produces urban sprawl in any development. A systemic view of the drivers or catalysts of urban sprawl can be seen in Figure 2.2.



* Though perception of hazards and risks is deemed to be a potential initiator or generator of urban sprawl and is generally indicated in this model, its relevance – particularly as a historical driver – is much felt in the United States and Korea than other countries. For completeness, it is added to this conceptual model. However, its usage in the interpretation of this model should be done advisedly.

Figure 2.2 A Conceptual Model of Drivers of Urban Sprawl

2.2.4 Relevance of drivers and catalysts of sprawl to infrastructure costs

The interplay of the drivers or catalysts of urban sprawl certainly have implications on infrastructure costs. The extent and eventual implications may differ in both developing and developed countries. From the perspective of initiators or generators of urban sprawl, developed countries have higher urban dispersion potential in comparison with developing countries. This is because the magnitude of urban growth which is accounted for by economic growth would be relatively higher in developed countries than developing countries and hence enhance the affordability of households in developed countries to locate to very remote areas from already established areas. Again, the perception of hazards and risks appears to have a higher potential urban dispersion rate in developed countries as compared to developing countries, because developed countries have relatively higher capacity to ascertain the occurrence and impacts of possible hazards and risks which may eventually inform policy directions.

Holding topography constant, the level of development of the enhancers or facilitators of urban sprawl in developed countries indicates a relatively higher urban dispersion potential vis-a-vis developing countries. This is because apart from topography, the enhancers or facilitators of urban sprawl – as per the model in Figure 2.2 – are relatively developed and likely to promote sprawl in developed countries than in developing countries. Dispersion and location of developments have significant influence on infrastructure costs (See Speir & Stephenson, 2002). Higher dispersion rates and longer distances of new developments from existing infrastructure connote higher infrastructure costs.

2.3 Impacts of urban sprawl

Urban sprawl has some impacts, beyond infrastructure costs, which must be critically analysed. Like in almost all big infrastructural projects, no project passes for execution without proper assessment of the costs and benefits of that project. Similarly, it makes planning and economic sense, if the costs and benefits of urban sprawl could be accounted for or unveiled to better inform decisions on development patterns. Proponents and opponents of the widely known development patterns (urban sprawl and compact city) have been putting forward several arguments for and against these alternative development patterns, but still there are very few empirical evidences to justify each case and the decision still remains inconclusive (Alvin, 1993; Carruthers & Úlfarsson, 2008). Much quantitative work have been done in literature to prove to stakeholders of alternative development patterns as to which option is the best, but most of these works have their weaknesses and critical errors. Cases in question are Windsor (1979) and Altshuler (1977)'s criticism of ''The Cost of Sprawl'' by the Real Estate Research Corporation in 1974 and Litman (2004)'s criticism of ''The Costs of Sprawl Reconsidered: What the Data Really Show'' by Cox and Utt in 2004. In aiding decisions to better deal with urban sprawl, it would only be fair, if the impacts dimension of urban sprawl is considered in the debate.

2.3.1 Benefits of sprawl

The mere mentioning of sprawl brings into mind the picture of an undesirable development that must be wrestled to the ground immediately. However, no matter how sprawl is maligned by its critics based on alleged negative impacts that come with it, there are a number of benefits of sprawl that critics should consider.

At the time sprawl occurs, it provides a housing alternative economically satisfactory relative to other alternatives (Harvey & Clark, 1965). This assertion could be reflected in the lower cost of land further away from the urban core, lower taxes at the suburban areas, loose building and planning regulations at suburban areas and a host of other factors. However, critics of sprawl contend with the relative cheapness of housing at the suburban areas as deceptive as most sprawling developments are highly subsidised by the government and people living at the urban core (Sierra Club, 2000). If subsidising suburban developments is deemed to be fuelling sprawl, then residents in suburban areas must be made to pay the full cost of the developments as a means to curb sprawl.

Gordon & Richardson (1997) argue that the traffic consequences of sprawl are mild and that sprawl has been the dominant and successful mechanism for reducing congestion. Congestion, which is a major problem at the urban cores, could be eased with decentralisation. This may not go uncontended as critics argue that sprawl induces more travelling and consequently leads to congestion (Sierra Club, 2000). Ribbon or strip sprawl, which is the worse culprit of this phenomenon, is usually as a result of poor planning and the government's inability to control access to the major roads or thoroughfares. With properly planned accesses and exits to these thoroughfares coupled with sufficient right-of-ways, congestion should be avoided or alleviated in such circumstances (Holcombe, 1999). Automobile dependency, which is an obvious characteristic of sprawl, is associated with more efficient local travel that affects productivity and ensures some retail efficiencies (Litman & Laube, 2002).

An urban sprawl pattern like leapfrog nurtures compact commercial development patterns - retail stores, offices and businesses (Holcombe, 1999). What motivates most businesses is the market. Generally, most businesses will not relocate to the suburbs unless there is a market opportunity. With leapfrog development patterns, commercial centres find it attractive to occupy the vacant lands between the urban centres and the suburbs to meet the needs of the suburban dwellers. It is believed that the attractiveness and the high demand for those lands will ensure more compact and efficient land use patterns.

Environmentally, low density development patterns appear to help. Surroundings filled with trees and shrubs absorb dust and chemicals thereby ensuring smaller amounts of pollutants escaping into the air and water (Holcombe, 1999). This is in contrast with situations in most cities. Gordon & Richardson (1998) argue that the principle of consumer sovereignty has played an immense role in the increase in America's wealth and in the improvements in the welfare of its citizens. At the kernel of the urban sprawl phenomenon are choice and flexibility which appear to support the consumer sovereignty and their attendant benefits. Downtowns of most cities appear to have a number of problems which may be loathed by most households. Consequently, households resort to other alternatives to address those problems (Staley, 1999). The quest of households to deal with those problems at the urban cores is encapsulated in what Gordon & Richardson (1998) point out by stressing that, when families purchase single family homes in the suburbs they are not consuming land per se. Rather they are purchasing quite a number of attributes such as access to good public schools, relative safety from crime, easy access to recreation and shopping opportunities and low taxes.

Urban sprawl is believed to have some benefits that are reasonably significant, but cannot be measured empirically (Burchell, et al., 2002). Table 2.4 gives a summary of some of the alleged benefits of urban sprawl.

Table 2.4 Extent of Alleged Benefits of Sprawl to Society

Benefits of Sprawl	Perceived as a Benefit by Many People	Actually Caused by Sprawl or its Traits	Appears Widespread in Regions of the U.S.	Has Serious Negative Side Effects	Perceived as a Disadvantage by Many People	Unequivocally a Net Benefit to Society as a Whole
Lower land and housing costs	**Yes**	**Yes**	**Probably**	**No**	Partly	**Probably**
Larger average lot size	**Yes**	**Yes**	**Yes**	**No**	**No**	**Yes**
Larger home and room sizes	**Yes**	Not clear	Not clear	**No**	**No**	No, because actual extent of occurrence is not clear
Reflects low-density preferences	**Yes**	**Yes**	**Yes**	**No**	Unclear, some say not enough other choices are available	**Yes**
Shorter commuting time	Probably	Not clear	Not clear	**No**	Yes, because longer driving distances are involved	Not clear
Less-intensive traffic congestion	Only by a few people	Not clear	Not clear	**No**	Yes	No, because actual extent of occurrence is not clear
Lower overall transport costs	No	No	No	**No**	Yes	No
More efficient use of infill sites	Only by a few people	**Yes**	Not clear	**No**	Yes	No, because actual extent of occurrence is not clear
Neighborhoods with lower crime rates	**Yes**	Partly	**Yes**	Yes, partly caused by exclusionary behavior	**Yes**	No, because partly caused by exclusionary behavior
Better-quality public schools	**Yes**	Partly	**Yes**	Yes, partly caused by exclusionary behavior	Yes	No, because partly caused by exclusionary behavior
Greater consumer life-style choices	**Yes**	**Yes**	**Yes**	Yes, helps perpetuate exclusionary behavior	Yes	**Yes**
More homogeneous communities	**Yes**	**Partly**	**Yes**	Yes, based directly upon very exclusionary behavior	Yes	No, because based directly upon very exclusionary behavior
Stronger citizen participation and influence in local governments	**Yes**	**Yes**	**Yes**	Yes, helps perpetuate exclusionary behavior	**No**	**Probably**

Note: Shaded cells show conditions supporting value of benefits
Source: Burchell, et al. (2002)

2.3.2 Costs of sprawl

The perceived negative impacts of urban sprawl in terms of social, environmental and economic toll on urban developments are considered under a study area termed as "Costs of Sprawl" in literature. The environmental and social costs of urban sprawl are extensively discussed in literature. This study only points out a few environmental and social costs of urban sprawl while focusing primarily on the economic costs, particularly the infrastructure costs.

Environmentally, urban sprawl is deemed to be linked with loss of environmentally fragile lands, reduced regional open spaces, increased air pollution, higher energy consumption and decreased aesthetic appeal of landscape (Burchell, et al., 1998). Another alleged cost of sprawl is the loss of agricultural lands (Harvey & Clark, 1965; Adelmann, 1998). Some researchers believe that flooding and the risk of it could be increased by urban sprawl (Adelmann, 1998; Livingston, Ridlington, & Baker, 2003). It is believed that one acre of parking lot produces about 16 times the volume of run-off that comes from one acre meadow (Surface Transportation Policy Project, 2001). Studies have shown that once a given area is 10% covered with impervious surfaces, water quality quickly and significantly deteriorates (Schueler, 1995; Benfield, Raimi, & Chen, 1999). The decline in water quality has an economic consequence on water supply companies, specifically their operation costs, as they have to spend more money in treating drinking water.

Socially, a sprawling development is considered a toll on the time of suburban dwellers (Harvey & Clark, 1965; Downs, 1998; Duany, Plater-Zyberk, & Speck, 2000; Sierra Club, 2000). This is reflected in the amount of time suburban dwellers have to spend traversing vacant lands to meet their needs. However, in literature this is hotly debated as proponents of sprawl claim that the commuting times between urban and suburban dwellers are almost the same or the difference being so insignificant that it could be disregarded (Gordon & Richardson, 1997). Social structure and equity are deemed as problems of sprawl as people tend to be segregated on the lines of income and race (Batty, Besussi, & Chin, 2003). However, Gordon & Richardson (1997) contend that in the United States, especially Southern California, the non-white population share in many suburban communities is quite high and sometimes the majority. Increased motorisation that comes with sprawl may lead to increased accidents and fatalities. The loss of lives and physical incapacitations flowing out of these accidents and fatalities may result in social outcomes which may not be desirable. Table 2.5 indicates the rising fatalities with increased motorisation and sprawl. The case of developing Asian cities is an outlier, which may be as a result of poor traffic regulations, infrastructure and conditions of vehicles in those cities. Automobile dependency in sprawling areas means reduction in quantity and quality of transportation choices for the poor (Litman & Laube, 2002). A lack of transportation choices for non-drivers can be a major barrier for the welfare-to-work efforts and for many employers who rely on lower income workers who often have limited access to automobiles (Blumenberg, Moga, & Ong, 1998).

Table 2.5 Automobile Dependency and Fatalities

Indicators	Australian Cities	US Cities	Metro Toronto	European Cities	Wealthy Asian Cities	Developing Asian Cities
Per capita car use (Kms)	6,536	10,870	5,019	4,519	1,489	1,611
Transport deaths per 100,000 population	12.0	14.6	6.5	8.8	6.6	13.7

Source: Newman & Kenworthy (1999)

Among the costs that are extreme with urban sprawl are those that come with capital facilities (Harvey & Clark, 1965; Batty, Besussi, & Chin, 2003). Most critics of sprawl claim urban sprawl is unduly expensive from the point of view of infrastructure capital and operating costs. Water and sewer lines, schools, roads and emergency services such as fire and police protection can cost twice as much in low density subdivisions as in compact development patterns (Livingston, Ridlington, & Baker, 2003). With the movement from the inner city to the suburbs, sprawl causes a decline in the local revenues in the inner city while service requirements must be maintained or even improved (McKee & Smith, 1972). The disappearance of the inhabitants and the fiscal imbalance lead to under-utilisation and the deterioration of the inner city and attendant infrastructure (Harvey & Clark, 1965). Urban sprawl is usually described by its critics as a network city. This implies more intense road construction culminating into high land consumption for roads and attendant infrastructure (Litman, 1997). In Europe where urban sprawl and automobile dependency are relatively low, the amount of total urban land consumed by roads and attendant infrastructure is 25% while in the United States where sprawl is perceived to be eminent, 30% (Camagni, Gibelli, & Rigamonti, 2002).

Urban sprawl increases expenditure on roads (See Table 2.6), traffic services and parking facilities, costing households several dollars annually (Newman & Kenworthy, 1999). Newman & Kenworthy (1999) further claim that heavy automobile dependency can reduce regional economic development. The heavy expenditure by governments on road infrastructure will generate into heavier tax burdens on businesses and households which makes it difficult for businesses to compete fairly on the international market. Table 2.6 below indicates the relationship between economic development and automobile dependency which is a major characteristic of urban sprawl across major continents in the world.

Table 2.6 Economic Development and Automobile Dependency in Global Cities, 1990

Indicators	Australian Cities	US Cities	Metro Toronto	European Cities	Wealthy Asian Cities	Developing Asian Cities
Per capita Gross Regional Product (GRP)	$19,761	$26,822	$22,572	$31,721	$21,331	$2,642
Per capita car use (Kms)	6,536	10,870	5,019	4,519	1,489	1,611
Per capita road expenditure	$264	$142	$150	$135	$88	$39
Road expenditure per $1,000 GRP	$7.19	$9.84	$6.65	$4.26	$4.13	$14.76
Transit operating cost recovery	40%	35%	61%	54%	119%	99%
Transport deaths per 100,000 population	12.0	14.6	6.5	8.8	6.6	13.7
Total car and transit operating expenditure as a portion of GRP	13.2%	12.4%	7.4%	8.1%	4.8%	15.9%

Source: Newman & Kenworthy (1999)

Burchell et al (2000) compared the development costs of a smart growth development pattern with a sprawling development pattern over a period of 25 years and revealed significant costs savings in favour of the smart growth (See Table 2.7).

Road savings

It is believed that since smart growth directs growth more intelligently to areas that are already advantaged in terms of road development and network, the demand for road construction to support new growths will be less. However, motorways and regional highways are not affected that much in terms of reduction in construction as they still have to traverse open lands to connect regional centres. Table 2.7 still shows the amount of savings accrued due to a smart growth development as compared to the more conventional pattern.

Infrastructure savings

The concept of smart growth assures the provision of mix housing choices. In this regard, there appears to be a substantive saving in infrastructure cost with respect to laterals in the case of network infrastructure as compared to purely single family housing which is a main feature of urban sprawl. See Table 2.7 for comparison.

Table 2.7 Smart versus Sprawling Growth Savings

Areas of savings	Savings per dwelling unit	Total savings over 25 years
All lands (acres)	0.124	3,099,000
Land cost	$ 619.79	$15.49 Billion
Agricultural lands (acres)	0.0694	1,735,000
Frail environmental land (acres)	0.0341	852,000
Local roads (lane miles)	0.0036	91,000
Local road costs	$1,325.08	$33.13 Billion
State roads (lane miles)	0.0001	3,000
State road costs	$106.49	$2.66 Billion
Water laterals (Number)	0.0902	2,255,000
Water laterals costs	$185.52	$4.64 Billion
Sewer laterals (Number)	0.0966	2,416,000
Sewer laterals costs	$167.45	$4.19 Billion
Housing costs	$5,791.78	$144.79 Billion
Non residential costs	$861.25	$21.53 Billion
Fiscal impacts	$964.02	$24.10 Billion

Note: Amounts are expressed in 1999 dollars, per residential unit, multiplied by 25 million units for U.S. growth from 2000 to 2025. Dollar savings are $250 billion, or $10 billion/year ($10,000/dwelling unit).

Source: Burchell et al. (2000)

Fiscal impacts savings

When growths are directed and distributed smartly, it is possible for new growths to be accommodated where infrastructure are already existing with spare capacities. Even though some developments (single family dwellings) may still be accommodated on undeveloped lands for people who can afford the full cost with regard to smart growth, on the whole, smart growth ensures higher fiscal impacts savings in comparison with sprawling developments. See Table 2.7 for amount of savings.

Public services cost savings

Directing growth to areas that are already established in public services is likely to significantly reduce public services cost than providing new infrastructure for the same services in new development areas that are far and distant. The reduction in costs of public services due to this approach coupled with improved revenue due to growth will invariably produce fiscal surpluses for city administrations and authorities. See Table 2.7 for likely savings.

2.4 Externalities of urban forms and infrastructure financing

Generally, urban forms and attendant infrastructure costs would be efficient and planners, policy or decision makers would also be indifferent about the location and form of developments, if the all the costs and benefits of developments were properly accounted for and reflected in the transaction price. Brueckner (2001) argues that the process of urban growth, with emphasis on urban sprawl, is inefficient and underpinned by market failures. At least three types of market failures (See Brueckner 2001 and Downs 1999 for more discussions on market failures) are deemed to cause the inefficiencies and hence the excessive spatial expansion of cities (Slack, 2002). The first type of market failure is reflected in the negative externalities associated with highway congestion, which makes the social costs of commuting higher than the private costs. Slack (2002) opines that highway users consider only the private costs of commuting – fuel, licences fees, depreciation, car insurances and their own time. However, if highway use were priced to reflect the marginal social costs (including the costs of construction, the external costs of pollution and congestion), residents of suburban areas will make rational choices, fewer people would drive and more people would choose to live closer to where they work.

Secondly, the market failure is reflected in the non accountability of the full environmental and social values of open spaces and agricultural lands by developers and residents of suburban areas (Downs, 1999). The conversion of open spaces or agricultural lands to urban uses should occur when the value of the land for open spaces and agricultural purposes, reflected in the environmental and social benefits to cities they surround, is lower than the value for urban uses. However, the full social and environmental values of open spaces and agricultural lands are, rarely, accounted for in the prices of urban transactions. Perhaps, this is due to the extreme difficulty in assessing these values.

Thirdly, the current fiscal arrangements lead to – artificially – low development costs and distort the market, thereby producing inefficient urban forms (Slack, 2002). Some authors (Brueckner, 2001; Slack, 2002) argue that residents and businesses who enjoy the benefits of urban sprawl do not pay the higher costs associated with that type of urban form. Essentially, the shortfalls in the costs of these outlying residents and businesses are subsidised by residents and businesses in consolidated areas. This results in negative externalities for residents and businesses in consolidated areas.

Acknowledging the improper pricing of social and environmental externalities in urban transactions leading to market distortions and inefficient urban forms, the subsequent discussion under this subsection will further focus on how the current fiscal arrangements lead to market failures and subsequently inefficient urban forms.

The schemes cities and municipalities use to raise revenues and also to finance infrastructure influence the nature and location of developments (Slack, 2002; Knaap, Talen, Olshansky, & Forrest, 2001; Skaburskis & Tomalty, 2000). Broadly speaking, and taking cognisance of the specific financing arrangements in literature, urban infrastructure financing schemes could be categorised into cost-sharing and impact-fee approaches. The former, with average pricing principle, is deemed as a historical approach while the latter, with marginal pricing principle, is supported by recent policies to finance urban infrastructure with the aim of introducing – somewhat – fairness in the infrastructure financing structure. Under the cost-sharing scheme, infrastructure cost is paid upfront but the cost is then shared among all the landowners in the city. On the other hand, under the impact fee scheme, the costs is paid in full at the time of development by the developer who is the owner of the land and subsequently transferred to home buyers. A cost-sharing scheme implemented through a property tax system, essentially, requiring infrastructure payments to be done based on the value of the property (land and structure) may have a sprawling effect on urban development. Basically, any improvement to the property (including intensive use of lot) raises the assessed value of the property and consequently warrants a higher tax. This serves as a disincentive to land intensification at central areas and fosters, a relatively, low density development or urban sprawl. Besides, it appears there is a distortionary effect on the mechanism of fairness or equity in using cost-sharing (implemented through property tax) as an infrastructure financing scheme. This is because one of the evaluating criteria of infrastructure financing schemes is equity (Slack, 1996). The principle of equity, with respect to infrastructure financing schemes, requires that people pay according to the benefits they receive from the service (Bird, 1994; Slack, 1996). Therefore, although residents at the city centre – intrinsically – may be enjoying the same benefits of infrastructure (roads, water supply, electricity supply and sewer systems) as residents at outlying areas, the residents at the city centre tend to pay – relatively – more for infrastructure financing under the cost-sharing scheme, usually implemented through property tax. Brueckner (1997) then argues that such a system of infrastructure financing is unfair as infrastructure payments, in this case, are proportional to the property value, which may depend on the land characteristics such as location. Slack (2002) further argues that since the cost of services (particularly capital cost) is relatively lower at the centre of the city, the consequence is that properties at the city centre are overcharged and those at the outlying areas are undercharged relative to what is economically efficient. Holding all other things constant, such a phenomenon will discourage development at the city centre and make the urban fringes more attractive or preferable for development. Again, proceeding on the path of economic efficiency, residents and businesses will make economically efficient choices, if costs of services were matched with the benefits of services. Generally, the standard or quality of public services (emphasis on recurring inputs) at consolidated areas is relatively lower vis-a-vis services at outlying areas due to the harsh environment that comes with higher densities (Ladd, 1992). Therefore, under cost-sharing approach of infrastructure financing, the residents of consolidated areas pay, relatively, more costs that do not match the benefits derived from services consumed. Conversely, residents of outlying areas pay costs that are less than the benefits derived from the services consumed. Essentially, such a development gives rise to positive and negative subsidies, influencing urban development pattern in an inefficient manner (Slack, 2002). Hence, to deal with the market distortions and to internalise the externalities with respect to infrastructure financing, the impact-fee approach is recently touted (Brueckner 2001).

Growth or new development under the impact-fee infrastructure financing scheme is, essentially, required to pay for itself. Developers are thus required to provide on-site infrastructure – streets, water mains, electricity, sewer, etc – as a pre-condition for development permit. Again, city authorities require developers to contribute to off-site infrastructure in kind or cash for new developments (Brueckner, 1997; Slack, 2002; Brueckner, 2001). In addressing the concerns of social infrastructure (schools, health facilities, open spaces, etc), city authorities require – in some cases – developers to still provide such infrastructure as requirements for development permits (Brueckner 1997; Slack, 2002).

The impact-fee financing scheme seeks to correct or internalise the externalities generated by the cost-sharing scheme. However, some authors (Cinyabuguma & McConnell, 2012) argue that the problem of externalities arises because residents and businesses in consolidated areas perceive only the costs of new residents and not the benefits of growth or new entrants (in terms of new jobs and increased tax base) that accrue to the whole city. Furthermore, it can be argued that when new residents and businesses are located in consolidated areas, it apparently introduces unwelcoming environments and exacerbates the under provision of services such as schools and open spaces in some areas (Troy, 1996). Such a phenomenon, invariably, generates negative externalities and – somewhat – marginal costs for existing residents. Hence, Cinyabuguma & McConnell (2012) posit that each new resident existing areas take in, there should be a subsidy paid to the existing residents.

Albeit marginal costs pricing of infrastructure financing (currently implemented through impact-fee scheme) is laudable and holds the promise to internalise all external costs to ensure efficient consumption of resources and urban forms, its implementation is not straight forward. Most cities find the calculation of marginal costs of providing services more difficult than calculating the average cost and this situation is also usually fed by the lack of sufficient information on costs to estimate marginal costs (Slack, 2002). Besides, alluding to Slack (2002), cities rarely use marginal cost pricing scheme because they are more concerned about charging user fees to raise revenues than they are about setting economically efficient prices that can result in more efficient use of resources or more efficient urban forms. More debates would be required in future researches on marginal cost pricing of infrastructure to fine-tune its implementation and to ensure residents and businesses make economically efficient decisions that will lead to efficient urban forms.

3. URBAN SPRAWL: A view from developing and developed countries

The phenomenon of urban sprawl as a global issue which is evident in both developing and developed countries has been discussed from a general perspective in chapter 2 of this study. However, this section discusses it from a contextual perspective – developing and developed countries' points of view. Urban sprawl is usually deemed to be one of the effects of urbanisation, though a careful analysis needs to be made as to what is a legitimate urbanisation in developing countries and undesirable expansion of cities. This assertion makes it imperative for urban sprawl to be looked at differently from the perspectives of developing and developed countries. The dynamics and contexts of urbanisation in developing countries, presently, are quite different from now-developed countries (Menon, 2004). Urban sprawl as a conventional development pattern is a view or observation from developed countries. All definitions and characterisations are as per the views of developed countries. However, the indicators, causes and impacts of urban sprawl in developing countries have points of departures from developed countries (Menon, 2004). A critical look at urban sprawl from the perspective of developing countries holds the key to dealing with the issue pragmatically in developing countries. Developing countries borrowing policies from developed countries to control, perceived, urban sprawl and its attendant infrastructure costs is not the problem. However, it is a question of whether or not those policies are bespoke in dealing with sprawl in developing countries. Analysing urban sprawl, with regard to similarities and differences, from the points of view of both developing and developed countries is needful to put the term *urban sprawl* in its proper perspective in the different economic regions of the world. Again, a better understanding of the nature of urban sprawl in developing countries would better inform policies that seek to deal with infrastructure costs concerns warranted by recent sprawling developments in developing countries. This chapter, in addition to contextualising the phenomenon of urban sprawl, discusses the applicability and transferability of the results of costs-of-sprawl studies conducted in developed countries to developing countries.

3.1 The analysis of Ghanaian and North American sprawl

The analysis of urban sprawl from the perspectives of developing and developed countries will premise on Ghana, a developing country in West Africa and North America, particularly, the United States, an epitome of urban sprawl. In literature, urban sprawl is usually characterised and described by mixing both causes and impacts (Jaeger, Bertiller, Schwick, & Kienast, 2010). Generally, every discussion of urban sprawl has to be approached from this two-pronged dimension. The recent analysis will, therefore, hinge on the causes and impacts of urban sprawl as perceived in both developing and developed countries to delineate the similarities and differences of the phenomenon in the different economic regions of the world. Only a descriptive approach would be employed in analysing the similarities and differences of the phenomenon of urban sprawl in both Ghana and the United States. It is thus suggested that further studies engage the descriptions provided in this analysis by means of empirical approaches to determine the applicability of the observations made. In that sense, more insights will be provided on the similarities and differences of urban sprawl in both developing and developed countries. Elucidating the descriptive approach, which seeks to draw out some similarities and differences of the phenomenon of urban sprawl in both Ghana and the United States, ten dimensions of urban sprawl which are widely discussed in literature are considered as the framework for the analysis. The ten dimensions of urban sprawl are primarily categorised into causes and impacts with a description of the situation of the phenomenon in both Ghana and the United States related to each dimension. Again, the ten dimensions of urban sprawl are evaluated against five assessment measures to further delineate the similarities and differences of the phenomenon in both Ghana and the United States.

3.1.1 General pattern of the urban development in Ghana

Though the emphasis of the analysis is on the dynamics of urban sprawl in Ghana and the United States, it is important to give a general description of the pattern of urban development in most Ghanaian cities as a backdrop for a better appreciation of the analysis. Generally in literature, several patterns have been proffered that directly or indirectly explain the urban development in most Ghanaian cities in Ghana. Yeboah (2000; 2003) identify the current urban development in Accra – the capital of Ghana – as *quality residential sprawl with unicentric urban form*. Such a tendency is not different from what is happening in most Ghanaian cities. Yeboah (2000) further argues that the *quality residential sprawl with* *unicentric urban form* in Accra is characterised by seven attributes: high quality buildings by the middle class, incremental building, building in anticipation of infrastructure, low density development, building for residential rather than commercial and industrial purposes, spontaneous and unplanned developments, functional interaction between Accra central and peri-urban developments. The *quality residential sprawl with unicentric urban* in Accra is deemed to be occasioned by global factors which manifest in trade liberation and foreign currency liberation, on one hand, and local factors such as the economic situation, weak institutional framework for delivery of lands, Ghanaian cultural considerations and innovations on the supply side of the housing market, on the other hand (See Yeboah, 2000).

Besides, in an empirical work by Owusu-Ansah & O'Connor (2010) on the pattern of urban development in Kumasi (the second most important city in Ghana), the authors described the nascent physical landscape as a "mosaic of housing structures scattered haphazardly on the fringes of Kumasi". Owusu-Ansah & O'Connor (2010) ascribed the current urban pattern in Kumasi to a rising demand and growth of single family housing at the peri-urban areas (motivated by changing values about residential location), a complex institutional system with respect to land administration and the incremental system of housing construction.

A more recent empirical work by Doan & Oduro (2011) further gives insightful information about the urban development pattern in most Ghanaian cities. Doan and Oduro (2011) employed spatial modelling (ArcGIS) and regression analysis on population census data and argue that the pattern of urban development in Accra (a replica of development in other cities in Ghana) could be best described as a combination of a spreading pancake, development node, village magnet and ribbon patterns.

On the spreading pancake development pattern, Doan & Oduro (2011) argue that population and development are concentrated at localities within and closest to the central city (Accra). However, with increasing distance from the central city (Accra), population and development decline in series of concentric rings around the central city (Accra). See Figure 3.1 for the phenomenon.

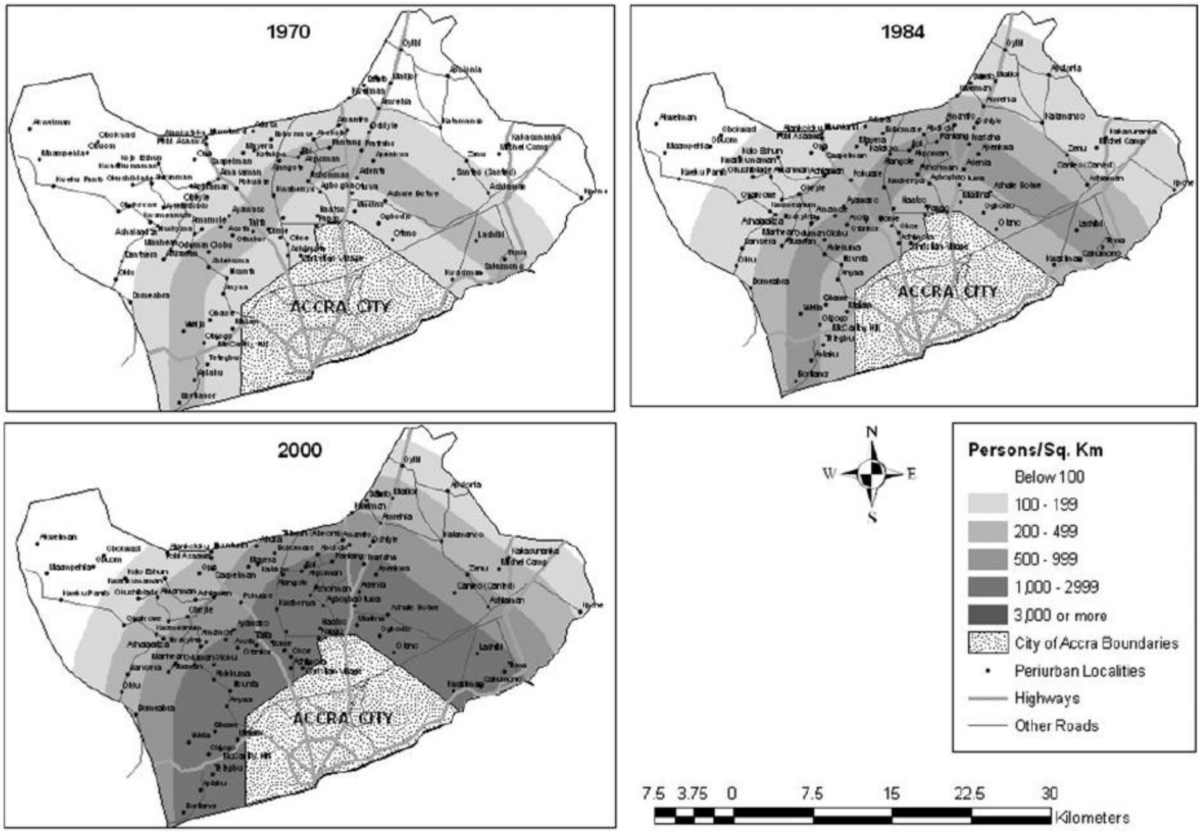


Figure 3.1 Population Density by Proximity to Accra, 1970, 1984 and 2000

Source: Doan & Oduro (2011)

Explaining the development node pattern, they indicate that localities close to a cluster of global investments are likely to experience population concentration and development than localities further away from that development node. Hence, Tema, the main harbour city in Ghana attracts higher concentrations of population and development at localities closest to it while population and development decline with distance away from it (See Figure 3.2).

According to Doan & Oduro (2011), in Ghana, existing villages with basic infrastructure (close to major urban centres) are engulfed by rapid urbanisation. Those villages become the nuclei of fast-growing densely populated pockets surrounded by slow-growing sparsely populated localities. Taking localities like Adenta, Ashaiman, Dome, Gbawe and Madina in the Greater Accra Metropolitan Area (GAMA), they identify a high concentration of population and development around those village magnets with population and developments declining with distance from those village magnets (See Figure 3.2).

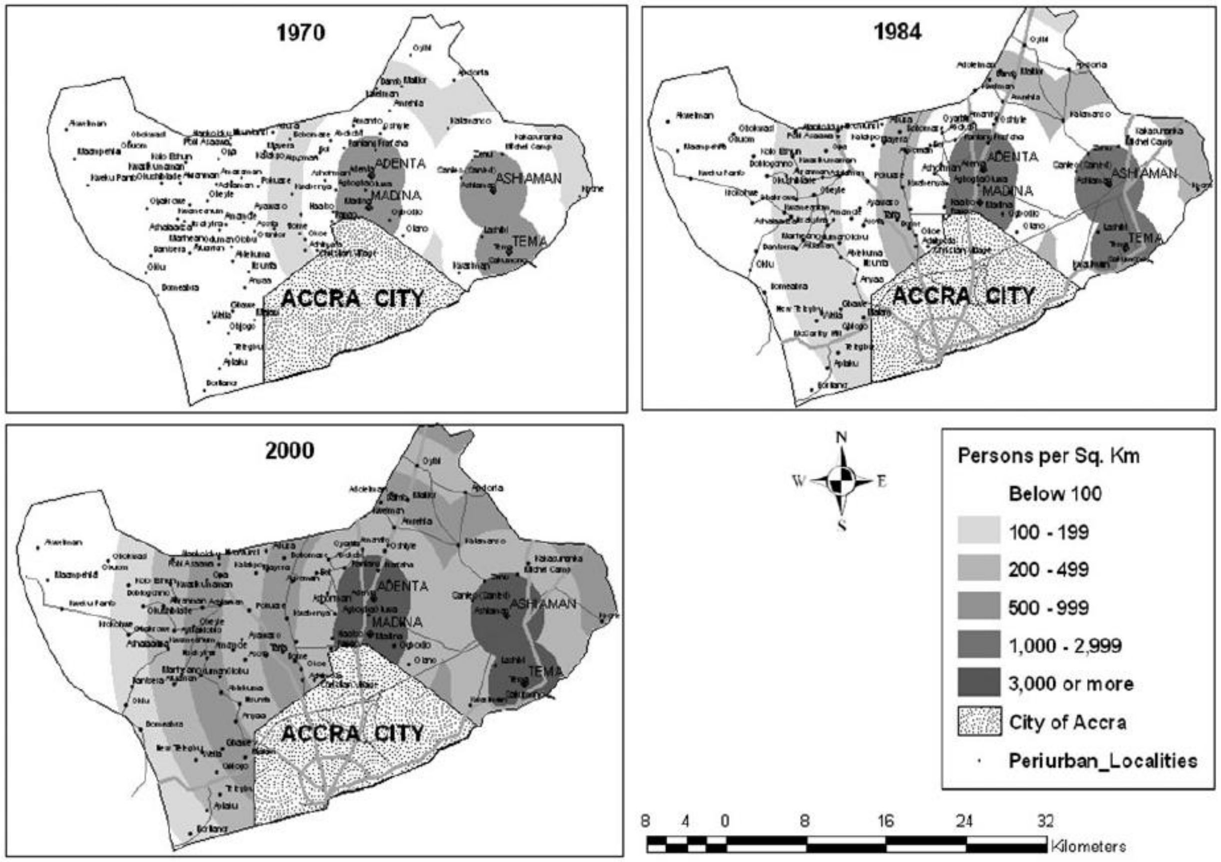


Figure 3.2 Population Density by Proximity to Tema, Ashaiman, Adenta, Dome, Gbawe and Madina, 1970, 1984 and 2000

Source: Doan & Oduro (2011)

Again, Doan & Oduro (2011) assert that the pattern of urban development, particularly at the peri-urban areas, in Ghana is ribbon in nature. They indicate that population and development are highly concentrated at localities close to highways emanating from the central city while population and development decline with increasing distance from those highways (See Figure 3.3). Accessibility and need to maintain a functional relationship with the central city by peri-urban dwellers are deemed to be the reasons for this pattern (Doan & Oduro, 2011).

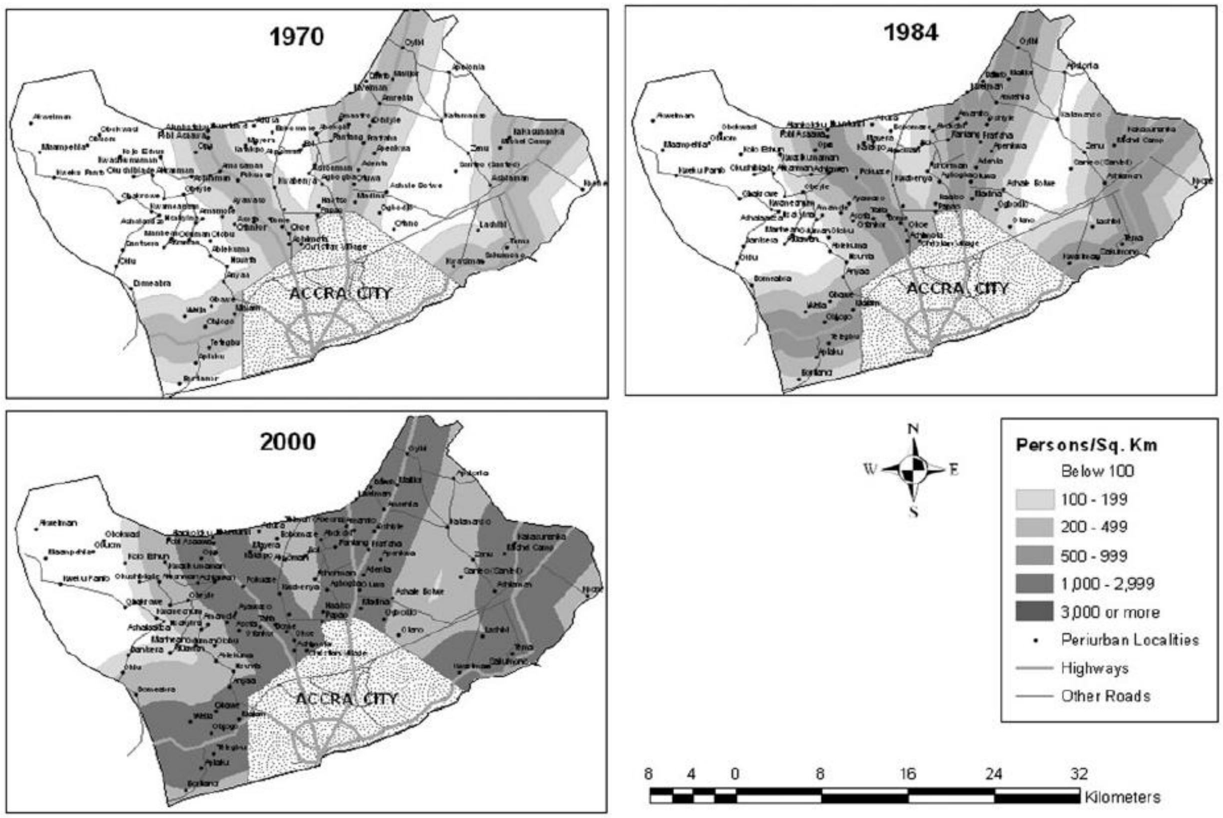


Figure 3.3 Population Density by Proximity to Highways, 1970, 1984 and 2000

Source: Doan & Oduro (2011)

3.1.2 Causes of urban sprawl in Ghana and the United States

Urban growth

The fact that urban growth, particularly population growth, induces urban sprawl cannot be denied in both developing and developed countries. Albeit, critically, mere population growth does not necessarily translate into urban sprawl and could invariably induce a compact development pattern through land intensification policies (construction of blocks and high-rise buildings), if uncontrolled could equally lead to haphazard developments and urban sprawl. The persistent urban population growth for the past five decades has seen tremendous rise in urbanisation and the number of urban localities in Ghana (See Table 3.1). Similarly, census data for hundred largest urbanised areas in the United States (U.S.) from 1970-90 reveals that about half (50.90%) of the sprawl in the U.S. is accounted for by population growth (Kolankiewicz & Beck, 2001). The source of the population growth coupled with the socio-economic situations in the urban areas determines the dynamics of urban sprawl in both developing and developed countries. In Ghana, a substantial share of population growth in urbanised areas is due to rural-urban migration (Twumasi-Ankrah, 1995). This phenomenon is anchored by the urban primacy nature of development in Ghana where a few cities are developed and served with good infrastructure. The primate cities and urban centres thus become attractive destinations for the rural dwellers. The influx of population at the major urban centres raises concerns about urban density and available space for manoeuvring. Menon (2004) indicates that in developing countries, people move to the suburban areas because there is not enough space for them to live at the urban core. The need for legitimate space in developing countries should be decoupled from luxurious need for space in developed countries. The basic need for space and the inability of the government to predict and manage urban population growth result in outward city expansions in Ghana. The rural immigrants squat on vacant government lands (in the form of slums) at the urban core, indirectly forcing new developments, to the peripheries.

Table 3.1 Growth in Number of Urban Localities and Population in Ghana

Year	Number of Urban Settlements	Urban Population
1948	41	570,597
1960	98	1,551,174
1970	135	2,472,456
1984	203	3,938,614
2000	364	8,278,636

Source: Songsore (2009)

To some extent, urban sprawl due to urban growth appears to be different in the United States. Kolankiewicz and Beck (2001) indicate that fertility rate as a major cause of urban population growth has dipped while most urban population growth in the U.S. is due to immigration. Immigration in the U.S. has been on the rise, especially after the World War II as indicated in Figure 3.4, and appears to account for a significant share of the percentage of overall sprawl caused by population growth. Figure 3.4 shows a dramatic increase in immigration in the U.S. around the 80s, exactly within the same time period that Kolankiewicz & Beck (2001) analysed data for factors contributing to sprawl in the U.S (See Kolankiewicz & Beck (2001) for more discussions on the factors of urban sprawl in the U.S).

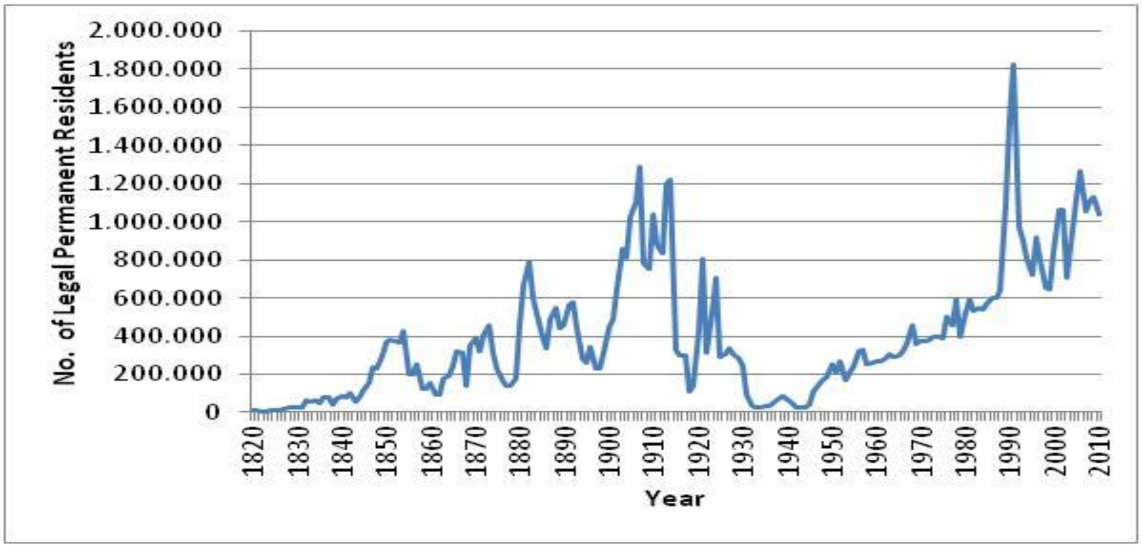


Figure 3.4 Legal Immigration to The United States: Fiscal Years 1820 to 2010 (in millions)

Source: U.S. Department of Homeland Security (2010)

Similar to Ghana, a significant share of suburban development in the U.S. is by preference (Gordon & Richardson, 1997; Fuguitt & Brown, 1990; Sullivan III, I994). High and middle income households desiring large tracts of land for single family homes at discounted prices at the suburban areas move from the urban core to the peripheries. The area of land consumed per household at the suburban areas may be relatively higher in the U.S. than in Ghana. This may, partly, explain why density is likely to be lower at the suburban areas in the U.S. than in Ghana.

Table 3.2 Declining U.S. Household Size

Year	1930	1950	1960	1970	1980	1990	2000	2009
Household Size	3.67	3.37	3.33	3.14	2.76	2.63	2.62	2.63

Source: El Nassar & Overberg (2011)

The increase in space and land per capita coupled with drop in household size (See Table 3.2) is fuelling sprawl in the U.S. The increase in space and land per capita in the U.S is partly reflected in the increasing total floor areas of finished single family homes from 1950 to 2004 (See Table 3.3).

Table 3.3 Finished Floor Area of Single Family New Home in The United States.

Year	1950	1970	1990	2004
Average Finished Area (Sq. ft)	983	1,500	2,080	2,349

Source: National Association of Home Builders (2006)

Benefits

Urban sprawl does not take place in abeyance. Its occurrence is linked to some perceived benefits among many people. In the U.S, lower land and housing costs; larger average lot size; larger homes and room sizes; preference for low density developments; neighbourhoods with lower crime rates; the desire for better quality public schools and stronger citizen participation and influence in local governments, among other benefits, are reasons why people opt for suburban settlements which, eventually, lead to urban sprawl (Knaap, Talen, & Olshansky, 2000; Brueckner, 2000).

The benefits of urban sprawl as pertained in the U.S have some similarities in Ghana since most of the new housing stock in major cities, currently, are owned by Ghanaian who have either lived abroad or are still living abroad (Diko & Tipple, 1992; Grant, 2007). Yeboah (2003) indicates that half of the new housing stock in Accra now is owned by Ghanaians living abroad. Ghanaians abroad, certainly influenced by the western culture particularly the U.S, are prejudiced with regard to the location and type of houses they construct. In Ghana, suburban settlement may not promise better quality school as the case of U.S may be, however there are some local and cultural factors that give rise to single family homes at the suburban areas in Ghana. There is usually pressure exerted by family members (Yeboah, 2000) and the society on up-and-coming people to own their own homes. Building a house in Ghana shows the social status of the builder (Korboe, 1992; Grant, 2007; Malpezzi & Tipple, 1990; Diko & Tipple, 1992). Hence building a house in Ghana, which is more likely at the suburban area, gives relief from family pressure and raises one's social status. Besides, suburban development through real estate developers provides an escape route for the numerous controversies surrounding land acquisition and building development in Ghana (Grant, 2007; Doan & Oduro, 2011). A survey conducted by Grant (2007) reveals that, Ghanaians preferred single family homes so as to achieve financial independence from the extended family.

Public and statutory regulations

Public and statutory regulations are generally deemed as drivers of urban sprawl in most parts of the world. In the U.S, the role of public and statutory regulations in inducing urban sprawl is very much noted and opined by many researchers (Harvey & Clark, 1965; Snyder & Bird, 1998; Persky, Kurban, & Lester, 2000; Knaap, Talen, & Olshansky, 2000; Pendall, 1999; Shen, 1996; Feitelson, 1993; Levine, 1999). Government's investment in physical infrastructure (Knaap, Talen, & Olshansky, 2000) without any consideration for subsequent effects on urban forms and zoning (Pendall, 1999; Shen, 1996; Feitelson, 1993; Levine, 1999) are perceived to cause urban sprawl in the U.S.

Unlike the U.S, in Ghana, the lack of enforcement of public and statutory regulations contributes partly to unserviced lands. The unserviced lands in most urban areas culminate into lower land values (Asiama, 1989) which promote urban sprawl. Again, the non existence of proper planning measures coupled with lack of enforcements, in Ghana, has the same tendency of scattering developments and lowering overall densities as the case of zoning may be in the U.S. The compulsory acquisition of land by the government from families and traditional authorities without proper compensation, sometimes, leads to litigation and large vacant lands skipped in urban developments.

3.1.3 Impacts of urban sprawl in Ghana and the United States

Economic decentralisation

The displacement of economic activities from the urban core to the suburban areas usually characterise urban sprawl. Glaeser and Kahn (2003) refer to decentralisation as the spreading of employment and population throughout out the metropolitan areas. Addressing the situation of decentralisation in the United States, Office of Technology Assessment (1995) reveals that job creation and office spaces have been more active at the suburban areas in the United States. Local and state governments' actions to entice businesses and residents through public subsidies for infrastructure for new business and housing developments, partly explain the increasing rate of decentralisation in U.S. (Kolankiewicz & Beck, 2001; Glaeser & Kahn, 2003). American cities are becoming highly polycentric with many specialised centres being established at suburban areas other than the traditional urban cores (Batty, Besussi, & Chin, 2003). A variant of this pattern is evident in China with the establishment of new university towns and technology or industrial enclaves, away from already established urban areas (Zhang, 2000).

The case of Ghana, with regard to decentralisation, appears to be different. Much as there is evidence of decentralisation, it could not be taken as economic based. The spread to the suburban areas is significantly dominated by residential developments. Commercial and business activities are still located at the urban core. Suburban dwellers commute to the city centre to engage in economic activities. Consequently, Yeboah (2000) describes the development pattern of Accra, a replica of other cities, as a *quality residential sprawl* with *unicentric urban form*. The description of *quality residential sprawl* is given credence by the high share of “own account workers” or informal petty traders, other than formal industrial employees, in urban areas and Ghana as a whole (See Table 3.4).

Table 3.4 Employment Status of Currently Employed Above 15 Years in Ghana

Employment status	Urban		Whole Ghana
	Male (%)	Female (%)	(%)
Employee	49.7	20.1	17.6
Employer	7.4	5.5	4.5
Own account worker	33.8	60.3	55.0
Contributing family worker	4.1	11.0	20.4
Apprentice	4.7	3.0	2.3
Other	0.3	0.1	0.1
All	100.0	100.0	100

Source: Ghana Statistical Service (2008)

The “own account workers”, undertaking their economic activities mainly at the urban core, contribute significantly to new residential developments at the urban peripheries.

Low density development

In the U.S., urban sprawl is perceived as a low density and spatially extensive development pattern (Fulton, Pendall, Nguyen, & Harrison, 2001; Glaeser & Kahn, 2004; Bruegmann, 2005; Úlfarsson & Carruthers, 2006; Ewing, 1997; Galster, Hanson, Rafcliffe, Wolman, Coleman, & Freihage, 2001; Burchell & Mukherji, 2003). The phenomenon of single family homes at the suburban areas in the U.S. is not different from similar developments in Ghana.

Single family homes built on lots of two to five acres (McKee & Smith, 1972) at the suburban areas are deemed to cause low density developments in U.S. Low density developments are equally evident at the suburban areas in Ghana not necessarily because of demand for large lot sizes, but partly due to the predominant system of building. Diko & Tipple (1992) and Yeboah (2000) assert that in Ghana, buildings are designed and constructed incrementally. The incremental development of buildings, particularly for residential purposes, is occasioned by the financial ill-preparation of home builders (who still commence development with the hope of completing in a remote future and also as a means of securing the land) and the wide-spread informal housing development system in Ghana. The worse effect of incremental building is felt on urban development when substructures and portions of superstructures of buildings are constructed and left over a considerable time without occupancy. Table 3.5 shows some indicators of incremental building system at selected peri-urban areas in Kumasi, the second populated city in Ghana. At least 10% of the developments in each locality is either at the substructure level or not developed at all. The worse situation is the Adarko Jachie locality which has more than 50% of its development at the substructure level or not developed at all.

Table 3.5 Indicators of Incremental Building System Around Kumasi

Suburban Area	Numbers of Lots	Completed & Occupied	Partially Complete & Occupied	Substructure or Skeletal Structures	Vacant Land
Ayeduase	790 (100)	587 (74)	102 (13)	80 (10)	21 (3)
Kenyase	738 (100)	425 (57)	130 (18)	79 (11)	104 (14)
Adarko Jachie	420 (100)	106 (25)	76 (18)	138 (33)	100 (24)
Esreso	545 (100)	282 (52)	76 (14)	120 (22)	67 (12)

Note: Figures in parenthesis are percentages of the selected indicators

Source: Owusu-Ansah & O'Connor (2006)

As shown in Figures 3.5 and 3.6, the usual view of most suburban areas in Ghana is proliferation of residential structures at various stages of completions. This system of home construction, spanning over several years, contributes to the low density developments at the urban peripheries. The complex mix of accelerated land demand by the urban middle class, the traditional land management structures embedded in the institution of chieftaincy and the official state land management structures (Owusu-Ansah & O'Connor, 2006) usually lead to confusions and litigations in land administration in Ghana.

Figure 3.5 A Section of Gbawe, A Locality in The Greater Accra Metropolitan Area, Showing Residential Structures at Various Stages of Completion (Scale: 1:20m)

Source: (Google maps, 2011)

Figure 3.6 A Section of Ofankor, A Locality in The Greater Accra Metropolitan Area, Showing Residential Structures at Various Stages of Completion (Scale: 1:20m)

Source: (Google maps, 2011)

The consequence is that lands are being held from developments, increasing the share of vacant lands in between developments and lowering densities at the suburban areas. The vacant lots interspacing the uncompleted residential structures in Figures 3.5 and 3.6 are as a result of either a purchase by the middle class awaiting later development or land litigation.

Social problems

Urban sprawl is usually characterised by income and racial segregation (Batty, Besussi, & Chin, 2003). In developed countries, particularly in the U.S., the wealthy and white households move from the urban core to the peripheries to avoid the social problems that are associated with city centres (Audirac, Shermyen, & Smith, 1990; Glaeser & Kahn, 2003; Glaeser, Kahn, & Rappaport, 2000). This leads to population decline and loss at the urban cores. It is argued that transportation technologies play a major role in explaining this segregation (Gin & Sonstelie, 1992; Glaeser & Kahn, 2003). The main reason is that cars are expensive and the poor who cannot afford cars are forced to live in the city centres. This assertion is supported by Glaeser, Kahn, & Rappaport (2000) who posit that poverty rates are much higher, closer to public transit stops and where access to public transportation increases, poverty rates increases. Glaeser & Sacerdote (1999) point out that, in developed countries, urban sprawl results in people living in single family detached houses and are less likely to interact with their neighbours than people who rent in the city centres.

The urban cores in Ghana are active and booming with high population densities. Even though the urban cores are active and booming, there is movement to the suburban areas by the low, middle and high income groups in Ghana (Yankson, Kofie, & Moller-Jensen, 2004). The movement to the suburban areas or peripheries is not necessarily due to the middle and high income people wanting to flee the social vices in the city centres. Yankson, Kofie, & Moller-Jensen (2004) indicate that liberalisation policies resulted in a hike in rents (particularly in Accra), triggering the migration of both poor and wealthy households from the city centre to peri-urban areas in search of cheaper land and residential accommodation. Moreover, there are cultural and local factors in Ghana that support the movement of the middle and high income groups to the peripheries. There is a cultural perception that house ownership gives security and shows one's social status (Malpezzi & Tipple, 1990; Diko & Tipple, 1992; Korboe, 1992; Grant, 2007). Again, the housing system in Ghana does not facilitate the future ownership of rented houses in the city centre. The rented houses, mostly compound houses which account for 44.5% of housing stock in Ghana (Ghana Statistical Service, 2002), are usually family properties which cannot be easily transferred to non-family members (Grant, 2007). Adequate privacy of households is also not ensured in compound houses. The interplay of these factors forces the middle and high income households to meet their housing needs at the suburban areas. Unlike the U.S. and other developed countries, land use fragmentation (a characteristic of sprawl) reducing the transportation choice of the poor and confining them to the city centres and transit corridors is less evident in Ghana. The informal urban transportation system, primarily in the hands of the private sector and motivated by profit, makes every settlement point accessible. Local bus systems called *tro-tros* coupled with ubiquitous taxis provide the poor, nearly, the same accessibility as the wealthy who depend on their private cars. The incremental system of building in Ghana, which spans over several years, (Diko & Tipple, 1992; Yeboah, 2000) at the suburban areas provides homes for the urban poor who squat in those uncompleted structures and act as caretakers. A significant share of the single family houses at the suburban areas are owned by Ghanaian emigrants (living in mostly U.S., Europe, Australia and other developed countries) who have their houses occupied by caretakers after completion (Grant, 2007). These caretakers are usually the low income family members who interact socially. Social interactions at the suburban areas in Ghana are quite significant, especially with the proliferation of churches at the suburban areas.

Accessibility

Urban sprawl is usually linked with poor accessibility in the U.S. Ewing, et al. (2002) argue that, in the U.S., spread-out suburban subdivisions are a major feature of sprawl, and can make it difficult to provide residents with adequate nearby shopping or services, civic centres, or transportation options. The issue of accessibility in the U.S appears to be due to its fragmented and homogenous land uses. Looking at accessibility critically, transportation scholars refer to *access* as the purpose of travel, while *mobility* simply connotes the ease of getting from one point to the other (Levinson & Krizek, 2005). Furthermore, Crane (2008) posits that access is about being at places and doing things while mobility is the cost of getting to those places or destinations. The issue of accessibility as linked to urban sprawl appears different in Ghana. The informal system, supporting petty retailing and other social services, within neighbourhoods limits the purpose of travelling and also reduces the cost of mobility. Again, the weak planning system (reflected in outdated provisions and lack of enforcements) in Ghana does not ensure pure homogenous and fragmented land uses as the case of U.S appears.

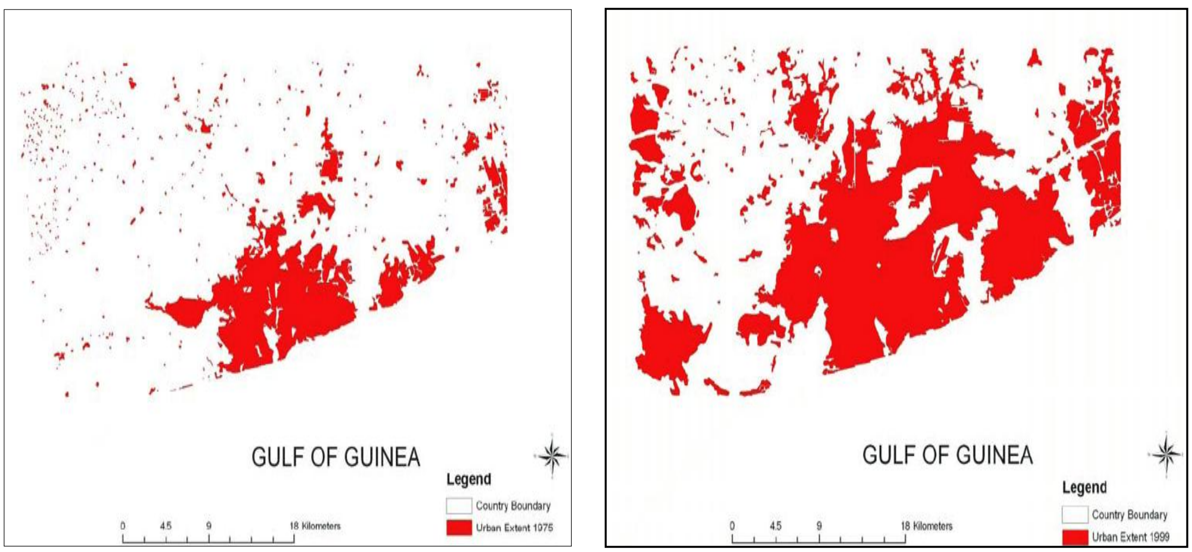
Urban development and expansion are residentially driven (Yeboah, 2000) and interspaced with petty commercial and social services to meet the needs of neighbourhoods. As already discussed under the social dimension of urban sprawl, the problem of accessibility that urban sprawl appears to create is benign in Ghana as the informal urban transportation system makes almost every settlement point accessible. The point on accessibility and its advantage in Ghana is with reference to *access.* That is, being able to get to places of choice and in touch with services without necessarily emphasising the ease of getting there. Obviously, the high car ownership rate in the U.S appears to enhance mobility and ensures ease of getting to places of choice as compared to Ghana. On the average, commuting times in the U.S would be lower as compared to Ghana due to the ease of mobility and relatively good roads.

Aesthetics

Aesthetically, urban sprawl is maligned in literature, particularly in the U.S, as aesthetically distasteful (Clawson, 1962; Abrams, 1971; Lessinger, 1962). One of the often criticised patterns apart from the dislike for its low density and scattered pattern is the *strip* or *ribbon pattern* - commercial developments flanking highways and exits of highways (Torrens & Alberti, 2000). In the U.S, those commercial developments along highways spring up to serve suburban commuters and dwellers. *Strip* or *ribbon* development pattern is an old and common phenomenon in Ghana. Poor road development and accessibility make most towns to develop, linearly, along highways and thoroughfares (See Doan & Oduro, 2011). Unlike the U.S where such *strip* or *ribbon* developments are more or less commercial alleys, in Ghana it is a mixture of both commercial and residential developments. In the U.S and other developed countries, where planning regulations are adhered to and enforced, highways or trunk roads are usually aligned from settlements or city centres with connections achieved through exits and ramps. However, the weak planning system (reflected in outdated provisions and lack of enforcements) coupled with poor accessibility in Ghana has made developments along highways an acceptable and conventional pattern of urban development. The aesthetic criticisms of the *strip* or *ribbon* development pattern are premised on deviation from the norm in the U.S. However, in Ghana whether or not *strip* or *ribbon* development pattern is an unintended planning practice or legitimate need for accessibility which has now become a norm is one issue that is debatable when describing urban sprawl.

Dynamics

Much as some researchers posit that urban sprawl is a moment of time (Harvey & Clark, 1965; Schmid, 1968; Ohls & Pines, 1975; Ottensmann, 1977; Peiser, 1989; Ewing, 1994), there is little in literature, particularly in the U.S, to prove empirically that sprawl metamorphoses into compact and desirable developments (Galster, Hanson, Rafcliffe, Wolman, Coleman, & Freihage, 2001). In the U.S, it appears this dynamics of development is discounted with urban sprawl usually perceived as a state and not a process. In Ghana, the dynamics of development cannot be discounted, as a development that is initially perceived as a sprawl could turn out to be filled-in and compact in a short time. Figure 3.7 shows a highly sprawled development in the Greater Accra Metropolitan Area (GAMA) in 1975, gradually metamorphosing into a dense development by 1999.



Built-up area of GAMA, 1975 Built-up area of GAMA, 1999

Figure 3.7 The Extent of Built-up Area of Greater Accra Metropolitan Area From 1975-1999

Source: Afeku (2005)

Unlike Ghana, some basic infrastructure (roads, water and electricity distribution networks) usually precede development in the U.S. This means that, in the U.S, development is a function of infrastructure which controls and predicts the possibility and rate of densification of an initial sprawling development. The case of Ghana is different. The development practice whereby houses precede or are built in anticipation of infrastructure (Yeboah, 2000) serves as a catalyst for development annexation and in-filling in Ghana. This practice makes land previously skipped to be rapidly used up for development and consequently ensure densification. Figure 3.8 indicates a high share of unpaved roads in top 15 urbanised areas in Ghana. The high share of the unpaved roads can be simply explained by the practice of development undertaken in anticipation of infrastructure. Most of the unpaved roads are located at urban peripheries.

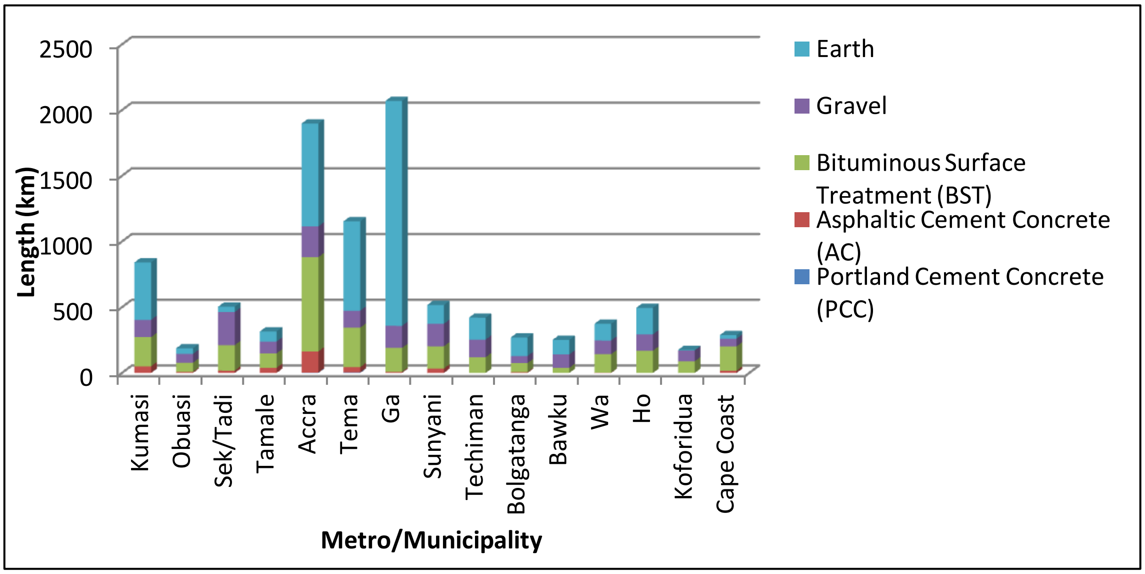


Figure 3.8 Composition of Road Surface Type in Metropolitan and Municipal Areas in Ghana As of 2006

Source: Ministry of Roads and Highways, Ghana, (2007)

A careful look at development patterns in Ghana depicts a continuum of development from what appears to be sprawl initially to a densed development later. The dynamic nature of development in Ghana makes urban sprawl to be more of a *process* than a *state* in Ghana.

Open space

The consequence of urban sprawl eroding open spaces is evident in both the U.S. and Ghana. Lands that were previously for agricultural and forest uses are now converted to urban uses in both countries. However, addressing the issue of eroding open spaces as a characteristic or indicator of urban sprawl requires a decoupling of its environmental concern from the recreational value in the Ghanaian context. In the U.S, both environmental and recreational concerns are fused when discussing the consequence of urban sprawl from the point of view of open spaces. The culture of relaxing and recreating at an open space such as a park is not part of the daily lifestyles of Ghanaians and are usually not emphasised in urban planning. Passmore (2011) also reveals that though larger conservation-style parks (Kakum National

Park, Mole National Park, etc) exist in Ghana, they are usually disconnected from the daily lives of Ghanaian and treated as sanctuaries, functionally, operating for tourists. Lifestyles are changing due to Ghanaians travelling abroad and foreign people, particularly with western descent, moving to Ghana. However, generally, the perception of an average Ghanaian of urban sprawl from the point of view of open spaces is likely to be its environmental concern and not for recreational purpose. This raises a concern of the acceptability of open spaces in and around urban areas in Ghana and whether their erosion is considered a phenomenon of urban sprawl.

3.1.4 Overview of urban sprawl in Ghana and the United States

Though literature on urban sprawl in developing countries has been emerging over two decades now, much work would still be required to further give more insights into the phenomenon in developing countries. Furthermore, analyses on the differences and similarities of the phenomenon between developing and developed countries are scanty. More researches and debates are required to fill the gap that exists in this area. The analysis of the differences and similarities of urban sprawl in U.S. and Ghana is summarised in Table 3.6.

Ten dimensions of urban sprawl, widely discussed in literature, were evaluated against five assessment measures. The dimension of cost was omitted from the evaluation since it is discussed extensively under section 3.2. In evaluating the urban growth dimension against the five assessment measures, urban sprawl appears to be similar in both countries (See Table 3.6). However, a slight distinction exits as in the way the socio-economic situation in Ghana influences urban growth as a cause of urban sprawl. Unlike the U.S., the uneven development and urban primacy situations fuel urban growth in Ghanaian cities to induce sprawl other than mere rise in per capita land demand as the case of U.S. may be. Besides, the benefits of sprawl which is deemed to induce such an undesirable development pattern share some similarities in both Ghana and the United States (See Table 3.6). However, the cultural consideration of Ghanaians which is deemed to support urban sprawl in Ghana (Yeboah, 2000) is one distinguishing factor of the Ghanaian version of sprawl from the version in the United States. From Table 3.6, public and statutory regulations are deemed to induce urban sprawl in both countries. However, the application or non-application of the public and statutory regulations reveals a distinction as to how urban sprawl occurs in Ghana and the United States.

Enforcements of public and statutory regulations appear to lead to sprawl in the U.S while lack of planning or no enforcements equally lead to urban sprawl in Ghana.

From the perspective of the social problems of urban sprawl, the versions in Ghana and U.S. share some similarities (See Table 3.6). The decline and loss of population at the urban core in U.S and the booming urban core in Ghana serve as one major difference with regard to the social implications of urban sprawl in both countries. Notwithstanding, both countries share a similar phenomenon of movement of people from the urban core to the peripheries. However, the reasons for the movement differ in both countries (See discussion under social problems dimension). Moreover, the high degree of informality in urban developments in Ghana makes the segregation problems of urban sprawl benign and deviates – to some extent – from the version in the United States.

As seen from Table 3.6, decentralisation, a defining characteristic of urban sprawl is evident in both Ghana and the United States. However, what differentiates the version of urban sprawl in Ghana – with respect to this dimension – from the version in the U.S. is the fact that in Ghana the decentralisation is mainly population based while in the U.S., it both population and economic based. On the dimension of low density development (See Table 3.6), the version of urban sprawl in Ghana is very similar to the version in the United States. Perhaps, what differentiates the version of urban sprawl in Ghana from the one in the U.S. – on this dimension – is what informs the low density developments in both countries (See discussion under the dimension of low density development). Furthermore, from the perspective of accessibility (See Table 3.6), the version of urban sprawl in Ghana is – to some extent – different from the version in the United States. The informal urban development feeding into traditional settlement systems differentiates the Ghanaian version of urban sprawl from the U.S. on the grounds of accessibility.

Table 3.6 Perception of Urban Sprawl in U.S. and Ghana

Dimension of Urban Sprawl	Evident in Both Countries	Strongly Linked to Urban Sprawl in Both Countries	A Deviation from the Norm[1] in Both Countries	Perceived as Undesirable in Both Countries	Unequivocally a Deviation from Developed Countries' Version of Urban Sprawl
Urban Growth	Yes	Yes	Yes	Yes	Probably
Social Problems	Yes, but urban decline in U.S. and booming urban core and slums in Ghana	Yes	Probably	Probably	Probably
Spread of Employment and Population to Suburban Areas	Yes in U.S., but mainly population based in Ghana.	Yes, but only on the account of population in Ghana	Yes	No clear agreement	Probably
Low Density Development	Yes, but with a relatively higher overall density in Ghana than the U.S.	Yes	Yes	Yes in U.S., but no clear agreement in Ghana	No
Poor Accessibility	Yes in U.S., but no clear agreement in Ghana	Yes in U.S., but no clear agreement in Ghana	Yes in U.S., but no clear agreement in Ghana	Probably	Probably
Poor Aesthetics	Yes	Yes	Yes in U.S., but no clear agreement in Ghana	Probably	No
Dynamics	Not clear in U.S., but Yes in Ghana	No clear agreement in U.S., but Yes in Ghana	Not clear	No	Yes
Open Spaces Erosion	Yes	Yes	Yes in U.S., but no clear agreement in Ghana	Yes in U.S., but not a general concern in Ghana	No
Benefits	Yes	Probably	No clear agreement	No	Probably
Public and Statutory Regulations	Yes	Yes, but enforcement leads to sprawl in U.S while the converse is true in Ghana	No clear agreement	Probably	Probably

All of the two environmental dimensions of urban sprawl (poor aesthetics and open spaces erosion) indicated a "No" deviation from the developed countries' version of urban sprawl

[1] Norm here refers to traditional or long-established practices which are usually perceived as yardsticks for comparing current developments.

(See Table 3.6). This means that the environmental effects of urban sprawl are felt and evident in both Ghana and the United States. With respect to the dimension of dynamics (See Table 3.6), the version of urban sprawl in Ghana appears to achieve a faster development compaction rate in comparison with the version in the United States. The conventional development process in Ghana seems to make the version of urban sprawl in Ghana a transitory phenomenon and – to a large extent – deviates from the U.S. version which is perceived as a stationary phenomenon.

3.1.5 Policy implications of analysis

The above analysis clearly shows that the phenomenon of urban sprawl albeit evident in developing counties (particularly Ghana), does not fit exactly into the developed countries' scheme of urban sprawl, both in causes and impacts. This requires urban sprawl to be partly dealt with, both in causes and impacts, in a more local or indigenous ways other than addressing it – completely – with policies from developed countries. For instance, the cause of urban sprawl in Ghana requires a national planning or development strategy to deal with the phenomenon. Such a national strategy must seek to alleviate the unevenness in regional developments so as to deal with the excessive pressures on primate cities which tend to sprawl under such excessive pressures. In that sense, the infrastructure demand and costs under such sprawling conditions in the primate cities could be reduced. Again, the local and cultural considerations of Ghanaians underpinning urban sprawl could be managed through an innovative housing supply scheme. The innovative housing supply scheme shall be in the form of public-private partnership where government policies and directives provide an enabling environment for private delivery of houses other than the uncoordinated decisions of individuals in the construction of homes.

Moreover, the impacts of urban sprawl in Ghana in terms of social problems, economic and population decentralisation, poor accessibility and development dynamics appear to differ (to some extent) from the scheme of impacts in the United States. This deviation is not accidental but can be explained by the adaptive failure of the modernist planning model (Doan & Oduro, 2011). Doan & Oduro (2011) argue that the urbanisation process in African cities is on one hand a reaction against the imposed orderliness of the "Western" planning model and on the other hand, a longing for the density and vibrancy associated with more traditional African urban forms. Hence, dealing with urban sprawl and its associated infrastructure costs in Ghana requires a considerable attention to be paid to the traditional values of Ghanaians. This could reflect in the engagement of local people, for the inclusion of their values, when carrying out formal planning rather than the direct imposition of the "Western" planning model. Again, since urban sprawl is more of a transitory phenomenon in Ghana unlike the U.S., infrastructure development could be carried out in a stepwise manner or in phases to reduce the up-front costs. That will require infrastructure development technologies or systems that lend themselves to future upgrading.

3.2 The Transferability of costs-of-sprawl studies results to developing countries

The discussion of the transferability of costs-of-sprawl studies results to developing countries focuses on infrastructure costs. Most literature on this subject is from developed countries. The question of whether or not the results are applicable to developing countries also deserves a consideration. The impacts of conventional development patterns, precisely fiscal cost of development, have been a great concern over the past three decades in developed countries. This has attracted and still attracting a lot of debates in literature. The debate intensified after the seminal work of Real Estate Research Corporation (RERC) in the U.S. in 1974 under the title "The Costs of Sprawl". The study attempted to unveil the excessive costs associated with urban sprawl by summarising what is known about the various costs as they apply to different neighbourhood types and to different community development patterns. The study, although, received much attention and wide spread citations in literature, did not go without criticisms. Some researchers (Windsor, 1979; Altshuler, 1977) criticised its assumptions and conclusions as flawed. Despite the criticisms, "The Costs of Sprawl" study is deemed to be the spine of costs-of-sprawl studies in developed countries as most studies in this field, after its publication, make most references to it.

Though methodologies of costs-of-sprawl studies in developed countries vary among authors, the objective is similar, if not the same – how do some features or properties of urban development relate to infrastructure cost? Literature so far reveals such features or properties of urban development as shown in Table 3.7.

Table 3.7 Features of Urban Development Related to Infrastructure Costs

Urban Development Feature	Source
Density	Real Estate Research Corporation (1974); American Farm Land Trust (1986); Duncan et al. (1989); Ladd (1992); Biermann (2000); Burchell & Mukherji (2003); Suen (2005); Najafi et al. (2007)
Lot size	Speir & Stephenson (2002); Mohamed (2009)
Lot shape	Suen (2005)
Location of development	Speir & Stephenson (2002)
Dispersion of development	Speir & Stephenson (2002)

The results in literature indicate that density varies inversely with infrastructure cost. As shown in Figure 3.7a, the cost of infrastructure decreases with increasing density. However, Ladd (1992) opines that there is a point in increasing density beyond which the infrastructure services cost per capita begins to rise. She claims that as density increases, it requires a commensurate quality of service which if ensured does no longer reduce the infrastructure cost per capita. Figure 3.7b indicates the increase in infrastructure cost with increasing lot size. Speir & Stephenson (2002) point out that lot size influences the infrastructure cost significantly and increases with increasing lot size. Mohamed (2009) however presents a contrary result that increasing lot size decreases infrastructure cost. The seemingly reduction in infrastructure cost with increasing lot size in Mohamed (2009)'s work is accounted for by the significant reduction in the standard of infrastructure. Suen (2005) empirically proves that infrastructure cost decreases with increasing parcel or lot shape index. Figure 3.7c shows an inverse relationship between infrastructure cost and parcel or lot shape index. In essence, higher ratios of lots' perimeters to the square root of their areas result in decreasing infrastructure cost and vice versa. Speir & Stephenson (2002) conclude that high development tract dispersion as well as longer distances of new developments from existing infrastructure leads to higher infrastructure cost. Figures 3.7d and 3.7e indicate a direct relationship between infrastructure cost and dispersion of developments and location or distance of new developments from already established centres respectively.

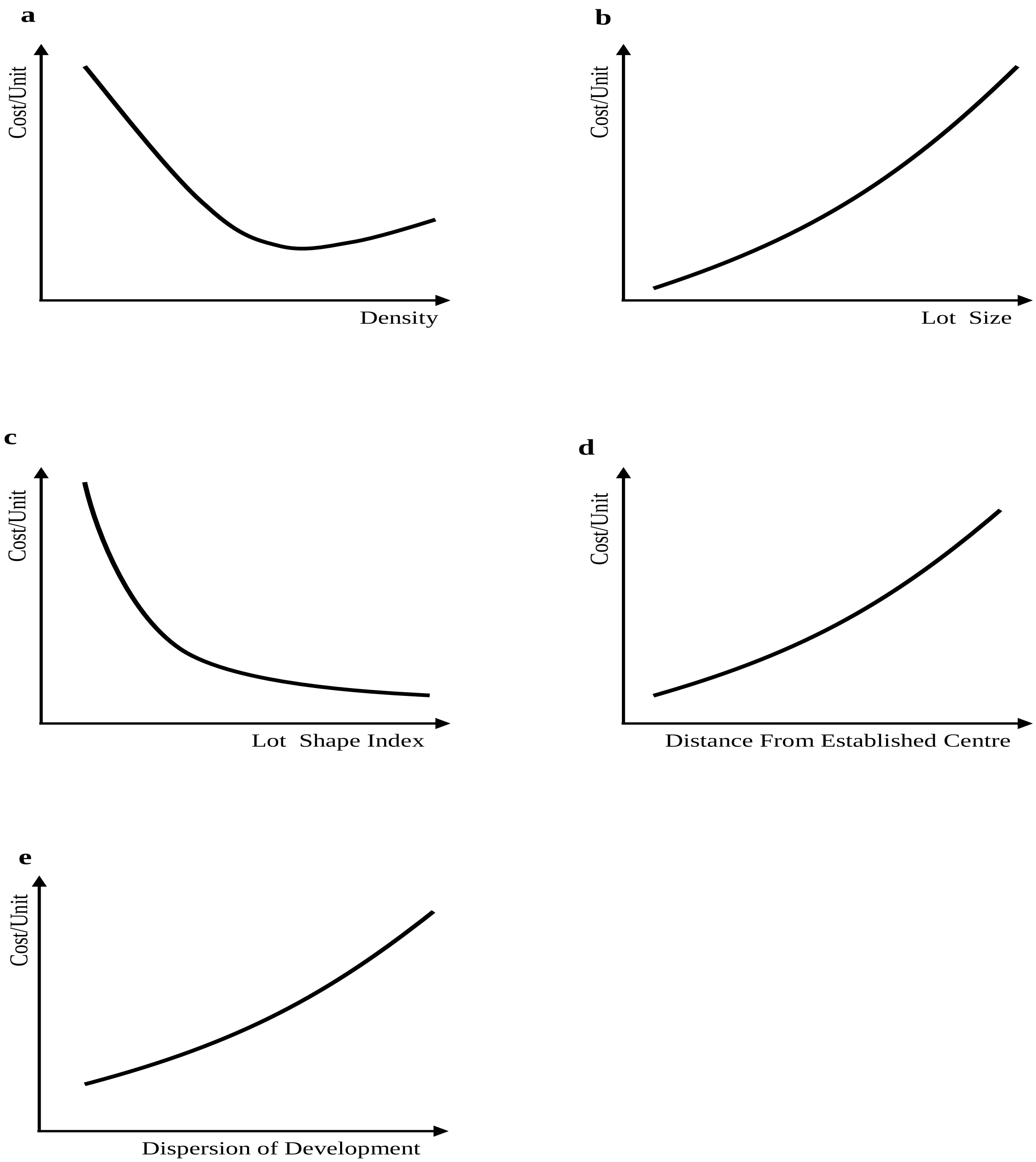


Figure 3.9 Relationships Between Infrastructure Costs and Urban Development Features

The relationship between these urban development features and infrastructure cost is independent of the socio-economic situation of any particular region. Hence, the results of costs-of-sprawl studies are, presumably, applicable in both developed and developing countries.

However, the cost figures that result from the various costs-of-sprawl studies in developed countries cannot be, wholly, taken and applied in developing countries. This is because the standards of infrastructure which form critical part of the assumptions of cost-of–sprawl studies in developed countries are quite different from the ones in developing countries. The standards of infrastructure in developing countries are usually lower as compared to developing countries. Therefore, it appears any comparative analysis between different development patterns (high density and low density) may reveal an insignificant difference in terms of infrastructure cost. Besides, most developing countries develop infrastructure incrementally, unlike developed countries where complete infrastructure are developed within a planned and a short time. The incremental development pattern changes the cost dynamics and makes it difficult to compare with developed countries scenario.

Generally, the intrinsic purpose and results of costs-of-sprawl studies in developed countries are relevant to developing countries as well. What is essential for developing countries is a cautious interpretation of the results from developed countries. Again, policy implications of the results of costs-of-sprawl studies in developed countries should be adaptive to the local environment in developing countries.

4. INFRASTRUCTURE COSTS OF URBAN FORMS: An analysis of developing and developed countries

In discussing how infrastructure costs relate to urban forms, especially with the focus on differences and similarities in developing and developed countries, it is important to analyse the urban structures of the different economic regions of the world. This provides the basis for identifying how infrastructure costs are fashioned by the urban structures in both developing and developed countries. On that premise, the required policies could be put in place to handle infrastructure costs vis-à-vis urban forms in the different economic regions of the world. The current chapter discusses the existing urban structures of both developing and developed countries and how the urban structures influence infrastructure costs and financing.

4.1 Urban structure of developing countries

Developing countries referred to in this discussion is with particular reference to Third World countries with colonial backgrounds. The picture of urban structures, in Third World countries, as painted and described in this chapter are just models and not typical and exact structures in any city even though most of the elements may be found in most cities in Third World countries.

The analysis of settlement patterns is very useful in optimising infrastructure services and facilities to human settlements and also to increase their carrying capacities (Mahavir, 2004). A better harmony can exist between settlement patterns and infrastructure optimisation, if there is an understanding of the existing spatial patterns. Smith (1965) posits an analysis of the evolution of areal patterns in order to understand the spatial patterns. This cannot be done without examining the genesis of cultural forms and an understanding of change over time (Al-Hathloul & Edadan, 1993).

Third World countries with colonial backgrounds, at a general level, have similarities that depict an evolution from an indigenous, colonial to modernism in their urban structures. In analysing the urban structures of developing countries with colonial backgrounds, one needs to consider all these three stages (indigenous, colonial and modernism) of developments in these countries. Objectively, some of the elements in the urban structures of these developing countries are as a result of traditions that have been modified by foreign influences that go back 300 years and more in India, parts of Africa and elsewhere (Weinstein & McNulty, 1980). Weinstein and McNulty (1980) further indicate that it is only in the most ideal sense or the most remote past can traditional urban structure be identified. In this regard it will be fair to discuss the urban structures of developing countries from the colonial era to the modern era.

4.1.1 Colonial urban structure

Understanding the urban structure of most developing countries, especially the Third World, requires a consideration of the social, economic and political history of those countries (Stren & Halfani, 2001). Stren & Halfini (2001) further point out that most of African major urban centres or cities were primarily founded for commerce and administrative purposes during the colonial times. This shows the deeply rooted colonial economic framework in the urban structures of African cities with the main emphasis on the exploitation of natural resources. Not only in Africa, but in other developing countries, Pacione (2009) claims that imperialism, mostly from European powers, influenced urban structures through investments in transportation and infrastructure mainly for the extraction of primary products. The economic benefits which were at the heart of colonialism also led to the location of many primate cities in those regions at the coast (McGranahan, Balk, & Anderson, 2007; Hardoy, 1977; Hugo, 1978).

Probably the most conspicuous characteristic of urban structure, cutting across most developing countries, was the partitioning of urban space into two highly uneven zones: an "European" space that enjoyed a high level of urban infrastructure and services and an "indigenous" space that was marginally serviced (Stren & Halfani, 2001; Richardson, 1978; Branwen, 2009). This phenomenon in most developing countries is referred to as *dual cities* in literature. These two forms exist side by side and are weakly interrelated producing their own morphological patterns (Friedmann & Wulff, 1975). This appears to be a major challenge in *spatial engineering* in most developing countries, especially where efficiency in human settlement patterns and optimisation of infrastructure services are required. McNulty (1976) captures the challenge vividly in the following statement: "More planning appears futile; less planning appears irresponsible; single-minded modernisation appears unpatriotic, single-minded promotion of traditional ways appears jingoistic. Yet, attempts to achieve a meaningful synthesis have not been able to displace the old formulas". Figures 4.1, 4.2 and 4.3 depict the phenomenon of urban dualism in Africa, Latin America and South East Asia respectively.

In Africa, economic activities were centralised at the urban core with the rich indigenes, actively engaged in economic activities, locating close to the urban core while the less privileged and the poor located at the urban peripheries. Furthermore, in Latin America, Smith (1955) asserts that the socially advantaged class lived in areas of accessibility, close to the seat of governmental and ecclesiastical powers surrounding the plazas, while the poor lived at the peripheries of urban areas.

Colonialism in most developing countries emphasised urban primacy where economic and political powers were concentrated in a few cities (Pacione, 2009). Regionally, this approach was not ideal as it laid the foundation for sharp disparities between primate cities and other areas. Unlike Latin America and South East Asia, this phenomenon has contributed to a great extent the low level of urbanisation on the continent of Africa, especially Sub-Saharan African countries.

4.1.2 Contemporary urban structure

The initial structures of cities in most developing countries were based on colonial mind sets and objectives and subsequent developments have been more of elaborations than transformations (McNulty, 1976; Smith, 1955). The colonial concept of urban development in a traditional setting has produced so called eclectical urban structures in most developing countries. Reinforcing the spatial eclecticism in developing countries, Hackenberg (1980) claims that unlike in Europe, North America and Japan where urbanisation evolved side by side with industrialisation, so called *secondary urban structures* are evident in developing countries as technically perfected and matured systems are introduced into traditional environments without any sufficient time for evolution and adaptation. The urban dynamics and forms in post-colonial African cities are shaped by urban residents, both powerful and subaltern (Simone, 2004). The weak legislations, reflected in outdated provisions and lack of enforcements, partly contribute to this challenge in most African cities.

Generally, developing countries in Africa, Latin America and South East Asia have common urban structures as seen from the models in Figures 4.1, 4.2 and 4.3. The contemporary urban structures of developing countries in Africa, Latin America and South East Asia radiate from central points called the Central Business Districts (CBDs) (See Figures 4.1, 4.2 and 4.3). These CBDs were originally traditional and local in their structures, but have currently evolved into two separate markets or districts – modern and traditional markets. Beyond this zone is a high density settlement. In Africa and South East Asia this zone comprises indigenous settlements which are unserviced. However, in Latin America, this zone used to be the settlement of the elite and the socially advantaged who wanted to be close to the seat of power, but have relocated to other parts of the cities classified as the elite zone. Consequently the settlement in this zone is serviced. In Latin America, portions of this zone - usually referred to as *zone of maturity* - are undergoing *gentrification* with support from government legislation to conserve some historic townscapes (Pacione 2009). However, in Africa and elsewhere, the gentrification process in the same zone is being spearheaded by private estate developers who build luxurious apartments and facilities for a section of the upper middle and higher income groups who want to enjoy locational advantages of their residences. The locational advantage is derived from the availability and proximity to infrastructure.

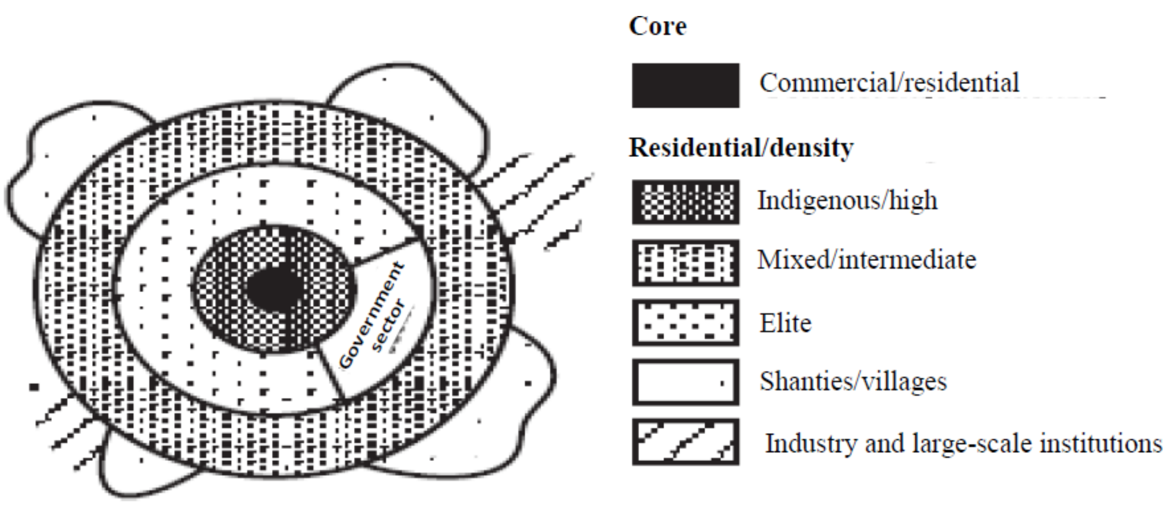


Figure 4.1 A General Model of An African City Structure
Source: United Nations (1973)

Adjacent to or beyond the indigenous zone is the elite zone which used to be the settlement of the former colonial masters with low density patterns and highly developed infrastructure. This zone houses the administrative and governmental quarters of the city.

Gilbert (1993) puts forward that the Structural Adjustment Programmes (SAPs) introduced in developing countries by the World Bank has produced a polycentric kind of urban patterns in Latin America due to improved infrastructure and accessibility coupled with diseconomies in large cities. On the other hand Briggs & Yeboah (2001) indicate that the trend of development patterns due to the SAP in Africa is different from the one in Latin America as the bulk of the capital investment is concentrated in the primate cities leading to urban sprawl. Despite the different impacts of the SAPs in Africa and Latin America, generally the colonial heritage of urban primacy in developing countries makes the primate cities preferred locations for Foreign Direct Investments (FDIs). These FDIs coupled with the SAPs have increased the expatriate communities and consumption in most primate cities of developing countries. This development has made the real estate sector very lucrative, driving cities outward (Briggs & Yeboah, 2001). The sporadic outward expansion of the cities has merged cities with old and formerly remote traditional settlements. In Africa this produces the zone of mixed/intermediate residences (See Figure 4.1). In Latin America it is the zone of in situ accretion (See Figure. 4.2).

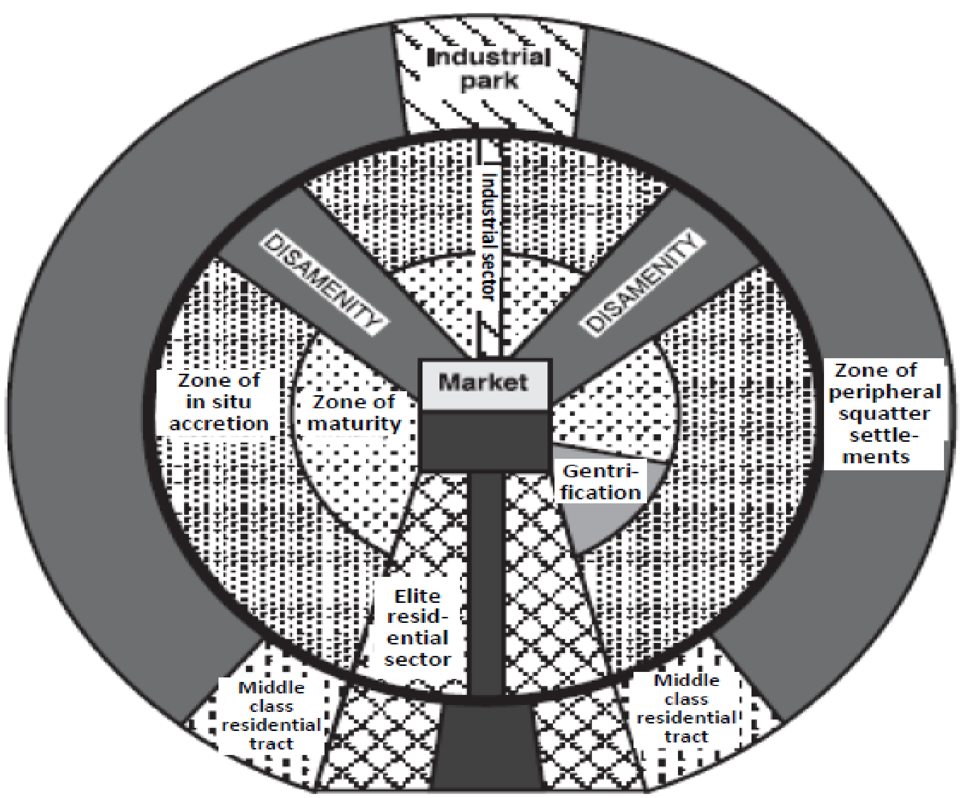


Figure 4.2 A Model of The Latin American City

Source: Ford (1996)

In South East Asia, this zone is seen as the new wealthy and middle class residential extensions with squatter settlement enclaves (See Figure. 4.3). The quality of housing in this zone varies from very poor quality to very posh ones. Service and infrastructure developments also vary in this zone. This zone is envisaged to improve over time, but that will primarily depend on the national economic health and the economic prospects of the residents (Pacione 2009). The zone of rural or squatter settlements forms the outer space of the urban structure of most developing countries. See Figures 4.1, 4.2 and 4.3 for this zone in African, Latin American and South Asian cities respectively. Within this zone are also located some heavy local industries. Even though some of these industries are located along designated spines called *industrial spines,* focusing on the Central Business District (CBD) as in the case of Latin America (See Figure. 4.2), industrial zones of developing countries are usually located at the urban peripheries. The zone of rural or squatter settlement is unserviced and provides home for the rural-urban migrants who are not able to afford expensive housing at the urban core and inner zones of the cities. Due to improvements in transportation nowadays in developing countries, the poor from this rural or squatting zone could commute long distances to the urban core to participate in economic activities.

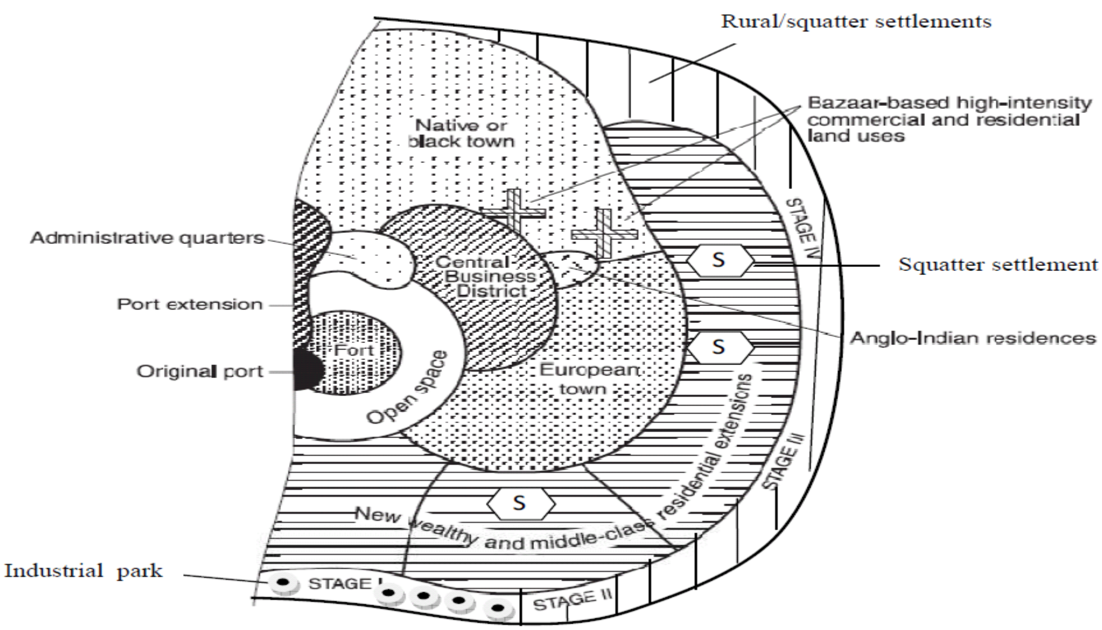


Figure 4.3 A Model of The Colonial Based City in South Asia

Source: Adapted from Brunn & Williams (1983)

4.2 Urban structure of developed countries

The developed countries as referred to in this section is with particular reference to Western European countries, North America, Australia, New Zealand and Japan.

Cities and towns might have occupied the same location for centuries, but the buildings and other physical infrastructure which constitute their built environment are not fixed but go through dynamic processes which are spearheaded by public and private interests (Pacione 2009). In understanding the dynamics of urban structures, the study of *urban morphogenesis* holds the key. The urban morphogenesis of all cities and towns take their roots from an influential work by Conzen (1960) who divided the urban landscape into three main elements of town plan, building forms or fabrics and land use. Conzen (1960) posited the reaction to change by the three main urban elements as follows:

- Town plan: comprising the site, streets, plots and block plans of building are most resistant to change.
- Building forms or fabrics: usually comprising heavy capital investments are adaptable to other uses without necessarily replacing them and hence change occurs at a slower rate.
- Land use: specifying the purpose of each tract of land and hence the most susceptible to change.

Players on the urban market, using these three main urban elements, give the structure to all cities and towns. In developed countries, a number of models have been developed over the years to paint a picture of the urban structures of cities and towns. However, in this chapter only the major ones will be described briefly to serve as the basis for how infrastructure costs and financing are influenced differently by urban forms in both developing and developed countries.

4.2.1 Burgess model

The Burgess urban structure model developed in 1925 was based on one city, Chicago in the United States. This has been one of the criticisms of the model. However, it still portrays the urban structure of some cities and towns in developed countries. The model is based on concentric circles of urban land uses or structure. It begins with the first and inner ring, Central Business District (CBD) which is the focus of commercial and social activities and spread out in subsequent concentric circles based on social, economic and ethnic classes (See Figure. 4.4).

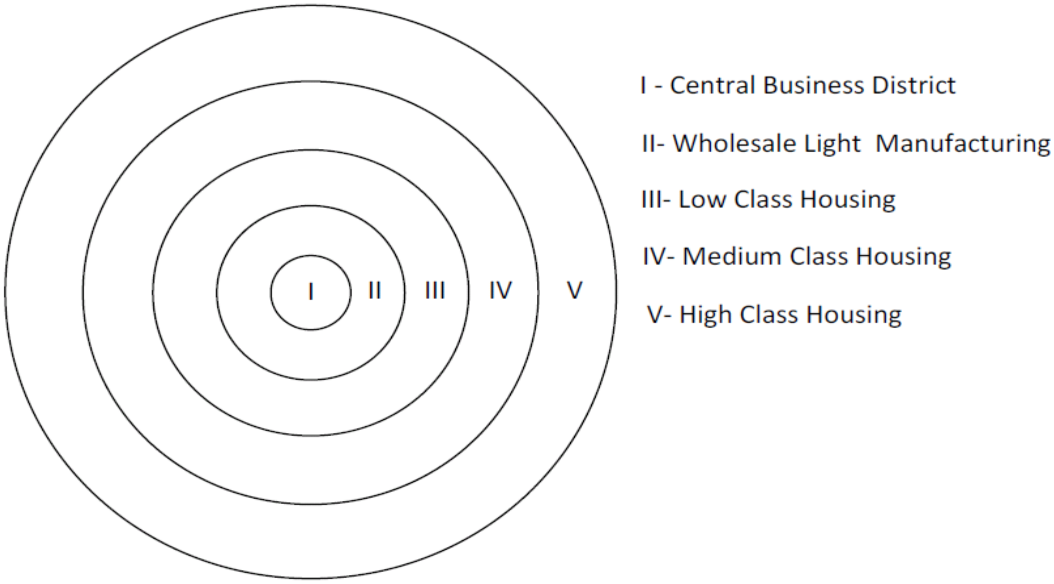


Figure 4.4 Burgess Urban Model of Land Use

Source: Barcelona Field Study Centre (2010)

From the model, light industrial land uses surround the CBD with the poor and immigrant workers locating close to these industries for economic purposes and also to avoid long commutes. The rich and the high social class groups, who have access to cars, locate far away from the city core in order to avoid the pollution and congestion at the city core. This is somehow in contrast with models of urban structures in developing countries where the poor and rural-urban immigrants locate at the peripheries of cities and towns.

The Burgess model is usually criticised for being old and not reflecting the current urban structures of today. Again, it is being discredited for assuming a flat land for all urban areas with equal transportation costs while neglecting the importance of good transportation to settlement developments.

4.2.2 Hoyt model

The Hoyt model developed in 1939 was based on 142 American cities (Hoyt, 1939). Hoyt mapped out the average residential values in each city and came out with the following conclusions and the consequent urban model as shown in Figure. 4.5.

- High income families lived in sectors, at desirable places along unpolluted rivers or beautiful landscapes, rather than in concentric circles as put forward by Burgess.
- High income families who can afford automobiles lived far away from the city centre, but settled along major roads and highways.
- Low income families occupied less desirable places or obsolete housing of the rich.

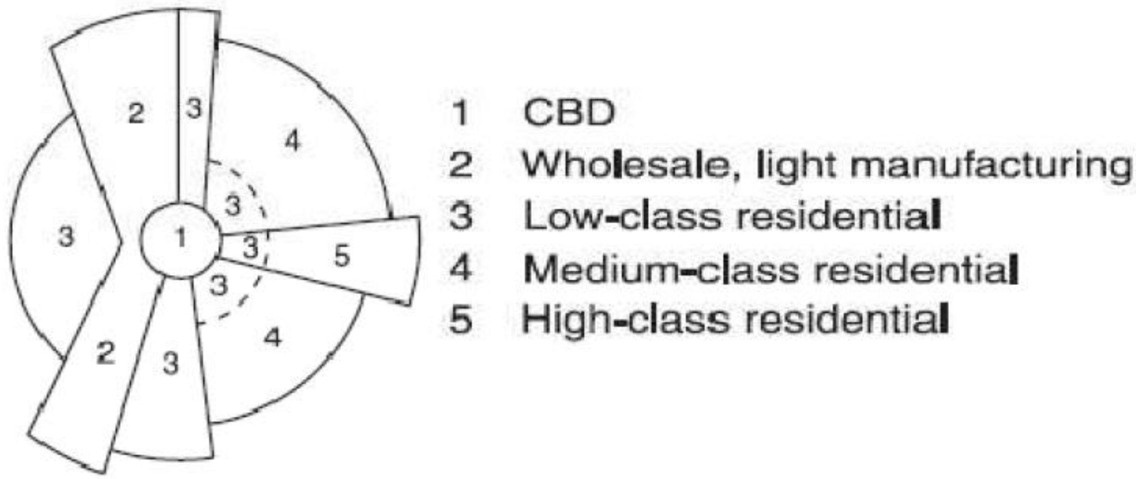


Figure 4.5 Hoyt's Urban Model of Land Use
Source: Pacione (2009)

The Hoyt’s model is also usually criticised for being outmoded. Not only that, its heavy emphasis on economic characteristics of spatial structure ignoring other equally important characteristics such as ethnicity and race is condemned by critics. Another major weakness of the Hoyt’s model lies with the fact that, it only considers residential land uses without considering other land uses in its spatial modelling of urban structures.

4.2.3 Multiple nuclei model

The recent developments in Information and Communication Technology (ICT) coupled with other factors have transformed most economies of developed countries from manufacturing base to service base. Improvement in transportation nowadays, working in tandem with this economic change, has made both capital and humans more mobile and diffused economic activities in most developed countries.

The Multiple Nuclei model, developed by Harris and Ullman in 1945, seeks to address the current trend of developments in cities and towns of developed countries and points out that both the concentric and sector models of city and town structures are overly simplistic (Pacione, 2009). At the kernel of the model is the fact that most cities do not grow around single CBDs, but do so by a continuous merging of separate nuclei or points of attraction (See Figure 4.6). The model is founded on the following principles:

- Some activities are not compatible as with industries and high income residences due to the high negative externalities
- The need for some specialised facilities by some industries, such as good transportation corridors and ports, may influence the location of these industries where those facilities could be found.
- The economic principle of *choice* may force some activities which may gain by locating close to CBDs, but because of their excessive demand for space and high ground rents at the CBDs, locate further away from them.
- Some activities could enjoy external economies of scale by locating close to each other.

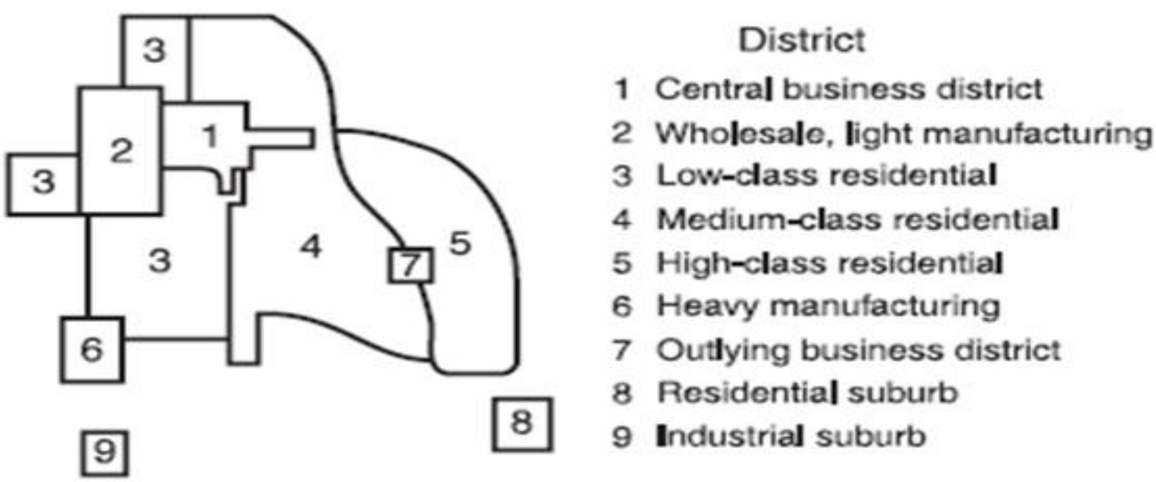


Figure 4.6 Harris and Ullman's Multiple Nuclei Model of Urban Use
Source: Pacione (2009)

The multiple nuclei model is also criticised for being economic centred without any cultural influences in explaining urban structures. It claimed that the sector model by Hoyt is overly simplistic and does not reflect so much of reality (Pacione 2009). However, analysing the principles of the Multiple Nuclei model critically, several sector-like patterns of urban structure with nuclei or points of attraction could also be envisaged.

4.3 Physical development costs in different contexts

In developed countries, most cities developed alongside industrialisation. Cities were planned with well defined layouts and infrastructure to support them. Evolution of cities in tandem with infrastructure development appeared to have ensured optimisation in the infrastructure development and costs in developed countries. However, in Third World developing countries, the existence of dual city structures seems to hinder the optimisation of city and infrastructure developments. Conventional infrastructure development began from the *European community* or *elite zones* with well defined layouts whereas the local settlements were compact with seemingly chaotic patterns. Extending infrastructure of the same standard as in the European community to the local settlements or developing conventional infrastructure within the local settlements becomes a subject of *threshold*. A threshold is reached with infrastructure development in such an environment as infrastructure cost rises suddenly beyond the normal with a lot of demolishing and compensations to be paid in order to lay the infrastructure. The elaboration of the dual city structures initiated by the colonial masters is also seen in another form through loose and unenforced state planning policies leading to eventual social segregation. Hardoy, Mitlin, & Satterthwaite (2001) claim that the poorest residents of cities in developing countries are usually forced (implicitly or explicitly) to inhabit flood plains and hazard-prone locations as they cannot afford suitable locations. The situation is a recipe for a physical threshold to be reached because any attempt to develop infrastructure in such an unsuitable environment could lead to a sharp rise in cost.

The subject of how infrastructure costs develop with urban forms is very important. However, the financing of the cost is equally important. In developed countries, the costs of infrastructure are financed by the inhabitants through the price they pay for the serviced lands. However, in most developing countries (especially in Ghana), governments or parastatals shoulder the costs of infrastructure (which usually follow developments) and recoup parts of their costs through connection fees and tariffs. Generally, in developed and developing countries, the means of financing infrastructure is based on the average cost principle. This has generated a lot of debates in literature among developed countries on the grounds that the average cost scheme of financing infrastructure does not ensure equity as suburban dwellers continue to be heavily subsidised by residents of inner cities (See Snyder & Stegman, 1986; Altshuler & Gomez-Ibanez, 1993; Brueckner, 1997). In view of this, it is advocated that marginal cost financing schemes, where new residents are made to pay the full costs of new infrastructure, be introduced in infrastructure costing and financing to deal with the inequity. The marginal cost financing scheme seems to be a pragmatic approach in developed countries as the urban structures in those countries (See Figures 4.4, 4.5 and 4.6) indicate the high income and the elite classes locating to the urban peripheries. The marginal cost approach in developing countries (particularly Ghana) may be unrealistic. The models of urban structures in Africa, Latin America and South Asia in Figures 4.1, 4.2 and 4.3, respectively, indicate the settlements of the low income households or squatters at the urban peripheries unlike the urban structures of developed countries. The model of African urban structure is supported by the recent empirical work of Doan & Oduro (2011) which described one of the urban development patterns in Accra as "village magnets" (See Figure 3.2).

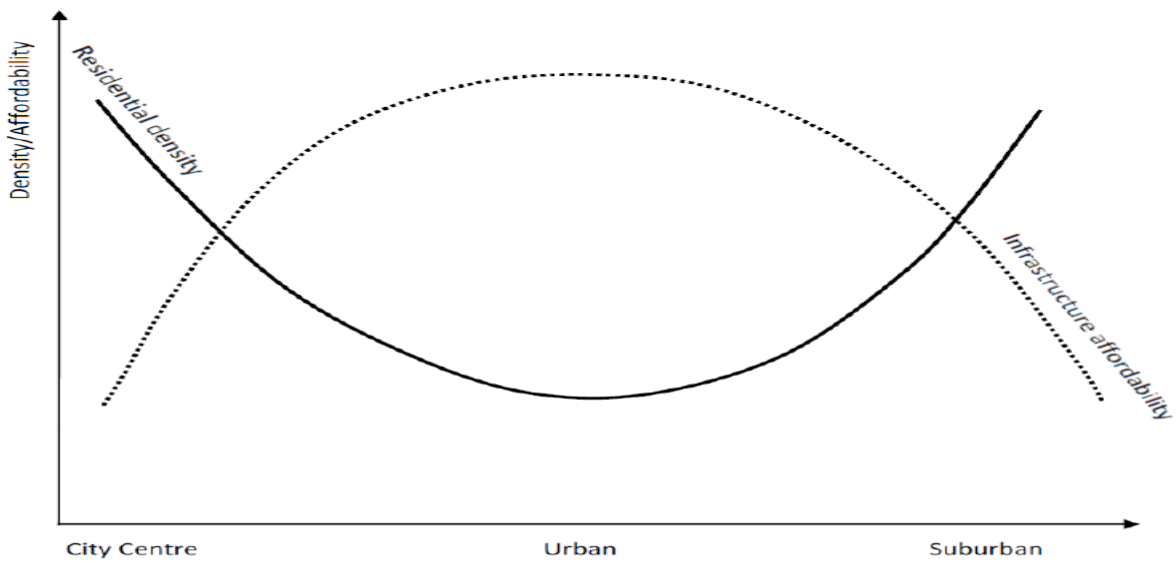


Figure 4.7 Pattern of Residential Density and Affordability in Third World Developing Countries

However, due to rapid urbanisation, especially in Ghana, those locations referred to as shanties in the UN model (See Figure 4.1) and otherwise termed "village magnets" (See Figure 3.2) in the work of Doan & Oduro (2011) have now become fast-growing densely populated pockets with predominantly low income households. Simon, McGregor & Nsiah-Gyabaah (2004) argue that – in Ghana – the difficulties of finding or affording accommodation within the existing city have warranted a substantial proportion of predominantly poor urban dwellers to resort to the urban fringe or peri-urban areas to buy, rent or construct their own shelter. This raises doubts on the applicability of the marginal cost system of financing infrastructure (especially in Ghana), since infrastructure have to be extended from locations close to the inner city to the urban peripheries which is predominantly settled by low income households. Brueckner (1997) argues that an efficient infrastructure financing scheme for a city is that which generates an efficient population path. He further argues that since consumer welfare is fixed, the efficient population path for a city is chosen to maximise the aggregate present value of net income of landowners in the region containing the city. However, since the income levels of the low income households at the peripheries are relatively low, it raises the question of whether or not making such low income households at the peripheries pay the full costs of required infrastructure, an efficient financing scheme. Again, as shown in Figure 4.7 for developing countries, as distance from the city centre increases, residential density decreases and begins to rise especially at the urban peripheries. This supports an assertion by Simon, McGregor & Nsiah-Gyabaah (2004) that the degree of "urbanness" (population growth and concentration), particularly in Ghana, follows a negative but a non-linear and non-uniform gradient in different directions around the city. The residential density pattern is matched by a rising income level of households with increasing distance from the city centre and thereafter falls, particularly, towards the urban peripheries (See Figure 4.7). The household incomes connote the ability of households to support the full costs of required infrastructure at those localities as indicated by the affordability curve.

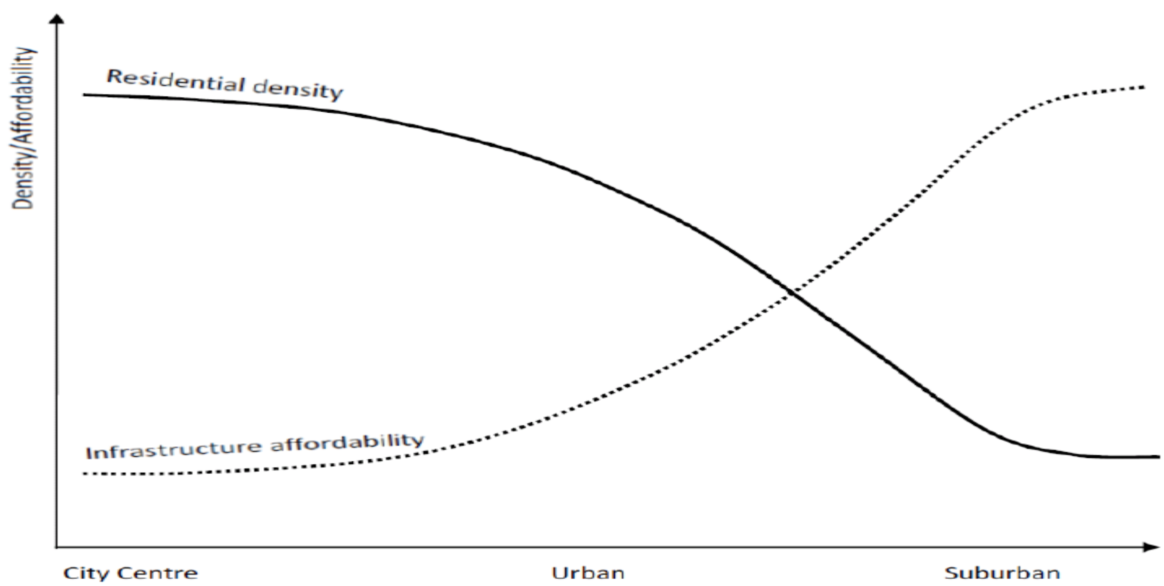


Figure 4.8 Pattern of Residential Density and Infrastructure Affordability in Developed Countries

On the other hand, Figure 4.8 indicates that in developed countries, residential density decreases with increasing distance from the city centre towards the urban peripheries.

Furthermore, as indicated by the models of urban structures of developed countries, the peripheries of developed countries unlike developing countries are characterised by middle to high income households. Hence, a corresponding affordability curve (ability of households to pay full costs of required infrastructure) in the case of developed countries shows a rising affordability curve with increasing distance from the city centre towards the urban peripheries. As seen from Figures 4.7 and 4.8, the dynamics of urban structures vis-à-vis infrastructure costs affordability in Third World developing countries are quite different from that in developed countries. This makes it very important to exercise some caution when interpreting and transferring physical development costs studies done in developed countries to Third World developing countries. Policies emanating from physical development costs studies in developed countries may not all be appropriate for Third World developing countries. Third World developing countries must focus on policies that could address their peculiar situations rather than taking, wholly, policies from developed countries with regard to infrastructure provision and financing. Hence, infrastructure financing policies that seek to adapt to the current financial capabilities, as well as maximising the net incomes, of the low income households at the urban peripheries would be deemed efficient policies in the context of developing countries. Such financing policies could be reflected in low costs infrastructure technologies which, importantly, have inherent mechanisms for upgrading to sophisticated standards in the future. The possibility of future upgrading to sophisticated standards will depend on the economic health of households as well as the nation.

5. CAPITAL AND SERVICES COSTS OF INFRASTRUCTURE AND URBAN FORMS

The variability of infrastructure costs with regard to urban forms has been confirmed in literature over three decades now. This section provides some key definitions and classifications as they relate to infrastructure and discusses the variability of infrastructure costs in view of urban forms. Besides, the chapter scrutinises previous seminal works on infrastructure costs vis-a-vis urban forms to ascertain the gaps and deficiencies of previous studies through an evaluation framework. The stand of previous studies ends this chapter.

5.1 Definitions of key terms

5.1.1 Infrastructure

The term infrastructure is used extensively in many fields and disciplines. However, looking at infrastructure from the point of view of physical planning, the Webster's Encyclopaedic Unabridged Dictionary of the English Language defines infrastructure as "the basic underlying framework or features of a system, as the military installations, communication and transport facilities of a country". In other words, infrastructure are deemed to be facilities that usually require substantial capital investments; provide public services or meeting needs perceived to be public's duty and are often planned, designed, constructed and operated by or under the support of government agencies (Goodman & Hastak, 2006). However, due to the inability of governments to meet the infrastructure needs of inhabitants recently, private set ups are also seen to shoulder what is perceived to be the public's responsibility. They are usually for profits, but under franchises from the governments. What is general with most infrastructure is that they provide the platform for the functionality of societies and other systems. Furthermore, infrastructure by their nature are derived features which are not necessarily consumed by consumers directly, but have the ability to deliver the specific needs of consumers.

Infrastructure are deemed to be features such as:

- Transportation networks and facilities – highways, bridges, railways, vehicle parking, tunnels, streets, canals, airports and fields

- Power generation and distribution facilities
- Water treatment and distribution facilities
- Communication facilities
- Storm water retention tanks and flood control facilities
- Waste water collection and treatment facilities
- Solid waste collection, treatment and disposal facilities
- Community and social facilities – schools, hospitals, police stations, fire stations, prisons, libraries, stadia, theatres, conference centres

5.1.2 Classification of infrastructure

In spatial planning, classifying infrastructure is very essential, especially in the sense of allocation of capital and services costs of infrastructure among stakeholders. Besides, classifying infrastructure reveals which kind of infrastructure is affected by spatial development patterns and which ones are less sensitive to it. Literature so far classifies infrastructure by two main themes, namely: form and location.

5.1.2.1 Form

By form, infrastructure is classified as:

- **Network or linear:** including highways, railways, streets, tunnels, canals, power, transmission and distribution structures, water transmission and distribution structures, communication distributions structures and sewers
- **Point or nodal:** including vehicle parks, airports and fields, storm water retention tanks, power plant stations, water treatment plants, waste water treatment plants, schools, fire stations, hospitals, police stations, prisons, stadia, theatres, conference centres, solid waste collection and treatment facilities, libraries and water storage reservoirs.

In terms of cost sensitivity, network or linear infrastructure are more sensitive to spatial development patterns as compared to point or nodal infrastructure.

5.1.2.2 Location

Location aspect of infrastructure reveals two main types of infrastructure.

- **On-site:** These are infrastructure facilities that are located on the lot or connect the residential, commercial or industrial structure to a remote infrastructure component. These include water and waste water laterals, streets and attendant furniture, power cables (overhead or underground), communication cables and drainage structures.
- **Off-site:** These are infrastructure located other than on the lot and are meant to serve a larger group of people or neighbourhoods. They could further be classified as intra-neighbourhood, inter-neighbourhood and regional infrastructure (Frank, 1989). Such infrastructure include water and sewer trunks, arterial roads, highways, high voltage transmission and distribution lines, airports and fields, storm water retention tanks, power plant stations, water treatment plants, waste water treatment plants, schools, fire stations, hospitals, police stations, prisons, stadia, theatres, conference centres, solid waste collection and treatment facilities, libraries and water storage reservoirs.

The knowledge of the location of infrastructure clearly sets out whose responsibility is it to finance the infrastructure both in capital and services.

5.1.3 Costs

The subject of cost is very broad and means a lot of things to different people. However, in the context of spatial planning and civil engineering, cost could take the form of monetary or non-monetary outlays. Furthermore, cost could mean financial as well as economic outlays. The monetary cost is the material value as seen in how much infrastructure projects will sell given the prevailing market price, while the non monetary cost does not usually have a material value and market price as seen in environmental and social lose due to infrastructure projects. The financial cost is the direct outlays between parties concerned with the construction of infrastructure projects while the economic cost goes beyond the financial cost to include other impacts which are not usually considered cost by the parties directly into the construction of infrastructure projects. Nowadays, with the principle of sustainability gaining prominence in most developed and developing countries, those other impacts (environmental and social costs) are being internalised in most infrastructure projects. This means that economic costs are becoming widely acceptable for both private and public infrastructure projects. For the purposes of this study, cost is defined as all the goods and services that are consumed in the production of infrastructure projects. To keep the cost analyses simple, only the financial cost of infrastructure projects is considered.

5.1.3.1 Capital cost

The capital cost is the cost incurred by investing into the infrastructure project before operation. It is otherwise called the investment or initial cost. The components of the capital costs are as follows:

- Land rights or costs: including all transaction costs related to it.
- Design and supervision costs: including all tendering costs
- Construction costs comprising the contractor's cost estimates for materials, labour, plants, overheads and profits
- Cost of investment capital: including interest on equity
- Contingencies comprising both technically, economically and legally unforeseen cost.

5.1.3.2 Services

Services costs of infrastructure projects are all the costs that are incurred when the facility is commissioned by the owner. Some of the costs are recurrent while others are periodic. However, usually this type of cost is expressed as an annual cost over the entire life span of the infrastructure project. This means that the periodic costs are estimated and annualised over the entire life span of the facility. The general components of the services costs of infrastructure facilities are:

- General operation and maintenance: including all recurrent expenditure for materials, labour and plants.
- Costs of major periodic maintenance
- Investment loan servicing
- Statutory charges or fees

5.2 Relationship between infrastructure costs and urban forms

The backbone of every development or settlement is infrastructure. Without infrastructure, certain human activities like mobility, production among other things may be difficult to carry out. This shows an important nexus between infrastructure and spatial development patterns. It is so obvious that the pattern of development or settlement affects the infrastructure required to serve it (Real Estate Research Corporation, 1974; Suen, 2005; Carruthers & Úlfarsson, 2008). This phenomenon coupled with the huge amount of money and resources needed to construct and service infrastructure has led to various researches trying to identify the most cost-effective form of development. The battle between compact development, smart growth, and sprawl has waged on for more than three decades with leading researchers like Burchell et al. (1998), Litman (2004), Frank (1989) and a host of others being stanch proponents of compact developments while counterparts like Gordon & Richardson (1997), Cox & Utt (2004) holding contrary views.

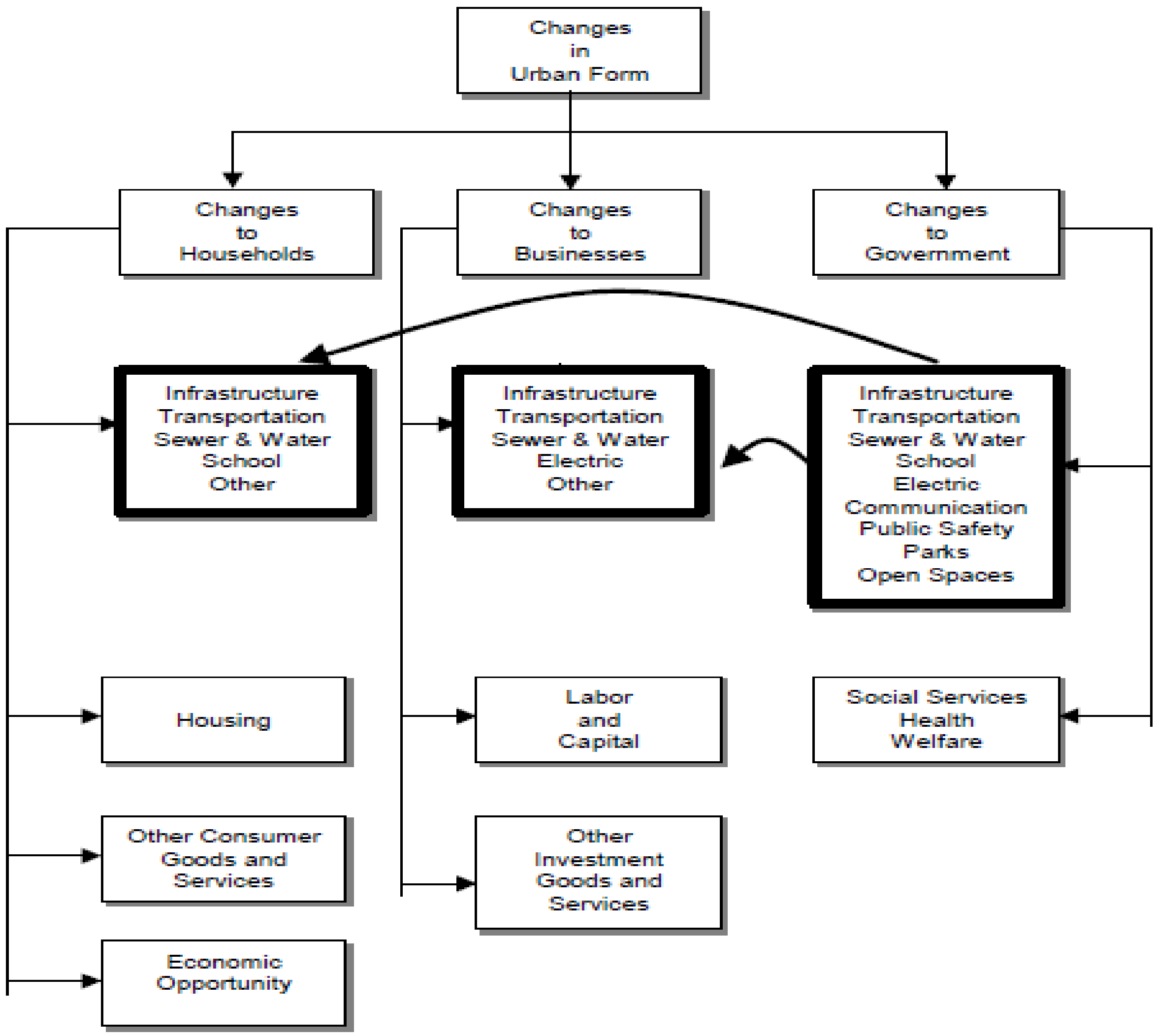


Figure 5.1 Changes in Urban Forms and Impacts on Costs

Source: Conrad & Seskin (1998)

In spite of all these debates, the fact as to whether compact development or sprawl is the most cost effective development pattern still remains unclear as studies so far have not been able to prove that empirically (Alvin, 1993; Carruthers & Úlfarsson, 2008). The quest for the most cost-effective development pattern cannot be trivialised as at the kernel of every development pattern are infrastructure provision and servicing which affect households, firms and the governments. Figure 5.1 shows the centrality and the impacts of infrastructure provisions and costs on the three major players in every country's economy. Policies to shape development patterns invariably have infrastructure concerns for households, firms and governments.

The notion of density and location having a significant impact on the capital and services costs of infrastructure is widely confirmed by most studies in literature (Real Estate Research Corporation, 1974; Frank, 1989; Ladd, 1992; Burchell, et al., 1998; Downing & Gustely, 1977; Duncan James and Associates; Florida Department of Community Affairs, Florida; Governor's Task Force on Urban Growth Patterns, 1989; Peiser, 1984). Although many researchers employ different data and methodologies, they appear to confirm the same conclusion that there exist a correlation between infrastructure costs and urban forms (Slack, 2002). What is central among most of the studies so far is the fact that the cost of infrastructure appears to vary directly with distance from the central infrastructure facilities. Besides, some studies (Frank, 1989; Burchell, et al., 1998) assert that density is inversely related to the cost of infrastructure provisions. This claim appears to be somehow debatable as Ladd (1992) proves with her study that except within the range of very low densities, the per capita public services costs increase with density. She regressed density or population change, while controlling for other factors, with per capita spending and came out with a "U" shaped curve as shown in Figure 5.2.

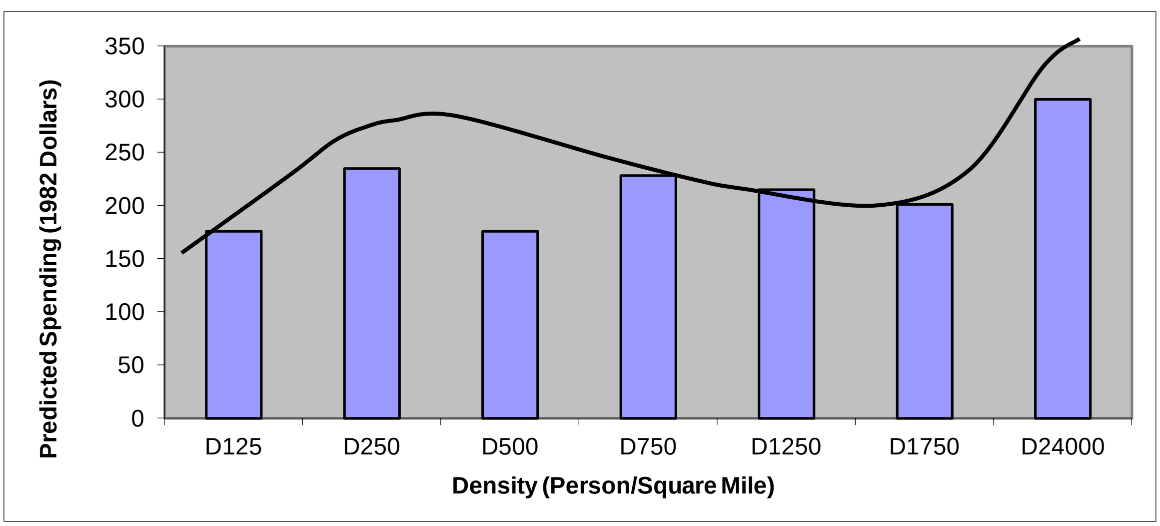


Figure 5.2 Infrastructure Costs and Density

Source: Ladd (1992)

Muller (1976) confirms the same notion. Furthermore, Peiser (1984)'s study showed a savings in road construction cost for unplanned or conventional development patterns as compared to a planned and compact counterpart. A much earlier study conducted in Great Britain by Stone (1970) concluded that both dwelling units and capital costs - including garage and site development for roads, sewers and utilities, but excluding land - were much higher for high rise buildings, an indicator of high density development. Dwelling unit costs were 17% higher for four-storey and 55% higher for ten-storey compared with costs for two-storey dwellings. The total capital costs were 14% and 43% higher for a four-storey and a ten-storey respectively as compared to a two-storey unit. The same study confirms a similar trend for both maintenance and operating costs (Stone, 1970). Biermann (2000) argues that infrastructure capital costs do not necessarily decrease with increasing densities and urban compactions, due to the unique interplay between infrastructure thresholds, capacities, location and density over time and space. She further indicates that the issue of infrastructure thresholds makes infrastructure costs of developments unrelated to the distance from the central area.

The relationship between infrastructure costs and urban forms is somehow not straight forward. Urban compactions and intensifications appear to drive up development costs due to economic, statutory and technical reasons. On the other hand, low density developments seem to present lower development costs to developers and suburbanites, but this is usually criticised on the grounds that the level of services for such developments, especially rural settlements, are poorer and most of the costs of infrastructure - capital and services - tend to be private. Some critics claim this as mere cost shifting and not necessarily cost savings on the whole. Consequently, Ewing (1997) sums it all up that the relationship between infrastructure costs and urban forms can be graphed as a tilde **(~)** as shown in Figure 5.3.

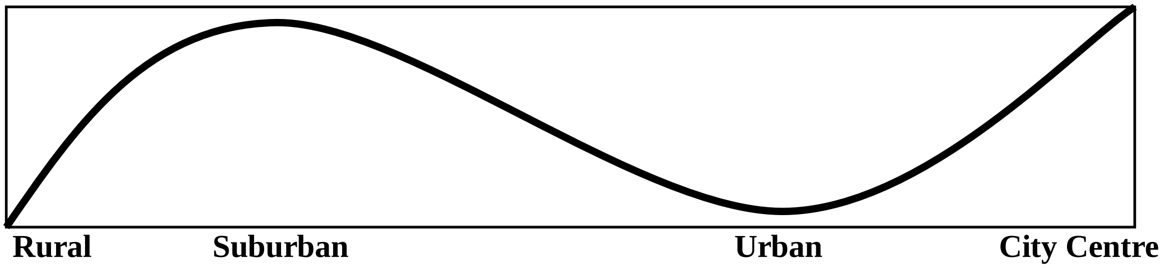


Figure 5.3 Infrastructure Costs and Urban Forms

Source: Litman (2004)

5.3 Determinants of Infrastructure Costs

Mostly in literature, the subject of the most cost-effective urban form, infrastructure-wise, is on the basis of density and location. However, there are more other factors that play very important roles in fashioning out the costs of infrastructure of developments. The consideration of these factors could augment the quest to finding the urban form that is benign on infrastructure costs and help inform better, the current debate on the most efficient urban form. Concluding on a particular urban form as the most efficient in terms of infrastructure costs in the light of one or a few of the determinants may skew the decision as there is an interplay of all the determinants in coming out with a more objective conclusion. Although several other factors may affect the costs of urban infrastructure, primarily, infrastructure costs of urban forms are influenced by the following: density, location, thresholds, procurement strategy and street patterns.

Density

Density has been the main hub for infrastructure cost effectiveness vis-à-vis urban forms in literature. The fact that density influences infrastructure cost is indisputable, but the question is which direction of density ensures urban infrastructure cost effectiveness? Acioly & Davidson (1996) like most other researchers argue that encouraging higher densities ensure efficiencies in the provision and maintenance of infrastructure. They further indicate that low density means long infrastructure runs and higher costs per capita for both installation and operation. Most studies by institutions and renowned researchers – Real Estate Research Corporation, 1974; Burchell, et al., 1998; Downing & Gustely, 1977; Duncan James and Associates; Florida Department of Community Affairs, Florida; Governor's Task Force on Urban Growth Patterns, 1989 – have tried to convince stakeholders that higher densities are more efficient and cost saving in terms of infrastructure costs. Interestingly, most of those studies emphasise capital costs of infrastructure to root for their arguments and claims. However, the operational or maintenance costs of these infrastructure in relation to density are far more significant in reality than the capital costs. A very credible study by Ladd (1992) proves this as shown in Figure 5.4.

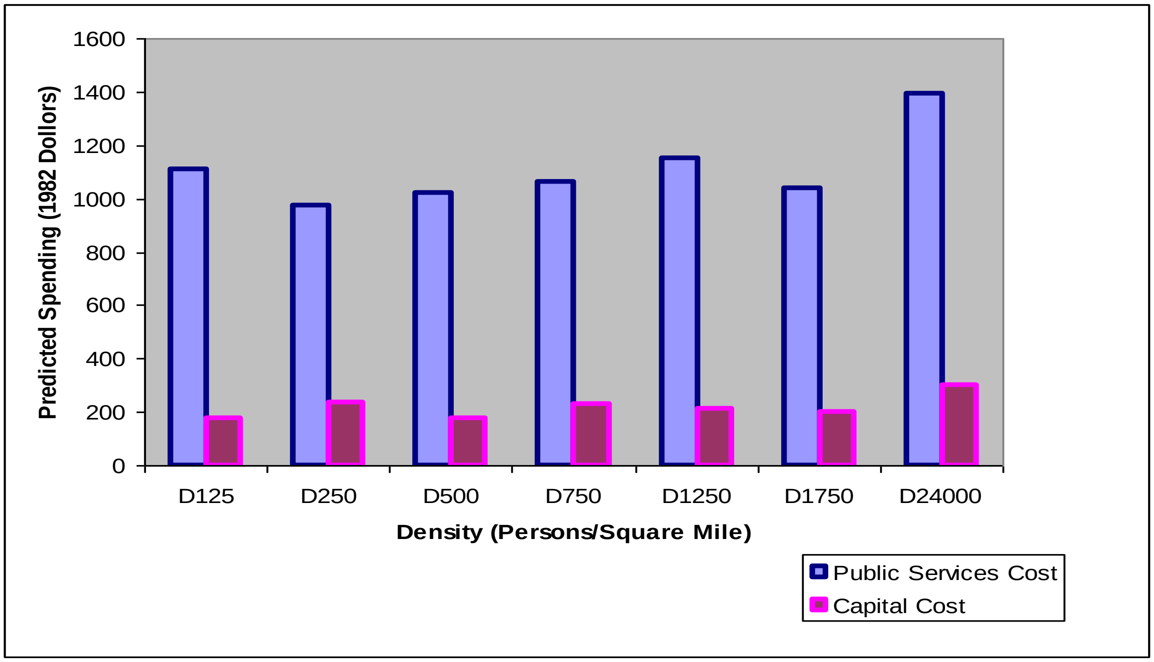


Figure 5.4 Capital and Public Services Costs Per Capita and Density

Source: Ladd (1992)

If the assessment of urban forms on the grounds of infrastructure costs must be done with the combination of these two cost elements (capital and services costs), then further research is required to make a meaningful conclusion. Furthermore, Ladd (1992) asserts that usually as density increases, the per capita public costs appear to decrease, but is usually accounted for by deterioration of municipal services. This then brings to the fore two types of costs: the cost of producing a given level of direct outputs as in police patrolling and the costs of a given level of final outputs as valued by the citizens in protection from crime. Most of the time, studies comparing different densities for infrastructure costs efficiency falter on this cost distinctions, if not deliberately arguing with the former cost type to prove that higher densities are efficient ways of growing, infrastructure wise. Ladd (1992) concludes that theoretical considerations alone are not enough to predict the exact functional relationship between density and the costs of providing a given level of final outputs.

Location

Location plays an important role in determining the costs of infrastructure needed to serve a given urban form. New developments that are farther away from already established areas are deemed to impose higher infrastructure costs as compared to closer ones. However, with network infrastructure like water, sewer, electricity and telecommunication, the supposed higher infrastructure costs could be reflected in the transmission costs from the supply or treatment plants to the new developments. Costs may not vary much at the distribution section, provided density and other factors are held constant. With regard to point infrastructure like schools, hospitals, fire and emergency stations, police stations and community centres, the excess infrastructure costs show up in the need to construct these infrastructure, newly, at those new development areas while probably excess capacities could be harnessed in already established areas.

Thresholds

Biermann (2000) points out that other factors influence infrastructure costs in a manner unrelated to distance (location) from the central areas. Thresholds could make significant differences in the infrastructure costs of urban forms. The main characteristic of thresholds is that they are not uncircumventable, but can only be overcome by higher cost in capital investment (Hughes & Kozlowski, 1968). Hughes and Kozlowski (1968) further indicate that thresholds have two impacts on infrastructure costs. Firstly, there is a sharp rise in cost as capital expenditure is required to open up new areas (See Figure 5.5). Secondly, it may require the need to use new higher-cost land for development as in using very sloppy or poor load bearing lands. Broadly, thresholds in urban developments with regard to infrastructure costs could be identified under three circumstances: physical, quantitative and structural thresholds.

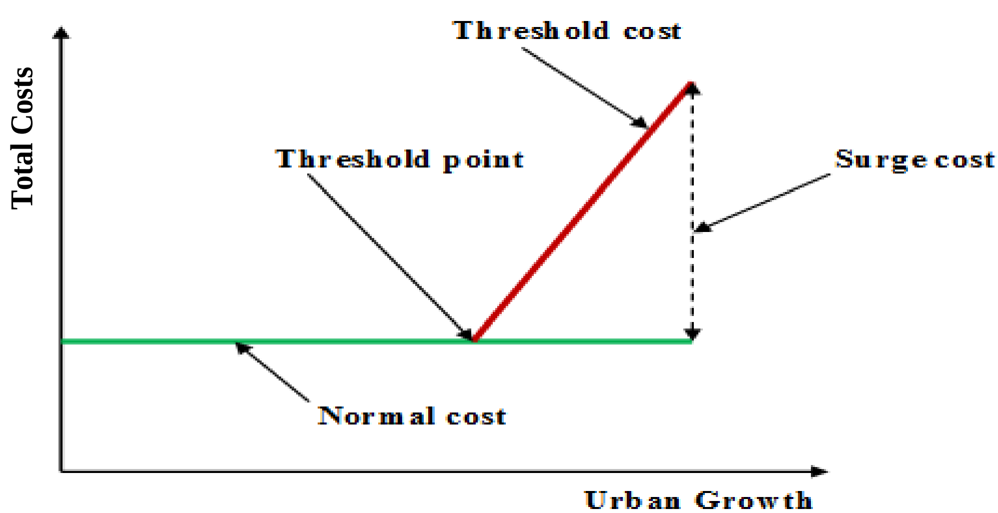


Figure 5.5 Threshold and Infrastructure Costs

Physical thresholds are related to limitations by topographical features and geotechnical conditions. On the other hand, the quantitative thresholds are related to capacities of infrastructure. When urban growth and developments exceed the existing capacities of infrastructure, major capital investments may be necessary to accommodate the growth and developments. Structural thresholds manifest themselves in the limitations imposed by the existing urban structure and land use. The existing urban structure or land use of a town or a city may impose some restrictions such that accommodating urban growth may occasion a major capital cost with respect to urban infrastructure (Hughes & Kozlowski, 1968).

Procurement Strategy

Procurement strategy, though very important, is rarely deemed as one of the major drivers of infrastructure costs among researchers in the field of costs of alternative development patterns. The way infrastructure projects are procured and delivered affects the costs. The costs consequences reflect in both the capital and the running outlays of the infrastructure. Poor verification of project needs, improper assessment of measures, ill-developed procurement and implementation strategies and bad project delivery are at the roots of most unduly expensive infrastructure projects. Most studies (empirical or theoretical) on infrastructure costs of alternative development patterns do not or rarely consider the influence of procurement strategy in their analyses and conclusions. This may not give a clearer picture of what the reality is in the quest for an urban form that is benign on infrastructure costs. Flyvbjerg, Skamris, & Buhl (2005) cited Bangkok’s US$2 billion Skytrain, a two-track elevated urban rail system designed to serve some of the most densely populated urban areas from the air as a good case for a bad procurement strategy. They indicated that the project was oversized, with location platforms too long for its shortened trains, many trains and cars sit in the garage because there is no need for them and a host of other negative consequences. Hence the high total costs or per capita costs of alternative development patterns may not necessarily be due to density, location and thresholds alone.

Street patterns

Street patterns appear to influence the costs of infrastructure. However, the extent to which street patterns affect infrastructure costs, particularly point infrastructure, is still unclear and requires further research, preferably empirically based ones. Incidentally, studies are currently emerging, though still in infant stages, on how street patterns influence the costs of infrastructure, precisely linear infrastructure. Southworth (1997) indicate that the total amount of land devoted to streets relates directly to infrastructure costs. Hence with a given land area, the grid street pattern is likely to produce a longer length of road network and attendant linear infrastructure, culminating into higher infrastructure costs vis-à-vis the curvilinear street pattern. Besides, streets in grid pattern, which are accessible to through traffic, must meet higher design standards than cul-de-sacs and loops and consequently increase the costs of infrastructure (Canada Mortgage and Housing Corporation, 2002). In a study that compared the traditional grid street pattern to the conventional curvilinear street pattern, Dillon Consulting Limited (2010) found the infrastructure (sewerage and drainage facilities, water mains, roads and sidewalks) costs to the traditional grid street pattern significantly higher in comparison with the conventional curvilinear street pattern, 31% higher on a 10 acre tract of land and 43% higher on an 100 acre tract of land.

5.4 Evaluation of Previous Studies

Many studies have been conducted and many more continue to appear on the costs of providing infrastructure to alternative development patterns. The diversity of the approaches and the data sources by the various researchers have led to different results and conclusions which have still made the debate on the most efficient urban form, infrastructure-wise, murky. Analysing the approaches of these studies and interpreting their consequent results are fundamental in arriving at a very objective conclusion on infrastructure costs vis-à-vis alternative development patterns. Trubka, Newman, & Bilsborough (2008) point out that interpreting those studies on infrastructure costs and alternative development patterns is quite challenging as infrastructure costs are heavily dependent on area-specific factors. Furthermore, the relationship between infrastructure costs and urban forms depends on many factors none of which is easy to isolate (Knaap, Talen, Olshansky, & Forrest, 2001). Knaap, Talen, Olshansky, & Forrest (2001) claim that interpreting the results of one study requires great care and suggest the following factors to be considered in interpreting the results of each study: types of costs considered, the forms of infrastructure, treatments of capital and operating costs, the measurement of costs, the level of service and the treatment of topography, the variation in estimates and the expected sequence of urban development.

5.4.1 Criteria for Evaluation

The evaluation of the previous studies is done based on the proposition by Knaap, Talen, Olshansky, & Forrest (2001).

Types of Costs Considered

Most of the studies on the costs of development patterns vary in the type of costs considered. This gives room for a wide range of cost figures assigned to different urban forms serving the same number of inhabitants in each case. The type of costs encompasses both monetary and non-monetary ones. Under the monetary aspect of cost, it is important to know whether or not the study considered only public costs, private costs or both. Non-monetary costs such as environmental and social costs need to be accounted for in the search for a more cost effective urban form.

The forms of infrastructure

Whether or not only on-site infrastructure, off-site infrastructure or both are considered could lead to various degrees of infrastructure costs to urban forms. Furthermore, the types of infrastructure considered in a study suggest the trend of infrastructure costs. Some infrastructure such as roads, water and sewer are spatially sensitive and hence their costs (Downing & Gustely, 1977; Duncan James and Associates; Florida Department of Community Affairs, Florida; Governor's Task Force on Urban Growth Patterns, 1989; Peiser, 1984). On the other hand, point infrastructure such as schools, hospitals, police stations, fire stations and host of others are less sensitive spatially. Thus, the need to look at the combination of these two categories of infrastructure costs in relation to urban forms could give a clear picture of the reality.

The treatments of capital and operating costs

Realistic conclusion could be made for urban forms vis-à-vis infrastructure costs, if both the capital and operating costs are considered in the study. A partial consideration of costs is likely to skew the conclusion. Even assumptions supporting the financing of capital investment of infrastructure to a development pattern could lead to cost differences.

The measurement of costs

Are costs of studies measured on per capita, per dwelling unit or per land basis? The unit of measurement of infrastructure costs, to some extent, reveals the magnitude of costs differences among alternative urban forms with regard to infrastructure development. A comparison of the infrastructure costs of alternative urban forms with costs related to population is likely to reveal smaller differences among the alternative urban forms vis-a-vis costs related to dwelling unit or land.

The level of service and the treatment of topography

The infrastructure costs to alternative development patterns vary in accordance with the level of service. Higher level of service is likely to require higher infrastructure costs and vice versa. It is thus important to ascertain, if studies distinguish between the levels of service. The question of whether or not topographical features are considered in determining the costs of infrastructure to alternative development patterns is important as topography plays a role in fashioning out the costs of infrastructure.

The variation in estimates

Do studies present point estimates or are information provided regarding the potential ranges over which the estimates may vary? It is opined that costs estimates of large infrastructure projects are usually inaccurate and hence lead to project costs over-runs (Flyvbjerg, 2007). Flyvbjerg (2007) further indicate that the problem of inaccurate estimates and costs over-runs are due to causes such as: technical errors on the part of the forecasters, psychological biasness on the part of the planners and promoters and lastly, political-economic interests on the part of planners and promoters. The existence of this situation may provide the platform for interrogating the results of hypothetical studies on infrastructure costs vis-à-vis urban forms as researchers may fall to the trap of biasness in order to promote a particular urban form. Hence, it is posited that to cure the mischief of inaccuracies and biasness in infrastructure costs estimation, a so-called “reference-class forecasting” be employed in addition to the traditional methods of costs estimation (Flyvbjerg, 2007; Lovallo & Kahneman, 2003). The reference-class method of forecasting infrastructure costs involves placing the infrastructure project, under consideration, in a statistical distribution of outcomes from a class of reference or similar projects (Flyvbjerg, 2007).

The expected sequence of urban development

Some researchers have hypothesised that given time, developments that are considered sprawling initially will ensure higher densities later, than originally planned fixed densities (Harvey & Clark, 1965; Schmid, 1968; Ohls & Pines, 1975; Ottensmann, 1977; Peiser, 1989). With reference to this hypothesis, it would be important that development over time is considered in the analysis of infrastructure costs in relation to urban forms.

A review of previous seminal studies on the costs of infrastructure in relation to urban forms based on the above mentioned criteria is shown in Table 5.1.

Table 5.1 Review of Previous Studies of Costs-of-Sprawl

Study	Types of Costs Considered	The Forms of Infrastructure	The Treatments of Capital and Operating Costs	The Measurement of Costs	The Level of Service and the Treatment of Topography	The Variation in Costs Estimates	The Expected Sequence of Urban Development	Remarks/Conclusions
Real Estate Research Corporation (1974)	Monetary and non monetary.	Network and point infrastructure on-site and off-site	Capital and operating	Cost per dwelling unit	Lower living space and development standards with increasing density. Topography not emphasised.	Point estimates	Fixed development pattern	Study prototype and not empirical. Residential land use was the focus of study. Development costs decrease with increasing density and better planning.
Peiser (1984)	Monetary	Network with qualitative description of point infrastructure cost. Only off-site.	Capital.	Cost per block of land	Same level of service and topography for each development pattern.	Point estimates	Fixed development pattern	Study prototype and not empirical. Residential and non-residential land uses. Qualitative description of non monetary cost. Planned developments less expensive than unplanned.
American Farmland Trust (1986)	Monetary	Network and point infrastructure off-site and on-site	Operating and capital	Costs per dwelling unit	Same level of service for each development pattern. Topography not emphasised.	Point estimates	Fixed development pattern	Study prototype and not empirical. Residential land use. Public costs decrease with increasing density.
Duncan et al. (1989)	Monetary	Network and point infrastructure. Only off-site	Capital and operating	Costs per dwelling unit	Level of service varied directly with cost for point infrastructure. Topography not emphasised.	Point estimates	Fixed development pattern	The study was empirical. Residential and non-residential land uses. Compact development less expensive than sprawling development
Ladd (1992)	Monetary	Network and point infrastructure off-site and on-site	Capital and operating	Costs per capita	Level of service considered and varied directly with cost. Topography not emphasised	Point estimates	Fixed boundaries and dynamic population and density	Study was empirical. Study considered public costs to all land uses at county level. Per capita public services costs increase with density

Study	Types of Costs Considered	The Forms of Infrastructure	The Treatments of Capital and Operating Costs	The Measurement of Costs	The Level of Service and the Treatment of Topography	The Variation in Costs Estimates	The Expected Sequence of Urban Development	Remarks/Conclusions
Fodor (1997)	Monetary	Network and point infrastructure. Only off-site	Capital	Costs per dwelling unit	Same level of service for all development patterns. Topography not emphasised.	Point estimates	Fixed development pattern	Study hypothetical. Residential land use. The costs of new developments are subsidised and misrepresented
Fodor & Knoder (2000)	Monetary	Network and point infrastructure. Only off-site	Capital	Costs per dwelling unit	Same level of service considered. Topography not emphasised	Point estimate	Fixed development pattern	Study was hypothetical. Residential land use. New urban growth results in heavy fiscal burden on local governments
Biermann (2000)	Monetary	Network infrastructure. Off-site and on-site	Capital	Costs per capita	Topography considered but level of service not emphasised	Point estimate	Fixed development pattern	Study was hypothetical. Residential and non-residential land uses. Densification is not necessarily a cost-effective alternative at all times under all situations
Speir & Stephenson (2002)	Monetary	Network infrastructure. Off-site and on-site	Capital and operating (only energy cost)	Costs per dwelling unit	Level of service considered and varied directly with cost. Topography not emphasised.	Point estimates	Fixed development pattern	The study was hypothetical. Residential land use. More spread out housing patterns are more costly to serve with infrastructure.
Burchell & Mukherji (2003)	Monetary and non-monetary	Network infrastructure. Off-site and on-site	Capital and operating	Costs per development pattern	Not emphasised	Point estimate	Fixed development pattern	Study hypothetical. Residential and non-residential land uses. Managed growth less expensive than sprawl.
Suen (2005)	Monetary	Network infrastructure. Off-site and on-site	Capital	Costs per parcel of land	Not emphasised	Point estimates	Fixed development pattern	Study was empirical. Residential land use. Infrastructure requirement varies inversely with residential parcel density and residential shape index.

Study	Types of Costs Considered	The Forms of Infrastructure	The Treatments of Capital and Operating Costs	The Measurement of Costs	The Level of Service and the Treatment of Topography	The Variation in Costs Estimates	The Expected Sequence of Urban Development	Remarks/Conclusions
Najafi, Mohamed, Tayebi, Adelaja, & Lake (2007)	Monetary	Network infrastructure	Capital and operating	Costs per parcel of land	Topography and level of service not emphasised.	Point estimates	Fixed development pattern	Study was empirical. Residential land use. Capital and life-cycle cost of infrastructure varies inversely with density.
Trubka, Newman & Bilsborough (2008)	Monetary and non-monetary	Network and point infrastructure. Off-site and on-site infrastructure.	Capital and operating	Costs per dwelling unit	Level of service not emphasised. Topography not emphasised in study but noted as a cost driver in infrastructure development.	Point estimates	Fixed development pattern	Study was based on literature review of previous studies. Residential land use. There are significant savings with urban redevelopment as compared to fringe development.
Mohamed (2009)	Monetary	Network infrastructure	Capital	Costs per parcel of land.	Lower infrastructure standards with decreasing density. Topography not emphasised in study.	Point estimates	Fixed development pattern.	Study was empirical. Residential land use. Infrastructure costs decrease with increasing lot sizes at the exurban areas.

5.5 The Stand of Previous Studies

The studies chosen for the purposes of the evaluation were carefully selected to reflect the time span, which the costs of alternative development patterns became a great concern for local governments and debates increased to address the issue. Besides, the studies are frequently cited in literature and provide methodologies and results that could form the basis for deciding which alternative development pattern to opt for on the grounds of development cost effectiveness.

In evaluating the studies, it was realised that most studies on the costs of development looked at more of physical costs of developments in the light of infrastructure capital and services costs than the non-monetary costs. Where non-monetary costs were considered in the study, only descriptions of likely costs were indicated without any real quantification of costs. This may be due to the extreme difficulty in quantifying the costs of those aspects of developments.

Most of the studies considered both network and point infrastructure simultaneously in arriving at their conclusions. This was important in arriving at a fair conclusion as network infrastructure are usually spatially sensitive to cost while point infrastructure rarely do.

Ideally, the capital and operating costs of alternative development patterns would be required to make a fair conclusion as to which development pattern is infrastructure costs efficient. However, about half of the studies considered looked at only infrastructure capital costs without any reference to the operating costs of infrastructure.

The way costs are measured in development costs studies is very important as it reveals the magnitude of costs difference between alternative development patterns. Measurement of costs in per capita usually shows an insignificant difference in cost between alternative development patterns as compared to measurement in costs per dwelling unit. More than half of the study reviewed measured costs in dwelling units depicting a glaring difference in costs between alternative development patterns. However, since a development cost is a derivative of a particular population, the question of which method of cost measurement is more appropriate needs to be answered and emphasised to make the results and interpretations of studies clearer.

The level of service in most studies was considered the same for all development types or was not emphasised at all. In the "Costs of Sprawl" by the Real Estate Research Corporation (1974), the living space and development standards were lowered with increasing density. This provides grounds to question any comparison of the results of the costs of alternative development patterns considered in the study – low and high density development patterns. Again, the same level of service assumed for all the alternative development patterns (both low and high density developments) is somehow deceptive in the light of infrastructure services costs. Higher density developments have harsher environments and put more pressure on existing infrastructure which eventually toll on the levels of service in those environments. Thus, attempts to meet the desired level of service of the inhabitants in such environments come with higher costs which were not factored into the overall development costs by most studies thereby casting some doubts on their conclusions. Since most studies were theoretical or hypothetical, topography were considered same for all development patterns or not emphasised at all.

Variation in costs estimates were not considered as all the studies considered only point estimates. The implication on conclusions in literature is quite significant, since most of the studies on infrastructure costs vis-a-vis urban forms are hypothetical and their results as well as conclusions may suffer some human inaccuracies and biasness. Therefore, empirical approaches to studies on infrastructure costs in relation to urban forms will help refine conclusions and improve on decisions.

With the exception of Ladd (1992) who allowed for a dynamic population and density with fixed boundaries, all the studies considered static development patterns over time. This reveals a gap in research as far as the debate on the costs of alternative development patterns is concerned. Filling in this research gap will better inform the debate that has dragged over three decades now.

Most of the studies informing the debate on the costs of alternative development patterns are theoretical or hypothetical and lack empirical evidence. This reality demands further research, particularly empirical ones to unveil the truth in this debate. Despite the inherent weaknesses and doubts in the approaches of most of the studies, the apparent conclusion is that managed or compact developments are less expensive in comparison to urban sprawl.

6. IN SEARCH OF AN EFFICIENT URBAN FORM IN GHANA

The issues of location and composition of land uses which made conventional development patterns (urban sprawl) objects of criticism, say 30 years ago (Ford, 1999), are less valid and important today. For example, since 1960, more apartment units have been built in the suburban areas than in urban cores in the U.S (Neutze, 1968). Similarly, in Ghana, the government in 2006 started an affordable housing scheme at the suburban areas of the regional capitals which were entirely apartment units. Again, in the U.S, shopping malls, employment centres and other amenities have relocated to the suburbs, once homogeneous in character (Ford, 1999; McNally & Ryan, 1992). Consequently, Fishman (1987), addressing this new phenomenon, calls it „technoburb". He makes the assertion that traditional suburbs were more residential in character while people commuted to city cores for work, but today's structures depict that of stand-alone cities. However, as earlier on mentioned, in Ghana the urban structure is more of residential sprawl, where the suburbs still remain predominantly residential (Yeboah, 2000). Currently, many of the concerns with regard to urban character are more closely linked to the details of architecture and urban design than to the sheer physical distance, homogeneity and remoteness (Ford, 1999). It is no wonder recent critics of suburban development have been deeply concerned with and are specific on issues such as street patterns and house forms (Wright, 1981; Southworth & Ben-Joseph, 2003; Girling & Helphand, 1994).

In searching for an efficient urban form in Ghana, it is required that the definition of urban form is made clear. From section 2.1.6, urban form was generally referred to the layout and design of physical features, influencing the overall size or shape of a city or a town. However, for the purpose of this study, urban form is defined and characterised by street patterns and density. The present chapter, therefore, models the capital costs of infrastructure to four hypothetical urban forms with varying densities to isolate the effects of configuration, specifically street patterns, and density on urban infrastructure costs. In highlighting a key urban planning goal of accessibility, the benefit of each hypothetical pattern in terms of accessibility is quantified and compared. This ensures that robust decisions on the appropriateness of urban forms are not only taken with respect to infrastructure costs, but also in relation to another benefit, which in this case is reflected in accessibility. The existing urban pattern (emphasis on street patterns) in Ghana is determined for comparison sake and also for policy information. Moreover, this chapter presents an infrastructure development economics model which seeks to further point out areas, in the development process, where infrastructure costs to urban forms could be reduced in Ghana and other developing countries.

6.1 The influence of street patterns on urban forms

There is the emergence of highly irregular urban patterns which are often perceived as amorphous or blobs (Frankhauser, 1998). Street patterns which are at the core of urban forms help to characterise urban forms. The layouts and distribution of streets contribute significantly to the form of any urban area. Generally, an attempt to describe urban patterns mixes the configuration of the street patterns and the configuration of the interstices. This makes the description of urban patterns difficult. However, in reality, this is an issue of a chicken and egg scenario. Whether it is the configuration of the streets that fashions the configuration of the interstices or the configuration of the interstices that fashions the configuration of the streets? Marshall (2005b) indicates that the complexities of shape and structure separate street patterns from many other objects of urban analysis. The urban pattern, though static in nature, significantly influences the long term dynamics of the urban system in general. On this premise, Marshall (2005b) posits that unless an adequate description of pattern or structure is considered, it will remain difficult to compare patterns or structures across cases. That is to say, identifying patterns that are *good* or *bad* for different purposes so as to make robust and generalisable recommendations for the design of urban layouts will be difficult. Street standards may be seen to be trivial, but they are such powerful tools which shape the built environment in which we live (Southworth & Ben-Joseph, 2003). Both theorists and practitioners have emphasised the transport system, precisely the street system or pattern, in its role as the primary structural element of the city (Hilberseimer, 1944; Smithson & Smithson, 1968; Roberts & Lloyd-Jones, 2001; Lillebye, 2001). The mobility patterns and behaviours of people can be considerably influenced by street patterns. Southworth & Ben-Joseph (2003) allude to the fact that street patterns contribute significantly to the quality and character of a community. The number of blocks, intersections, access points, loops and cul-de-sacs per unit area does not only influence trip generations, destination choices, mode choices and route choices but also the length of streets and other linear infrastructure along the streets (See Figure 6.1). Higher numbers of blocks and intersections per unit area lead to longer street lengths, reflecting in higher infrastructure costs for linear infrastructure. On the contrary, increasing numbers of loops and cul-de-sacs per unit area appear to result in relatively shorter street lengths and consequently reduce the costs of linear infrastructure.

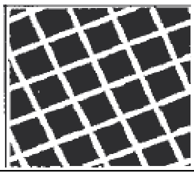
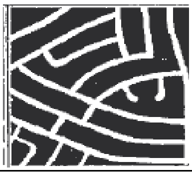
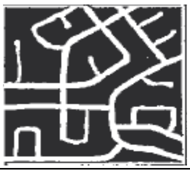
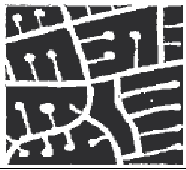
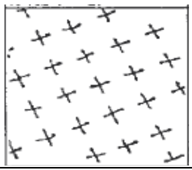
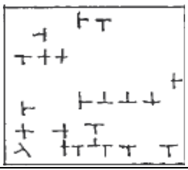
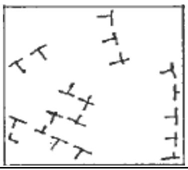
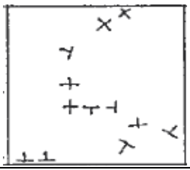
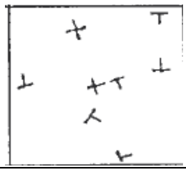
	Gridiron (c. 1900)	Fragmented Parallel (c. 1950)	Warped Parallel (c. 1960)	Loops and Lollipops (c. 1970)	Lollipops on a Stick (c. 1980)
Street Patterns					
Intersections					
Linear Feet of Streets	20,800	19,000	16,500	15,300	15,600
Number of Blocks	28	19	14	12	8
Number of Intersections	26	22	14	12	8
Number of Access Points	19	10	7	6	4
Number of Loops and Cul-de-Sacs	0	1	2	8	24

Figure 6.1 Comparative Analysis of Street Patterns
Source: Southworth & Owens (1993)

The streets as elements of the urban space do not function in isolation but play a very important role in urban functionality. Streets provide linkages (See Figure 6.2) with the public domain and also connect different parts of a neighbourhood (Canada Mortgage and Housing Corporation, 2002). This debunks the notion of the streetspace as a part of a mere arbitrary two-dimensional tessellation of land use parcels.

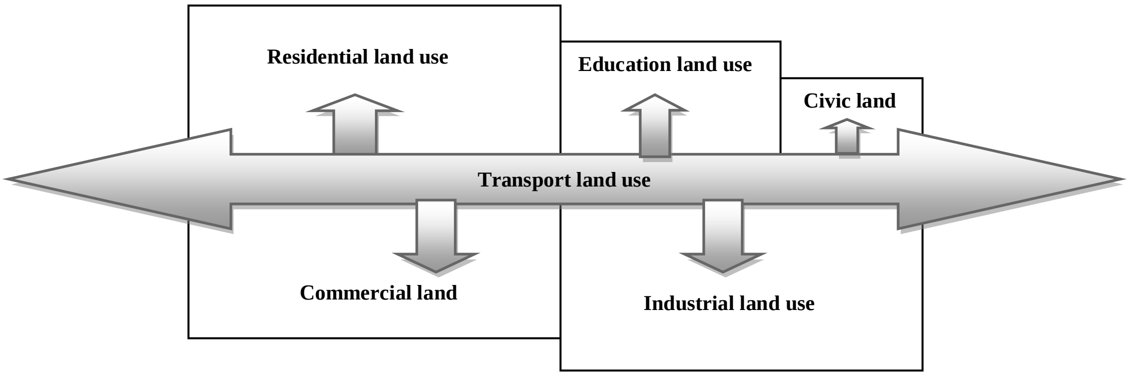


Figure 6.2 The Topological Significance of Transport Land Use
Source: Marshall (2005b)

Streets must not be randomly fitted into a patchwork of urban spaces, but must be influenced by the geometry of movement and the configuration of route connectivity (Marshall, 2005b). The need to take a critical look at the specifications and designs of urban street patterns is due to the enormous influence of transportation on the urban layout economically. Transport infrastructure (See Figure 6.3) is not only seen in its physical presence, but also as a land use in most urban areas (Marshall, 2005b).

(a) (b)

Figure 6.3 The Presence of Transport Infrastructure in Urban Areas (a) A Dual Carriage Road in Accra, Ghana. (b) A Clover Leaf Interchange (Tetteh Quarshie Interchange) in Accra, Ghana.

Excessive land being dedicated to transportation infrastructure reduces the supply of land for other uses and eventually drives up land prices in urban areas. The amount of land consumed by transportation related land uses such as streets, highways, intersections, car parks, lanes, etc approximately accounts for a third of total land area of urban areas in the United States (Southworth & Ben-Joseph, 2003; Alexander, Ishikawa, Silverstein, Jacobson, Fiksdahl-King, & Angel, 1977). Rodrigue, Comtois & Slack (2009) indicate that in Western Europe, roads account for 15% – 20% of the urban surface whereas in developing countries, this indicator stands at 10% (6% on average for Chinese cities).

6.2 Street patterns of alternative development patterns

Historical and current development patterns are associated with specific characters with respect to street patterns. Though there may not be a direct or scientific relationship between alternative development patterns and street patterns, there is a significant agreement among theorists and practitioners (See Table 6.1) as to how certain development patterns support certain street patterns. However, establishing a linkage between alternative development patterns and street patterns require a proper classification of street patterns. This helps to avoid the confusions associated with patterns as they relate to urban forms.

6.2.1 Framework for street pattern classification

A critical look at the description of street patterns in literature reveals multiplicity and repetition of names. Pattern classification and characterisation are necessary for dealing with the ambiguities involved with street pattern description. However, attempts to embark on pattern classification have always been controversial and arbitrary among authors and researchers (Hanson, 1989; Hillier, 1987; Marshall, 2005b). Marshall (2005b) further points out that "there is also a confusion of ways in which each label relates to each kind of form. In some cases, the same form could be described by different labels".

Pattern description requires a focus as to what is being described. Several attempts to describe settlement patterns by the road or street network have proved unsuccessful (Dickinson, 1961). Lynch (1981) posits that settlement patterns should be classified by clearly separating those types constituting settlement forms from those types constituting street or network patterns. Though Marshall (2005b) alludes to this approach, he indicates that street configuration, shapes of interstices and alignment of routes, however, considered for pattern distinction are not mutually exclusive in any urban space. In abstract terms, it is straightforward to admit that there are only two main street patterns: the grid and the tributary (Brindle, 1996). However, a more detail classification is required to describe those other patterns that may not precisely fit into the fundamental ones. What is relevant to this study is the urban pattern distinction or description based on street network pattern and shall be the main issue in subsequent discussions. This distinction provided by the street network pattern will provide the basis for comparison between different urban typologies in terms of infrastructure cost efficiency.

6.2.1.1 Elemental approach

Apart from pattern distinction based on forms of interstices and configurations of street network, some researchers (Haggett & Chorley, 1969; Marshall, 2005b) argue for pattern classification based on typology of elements. First proposed by Haggett and Chorley (1969), the main idea here is to classify patterns on the basis of topology of planar networks. Under this approach, patterns depicting linear structure realise three fundamental types: the path, the tree and the circuit (See Figure 6.4). Though these three fundamental types may be questioned as to how different are they from the common labels such as “radial” and “gridiron” (Marshall, 2005b), this approach provides a consistent means of characterising patterns so as to alleviate the problems associated with pattern descriptions.

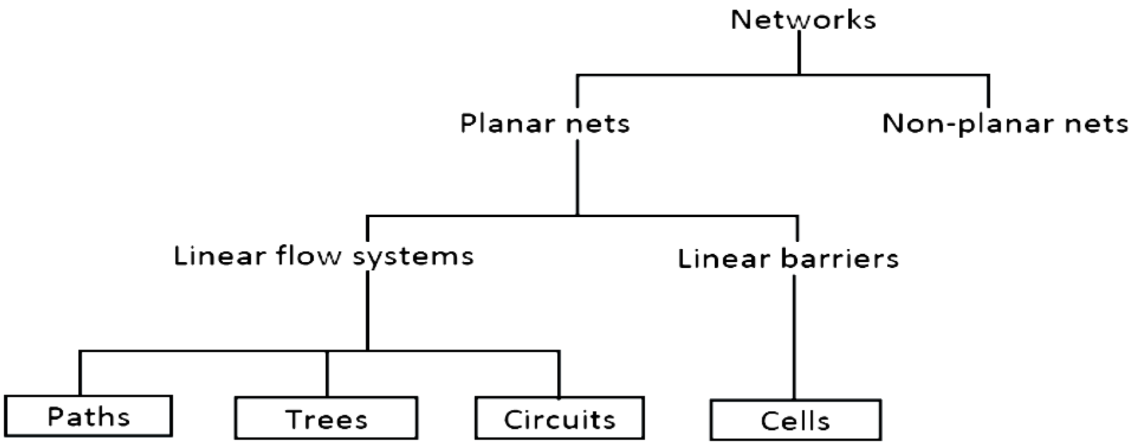
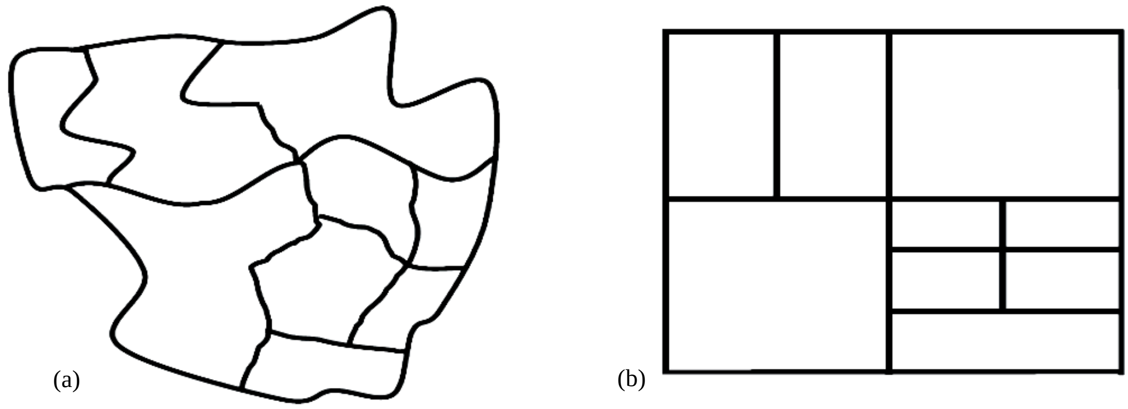


Figure 6.4 A Dendogram Showing Simple Systematic Sub-division of Patterns
Source: Marshall (2005b)

6.2.1.2 Composition and configuration approach

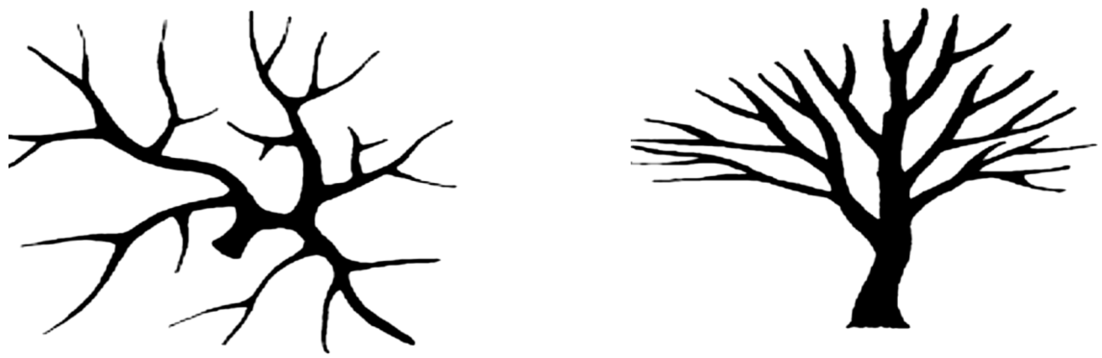
An analysis of composition and configuration provides another clue for classifying urban patterns more consistently. Much of the controversy and arbitrariness associated with urban pattern description could be as well addressed by this analysis. Composition deals with the physical geometry (distances, angles and areas) of forms (Norberg-Schulz, 1975) while configuration looks at topology (connectivity, orientation, proximity and adjacency) of forms (Laurini & Thompson, 1992). Real world patterns which are best represented by composition usually pose challenges with regard to precise description and classification and make the whole classification system very subjective leading to multiplicity of names, especially for the same form. However, viewing forms from the perspective of configuration ensures abstraction of complex real world forms and provides some form of consistency and transparency in urban pattern description and classification. Figure 6.5b shows a configuration and a clear structure of an otherwise unclear structure in Figure 6.5a.



(a) (b)

Figure 6.5 Representations of A Settlement Form (a) Settlement Form in Composition (b) Settlement Form in Configuration

An important question that may be asked in connection with this approach is: how abstract can a configuration of a composition be in order not to distort the organic structure of the urban pattern?



(a) (b)

Figure 6.6 A Tree Pattern Showing Two Different Compositions but Depicting The Same Configuration (a) A Semblance of A Radial Pattern for A Whole Settlement (b) A Tree-Like Structure, A Semblance of A Suburban Road Network

Source: Marshall (2005b)

As pointed out earlier on, the approach of composition and configuration eliminates a lot of the arbitrariness linked with urban pattern classification. Looking at Figure 6.6, figures (a) and (b) show different compositions. However, a careful abstraction (configuration) of the two different compositions reduces the two patterns to a single pattern: a tree or tributary pattern. Marshall (2005b) then alludes to the fact that the radial pattern is a special kind of a tree or tributary structure.

6.2.1.3 An integrated classification

Integrating the approaches discussed above and referring to Stephen Marshall's dendrogram of integrated taxonomy of patterns (see Figure 6.7), five patterns are fundamental and dominant in street pattern classification and characterisation. These are:

- The linear pattern
- The tree (tributary) pattern
- The radial pattern
- The grid (cellular) pattern
- The hybrid pattern

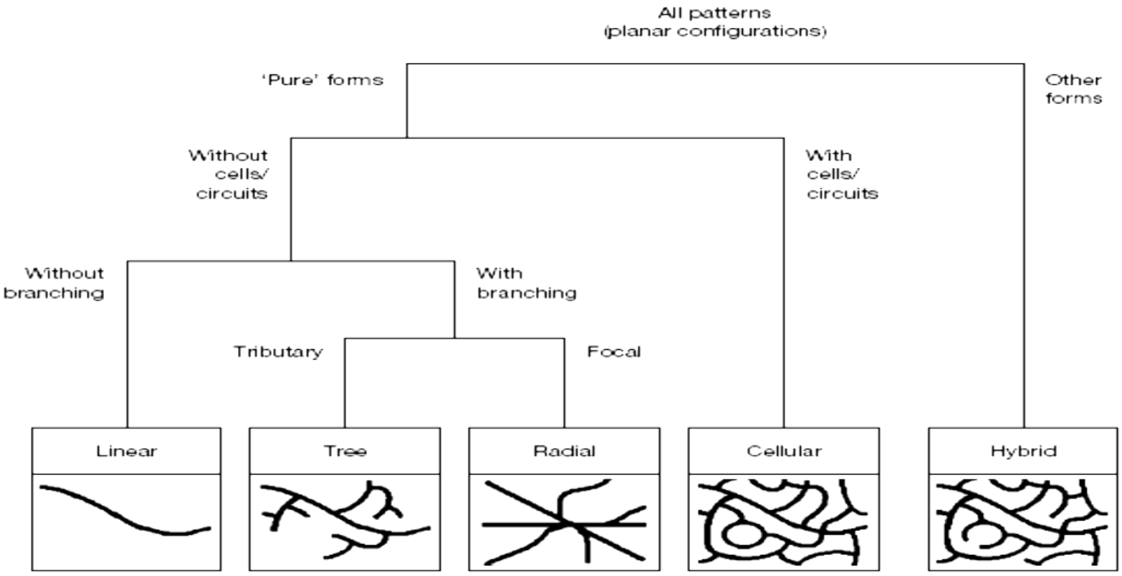


Figure 6.7 Dendogram of Taxonomy of Street Patterns

Source: Marshall (2005b)

These five patterns usually recur in literature but lack of consistent and transparent approaches in description and classification lead to controversy and arbitrariness. These five patterns are not exhaustive with regard to urban patterns. They provide broader ranges of classification or characterisation of urban patterns. Out of each of these five fundamental patterns could flow several other patterns in detailed forms but still inheriting the fundamental structure to reflect any local condition.

6.2.2 Evolution of street patterns and alternative development patterns

A review of literature confirms the support of certain street patterns by some alternative development patterns. As seen from Table 6.1, traditional or historic neighbourhoods often reveal grid-iron or radial structure. Traditional developments, particularly those configured as grid-iron, revealed simple geometric shapes for ease of surveying (Gallion & Eisner,

1986) as well as enabling land owners to squeeze out a lot more lots out of development tracts (McNally & Ryan, 1992). Besides, the choice of the grid-iron pattern was simply because it jointly optimises accessibility and available real estate (Rodrigue, Comtois, & Slack, 2009). The radial pattern, a heritage of the baroque era, portrayed the grandeur and authority of kings and rulers at that time (Gallion & Eisner, 1986). Though not very popular as compared to the grid-iron pattern nowadays, radial patterns are being employed by proponents of new urbanism as seen in communities that are planned on the ideals of new urbanism. A typical example is the West Laguna Community in Sacramento, California, designed by Peter Calthorpe and Associates (See Figure 6.9). Again, referring to Table 6.1, literature reviewed, though not exhaustive, did not indicate linear street pattern for traditional neighbourhoods. Much as linear street patterns are not impossible street patterns and are evident in some localities, they are rarely planned for. They usually, occur as a result of topographical challenges. Again, in most developing countries, particularly Sub-Sahara Africa, where accessibility is a challenge, a lot of towns and villages develop along highways and trunk roads linearly (Doan & Oduro, 2011).

Generally, traditional neighbourhoods reflect the difficulties encountered in mobility in former times and hence the compact settlement structures and mixed land uses in most traditional neighbourhoods. These ideals of compaction and mixed land uses are being reinforced by a modern day growth accommodation strategy like compact city.

Traditionally, the urban street was deemed to have united three physical roles (See Figure 6.8) - circulation route, public space and built frontage (Marshall, 2005b).

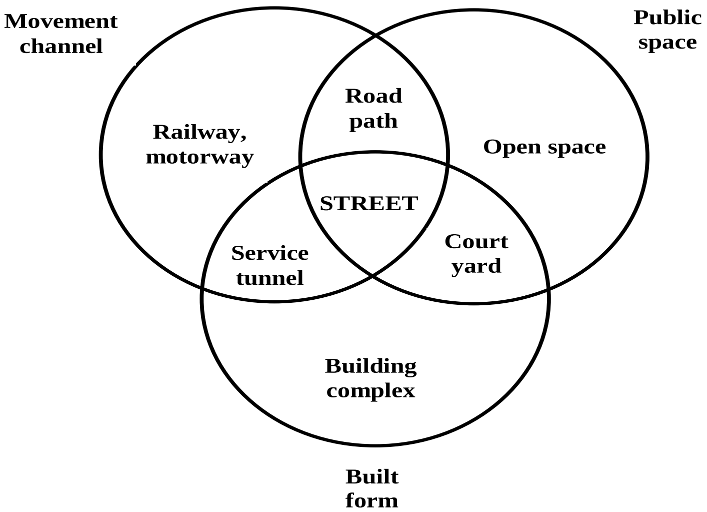


Figure 6.8 Elements and Functions of The Streets

Source: Marshall (2005b)

However, modernism with its emphasis on the automobile movement has succeeded in gradually eroding the bond provided by the urban street between the three physical roles. This is reflected in the morphology of urban spaces, especially from the beginning of the twentieth century, from a grid streetscape to curlicues (See Figure 6.1). Modernist model of the urban space has attracted a lot of descriptions and perceptions in literature.

Table 6.1 Street Patterns of Alternative Development Patterns

Source	Alternative Street Patterns					
	Traditional Neighbourhood			Conventional Neighbourhood	New Urbanism	
	Grid	Radial	Linear	Tree/Tributary	Grid	Hybrid
(Southworth & Ben-Joseph, 2003)	X			X		X
(Burden, 1999)				X		
(Grammenos, Craig, Pollard, & Guerrera, 2008)	X	X		X		
(McNally & Kulkarni, 1997)	X			X		
(Kulash, 1990)	X			X		
(Cervero & Gorham, 1995)	X			X		
(Canada Mortgage and Housing Corporation, 2008)	X			X	X	X
(Kostof, 1991)	X	X		X		
(Ford, 1999)				X	X	
(Steiner, 1998)					X	
(Leck, 2006)	X				X	
(Ellis, 2002)	X			X	X	
(Friedman, Gordon, & Peers, 1994)	X			X	X	
(McNally & Ryan, 1992)	X			X	X	X
(Wheeler S. M., 2008)	X			X	X	
(Rodrigue, Comtois, & Slack, 2009)	X			X		

Marshall (2005b) gives a picture that "rather than being locked together in street grids, the modernist model allowed roads to follow their own fluid linear geometry, while buildings could be expressed as sculpted three-dimensional forms set in flowing space". Martin et al.

(1972) perceive buildings in urban space, nowadays, as “stand-alone” pavilions. Bacon (1975) describes the disconnect between the three physical roles as a “great amputation”. Literature reviewed (See Table 6.1) revealed a significant support of tree or tributary street patterns by conventional or sprawling neighbourhoods. Conventional or sprawling development which is significantly underpinned by automobile dependence has transformed developments from human scale to automobile scale with emphasis on street network hierarchy. The undesirable consequences of conventional development patterns are a great concern among stakeholders of urban development. This has led to the “New Urbanism” or “Smart Growth” or “Neo-traditional Development” approach which seeks to correct the errors of conventional development patterns. One of the objectives of the new urbanism approach is to ensure pedestrian-friendly communities in modern era of the automobile (Ford, 1999). This is achieved by allowing both pedestrian and automobile accesses, however with significant emphasis on pedestrian mobility while de-emphasising automobile mobility. The desire to ensure pedestrian-oriented development (POD) requires a high connectedness in neighbourhoods which makes the grid pattern a preferred street layout by the new urbanism concept. The new urbanism approach also acting as a connector between the pure traditional and conventional neighbourhoods, sometimes, tries to borrow the values of the extreme paradigms. Hence as seen in Table 6.1, literature reviewed indicated a hybrid street pattern of some new urbanism communities in U.S. The Laguna West Community in Sacramento, California, is a typical case of a hybrid street pattern employed by new urbanism (See Figure 6.9).

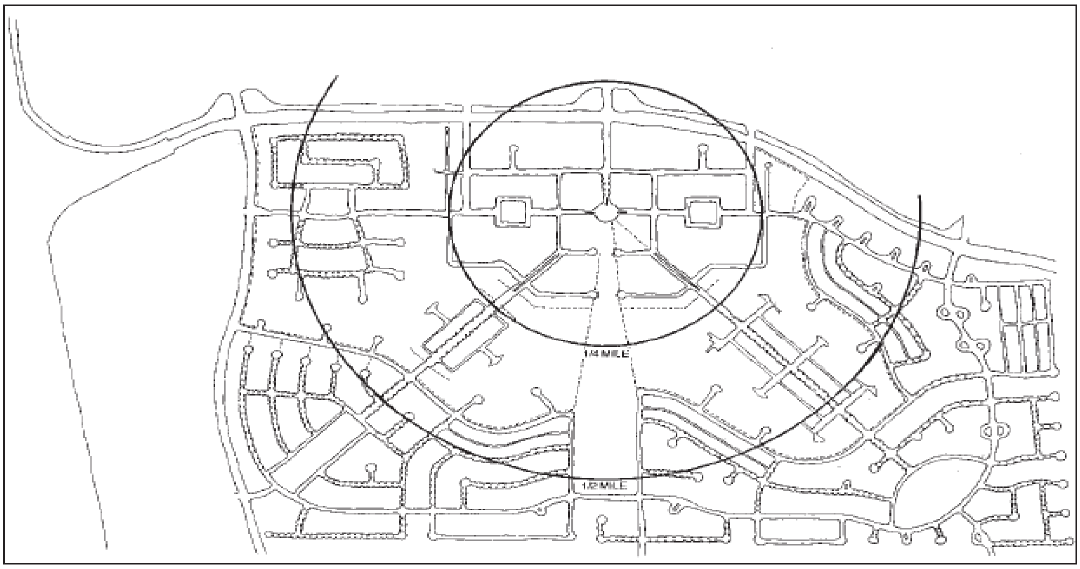
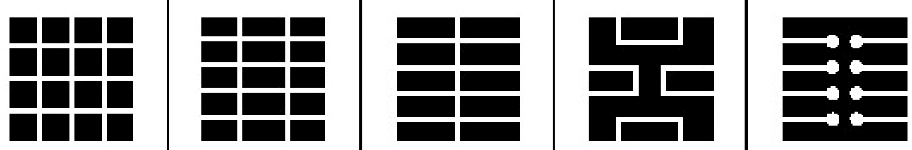


Figure 6.9 Layout of Laguna West Community, Sacramento, California

Source: Southworth & Ben-Joseph (2003)

6.2.3 Comparing street patterns

The recent debate on street pattern preference and design appears to be divided between concerns for the efficiencies of infrastructure and traffic and a consideration for aesthetics. Invariably, the debate boils down to the battle between conventional suburban loops and cul-de-sacs and traditional grid patterns (Canada Mortgage and Housing Corporation, 2002). Albeit there is no scientific evidence of a correlation between loops and cul-de-sacs and suburban developments (urban sprawl), it appears by convention the main character of street patterns at suburban areas (mostly in developed countries) is a combination of loops and cul-de-sacs. Similarly, it appears the grid street pattern is also conventionally linked to traditional neighbourhoods as some researchers have already alluded to this phenomenon (See Table 6.1). Therefore, the character of suburban or sprawling developments (particularly the street patterns) in combination with other factors usually provides the basis for criticism that suburban or sprawling developments are costly in comparison with traditional development patterns. Condemning urban sprawl on the grounds of unplanned, scattered and leapfrog developments should be decoupled from its loop and cul-de-sac street patterns. In opposition to general perception, loops and cul-de-sacs which are symbolic of suburban development patterns are efficient and economical in comparison with traditional grid patterns (typical of traditional neighbourhoods) in terms of the amount of land devoted to streets and attendant infrastructure. As seen from Figure 6.10, it is believed that suburban street layouts consume 16-25% less land than the traditional grids advocated by new urbanism (Canada Mortgage and Housing Corporation, 2002).



	Square grid (Miletus, Houston, Portland, etc.)	Oblong grid (most cities with a grid)	Oblong grid 2 (some cities or in certain areas)	Loops (Subdivisions - 1950 to now)	Culs-de-sac (Radburn - 1932 to now)
Percentage of area for streets	36.0%	35.0%	31.4%	27.4%	23.7%
Percentage of buildable area	64.0%	65.0%	68.6%	72.6%	76.3%

Figure 6.10 Comparison of Development Efficiency Among Different Street Patterns

Source: Canada Mortgage and Housing Corporation (2002)

Furthermore, Canada Mortgage and Housing Corporation (2002) opine that there is no direct correlation between residential density and street pattern. It is posited that the relationship between a residential density and street pattern is mediated by the amount of land devoted to right of ways (ROWs). More land being devoted to right of ways (ROWs) means less land being available for buildings and other open spaces. This, presumably, has a connotation of residential density. Incidentally, the density levels at suburban areas are lower in comparison with traditional neighbourhoods which, thus, seem to underutilise the gains made in buildable lands by suburban street layouts. However, the emphasis of this argument is on how much of productive land can be saved and how it could translate into reduction of development costs which eventually improves the fiscal situations of local authorities. Thus, it is worth noting that matters of discretion with respect to density are looked at differently.

6.2.4 Hypothetical neighbourhood patterns

This study builds on the pattern classification and alternative development patterns with their associated street patterns as reviewed in literature and models four hypothetical residential neighbourhood patterns, using AutoCAD, to reflect possible primary urban forms with regard to street patterns (See Figure 6.11).

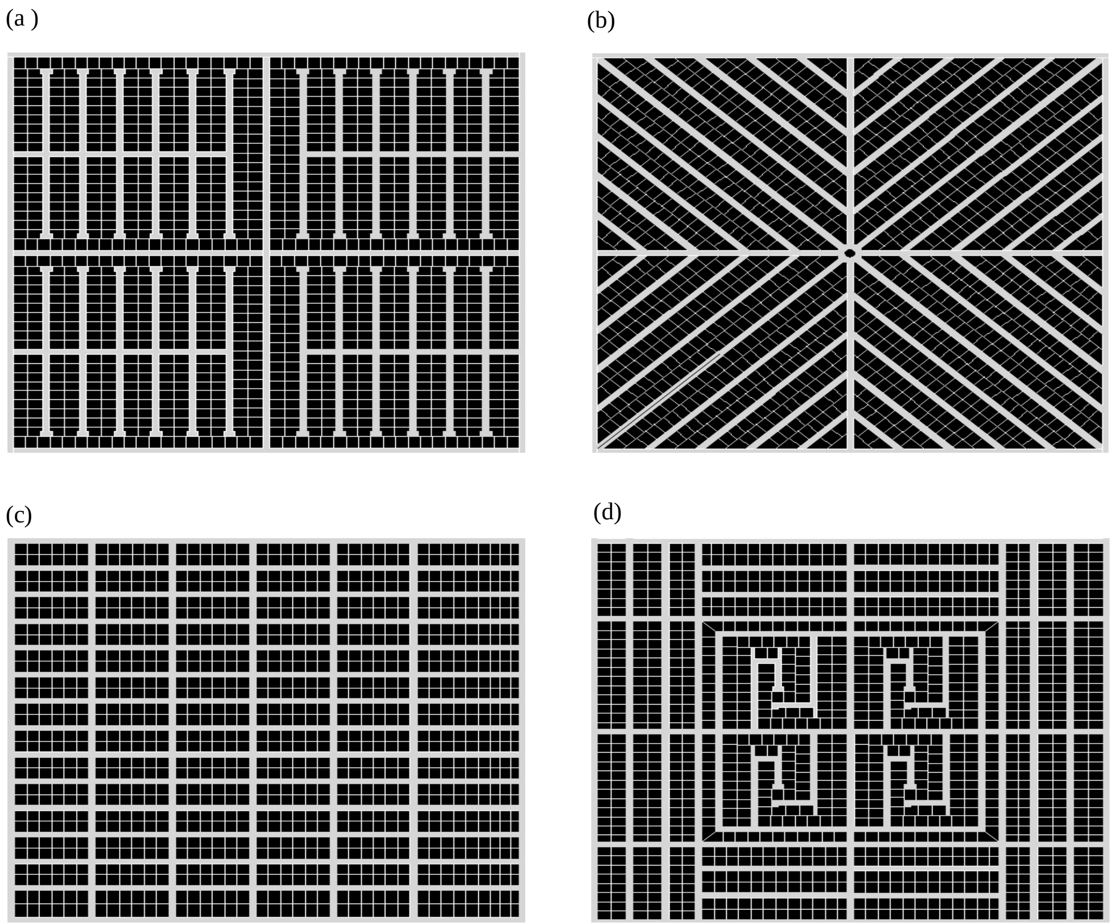


Figure 6.11 Hypothetical Residential Patterns (a) Tributary Pattern (b) Radial Pattern (c) Grid Pattern (d) Hybrid Pattern

The hypothetical patterns under consideration should not be taken as exhaustive and authoritative patterns in making conclusions. There could be several other street patterns with varied configurations still having the semblance of tributary, grid-iron, radial and hybrid in the real world situation. The configurations of the hypothetical patterns in this study are primarily for modelling purposes and also to unravel the efficiencies behind these street patterns with regard to infrastructure costs at a generic level. This helps to reveal patterns that are *preferred* and *discouraged* with regard to infrastructure efficiency. The four hypothetical residential neighbourhoods form the basis for modelling the infrastructure costs to alternative development patterns.

6.2.5 Non cost comparison of the hypothetical neighbourhood patterns

In avoiding biasness and ensuring a robust decision making on the appropriateness of urban forms, analysis should go beyond only infrastructure costs to also consider other benefits or losses of urban forms. Therefore, in this study, the benefits or losses are considered in how each hypothetical pattern fulfils or fails to fulfil the goal of accessibility which is an essential urban planning issue. Besides, street pattern or layout which is the main cost driver in this study has a primary function of accessibility.

Accessibility in planning and transportation literature is the availability or opportunity of activities in the society and the ease with which they can be reached (Pirie, 1979; Handy & Niemeier, 1997). This means accessibility is primarily concerned with particular locations where needs can be met and how one can get there. However, this study deals with the provision of network infrastructure to hypothetical residential sub-divisions without the decision of where activity centres are located. Therefore, accessibility in this case is focused on the connectivity within each residential neighbourhood. The configuration of the street networks and the residential blocks are analysed by the measurement of connectivity within the neighbourhood patterns.

6.2.5.1 Measures of connectivity

Connectivity is one of the spatial characteristics of urban patterns that can easily be measured quantitatively. A number of measures have been developed in literature to measure network connectivity and density in urban space. Table 6.2 shows some of the widely used measures of connectivity in planning and geography literature as well as their sources.

Block length

Block length as a measure of connectivity measures the length of the block from the curb or the centre line of the street intersections. Most local authorities usually specify maximum block length as a means to ensure connectivity within developments. Shorter block lengths mean more street intersections, better route choices and increased connectivity.

Table 6.2 Measures of Connectivity

Measure	Source
Block length (mean)	Cervero and Kockelman (1997)
Block size (mean area)	Hess et al. (1999)
	Reilly (2002)
Block size (median perimeter)	Song (2003)
Block density	Cervero and Kockelman (1997)
	Cervero and Radisch (1995)
	Frank et al. (2000) (census block density)
Intersection density	Cervero and Radisch (1995)
	Cervero and Kockelman (1997) (Number of dead ends and cul-de-sacs per developed acre)
	Reilly (2002)
Percent four-way intersections	Cervero and Kockelman (1997)
	Boarnet and Sarmiento (1998)
Street density	Handy (1996)
	Mately et al. (2001)
Connected Intersection Ratio	Allen (1997)
	Song (2003)
Link-Node Ratio	Ewing (1996)
Alpha Index	Berrigan, Pickle and Dill (2010)
	Dill (2004)
Gamma Index	Berrigan, Pickle and Dill (2010)
	Dill (2004)

Source: Adapted from Dill (2004).

Block size

Block size unlike block length is measured by the width and length to obtain either the area or the perimeter of the block. Using block size measured by area or perimeter as a standard is somehow flexible than block length for each side (Dill, 2004). Smaller and regular blocks ensure better connectivity and accessibility as compared to bigger and irregular blocks.

Block density

Block density is the number of blocks per unit of an area. Higher block density means smaller and more blocks per unit area. This indicates more intersections and better connectivity.

Intersection density

Intersection density is measured as the number of intersections per unit area. A higher density connotes a higher connectivity and accessibility.

Percent four way intersections

Four way intersections provide more route choices as compared to two and three way intersections. This has a connotation of relative connectivity and accessibility. A higher value of four way intersections means a higher connectivity.

Street density

Street density is measured as the ratio of linear length of street to square unit of an area. A higher street density indicates more streets and, presumably, higher connectivity (Dill, 2004).

Connected Node Ratio (CNR)

CNR as a measure of connectivity is the number of street intersections divided by the number of street intersections including cul-de-sacs (Handy & Butler, 2003). The maximum value of the index is 1.0. Higher values of this index indicate that there are relatively few cul-de-sacs and, theoretically, a higher level of connectivity.

Link-Node Ratio (LNR)

The LNR is the ratio of the number of links to the number of nodes (Ewing, 1996; Dill, 2004). The links are the street or road segments between intersections while the nodes are the intersections including cul-de-sacs. Higher value show higher connectivity levels in a development.

Alpha Index

The alpha index as a measure of connectivity, primarily, employs the concept of a circuit (a finite and closed path starting and ending at a single node). The alpha index is the ratio of the number of actual circuits to the maximum number of circuits (Berrigan, Pickle, &

Dill, 2010; Dill, 2004). Higher and better connectivity are associated with higher values of this measure. It is expressed as:

$$\text{Alpha Index} = \frac{L-N+1}{2*N-5}$$

where L is the number of link; N is the number of nodes.

Gamma Index

The gamma index is the ratio of the number of links in a network to the maximum possible number of links between nodes (Berrigan, Pickle, & Dill, 2010; Dill, 2004). The maximum possible number of links is expressed as 3*(Number of nodes – 2) because the network is abstracted as a planar graph. The values of the gamma index range from 0 to 1.0 and usually expressed as a percentage of connectivity. Higher values mean more connectivity. The gamma index is equal to:

$$\text{Gamma Index} = \frac{L}{3*(N-2)}$$

where L is the number of link; N is the number of nodes.

6.2.5.2 Applying connectivity measures

Three measures of connectivity were applied to the four hypothetical neighbourhoods in carrying out the connectivity comparison:

- Block density
- Connected node ratio (CNR)
- Link-node ratio

Intersection density, percentage of four way intersections and street density were omitted because they are highly and positively correlated with block density. The alpha and gamma indices, primarily, give indications of how far patterns are from ideal or optimum connectivity. However, since the comparison is focused on actual connectivity levels, the alpha and the gamma indices were eliminated. Block length and size were eliminated because data for computation of these measures were not common or similar to all the four hypothetical patterns. The connectivity measures of the four hypothetical neighbourhood patterns are presented in Table 6.3. The values of the block density were standardised to convert them to dimensionless values before aggregation to obtain the final connectivity index of each neighbourhood pattern.

Table 6.3 Connectivity Measure of Hypothetical Patterns

Neighourhood Pattern	Block Density	CNR	LNR	Aggregated Index
Tributary	-1,20	0,44	1,04	0,28
Radial	-0,07	1,00	1,52	2,45
Grid	1,25	1,00	1,79	4,04
Hybrid	0,02	0,80	1,38	2,20

As indicated in Table in 6.3, the grid pattern has the highest connectivity index (4.04) and hence the highest accessibility level. The radial (2.45) and hybrid (2.20) patterns are moderately high in connectivity indices and hence indicating moderately high accessibility levels. The tributary pattern is the lowest in connectivity index (0.28) indicating a, significantly, low accessibility in comparison with the grid, radial and hybrid patterns, respectively.

6.3 Characterisation of residential street patterns in Ghana

The characterisation of the residential street patterns in Ghana is limited to some residential locations in Greater Accra Metropolitan Area (GAMA) only (See Figure 6.12). GAMA is chosen as representative of Ghana as it remains the largest metropolitan and urbanised area in Ghana (Songsore, 2009). Moreover, due to availability of data, Greater Accra Metropolitan Area (GAMA) is being considered for the characterisation.

GAMA currently comprises the Accra Metropolitan Assembly (AMA), Tema Municipal Assembly (TMA), Ga East Municipal Assembly (GEMA) and Ga West Municipal Assembly (GWMA). Again, still owing to incomplete data within GAMA, the selection of residential localities was restricted to, primarily, AMA and a portion of GWMA. Selection of localities in AMA was done based on the income zoning structure of the metropolitan area. AMA is categorised into four income zones – first class residential area, second class residential area, third class residential area and fourth class residential area (Accra Metropolitan Assembly, 2002). The categorisation also reflects the housing and environmental conditions of the localities.

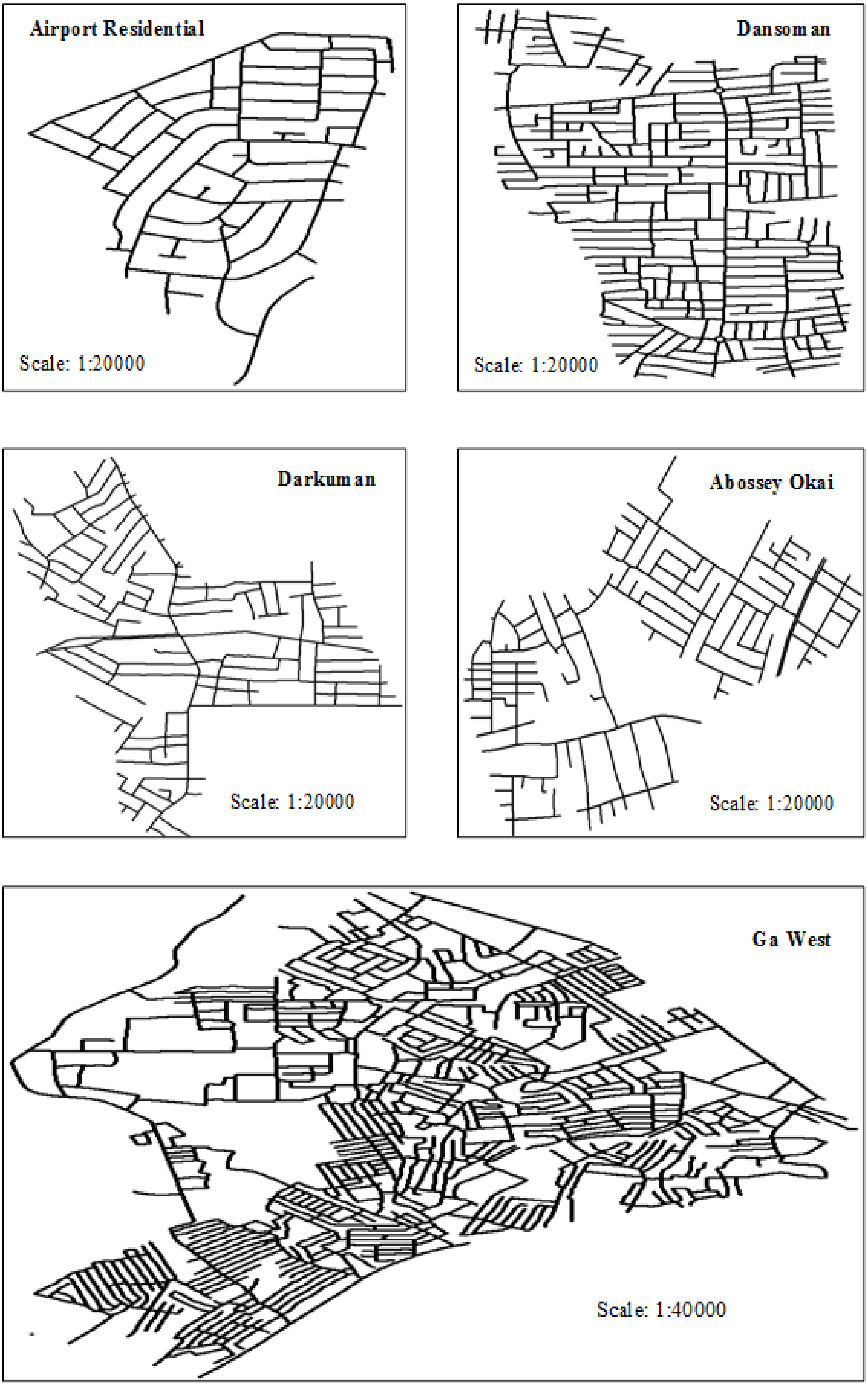


Figure 6.12 Street Patterns of Selected Localities in Greater Accra Metropolitan Area

Source: Author's Construct Based on Data from CloudeMade (2011)

A locality was chosen from each of the four income zones to provide an across board street pattern characterisation in the metropolitan areas. The selection of some residential localities in GWMA, formerly outskirts of AMA, is to reveal the trend of street patterns at the peripheries so as to provide a basis for comparison with the trend of patterns at the same location in developed countries. The pattern analysed under GWMA includes a combined area of Sowutuom, Israel, New Achimota and Ofankor localities.

In delineating the residential neighbourhoods for analysis (See Figure 6.12), the shape file of census enumeration areas was overlaid on the shape file of streets of GAMA. The boundaries of the census enumeration areas coincide with the boundaries of the localities.

6.3.1 Quantifying street patterns in Ghana

Describing the real character of street patterns in Ghana requires the ability to handle heterogeneity. This is because, in reality, the character of the street pattern as a whole emanates from parts or components which may be heterogeneous. The proportions of these components or parts (T-junctions to X-junctions or cellular blocks to cul-de-sacs) in any street system give an indication of the general character of the whole street system – pure grid, pure tributary or a continuum of the pure paradigms. A demonstration of simple quantitative parameters and presentational devices not only help to analyse and characterise street patterns, but also ensures a better appreciation of the morphological continuum of street patterns (Marshall, 2005b).

T Ratio and X Ratio

In an attempt to quantify the street patterns in Ghana, the parameters are first defined. The T ratio is defined as the ratio of T-junctions to the total number of junctions while the X ratio is the ratio of the X-junctions to the total number of junctions. In any street network constituting only T-junctions and X-junctions, the sum of the T ratio and the X ratio will be equal to one (Marshall, 2005b).

Cell Ratio and Cul Ratio

The cell ratio is the ratio of cells to the total number of cul-de-sacs and cells. On the other hand, the cul ratio is defined as the ratio of cul-de-sacs to the total number of cul-de-sacs and cells. The cell and cul ratios sum up to one (Marshall, 2005b). In a pure cellular street pattern, there will be no cul-de-sac and the cell ratio will be one while the cul ratio turns to zero. This is also true in a reverse situation where you have a pure tributary street pattern.

The combined plot

The parameters of the selected locations in GAMA are indicated in Tables 6.4 and 6.5. Thereafter a plot of T–X ratio is made against cell–cul ratio in a two-dimensional space as seen in Figure 6.13.

Table 6.4 T and X Ratios for Selected Localities in GAMA

Selected Localities in GAMA	Airport Residential	Dansoman	Darkuman	Abossey Okai	Ga West
Number of T-intersections	37	133	42	38	332
Number of X-intersections	19	98	69	73	217
Total	56	231	111	111	549
T ratio	0.7	0.6	0.4	0.3	0.6
X ratio	0.3	0.4	0.6	0.7	0.4

Table 6.5 Cell and Cul Ratios for Selected Locations in GAMA

Selected Localities in GAMA	Airport Residential	Dansoman	Darkuman	Abossey Okai	Ga West
Number of cells	103	520	195	156	997
Number of cul-de-sacs	3	47	52	10	203
Total	106	567	247	166	1200
Cell ratio	0.97	0.9	0.8	0.9	0.8
Cul ratio	0.03	0.1	0.2	0.1	0.2

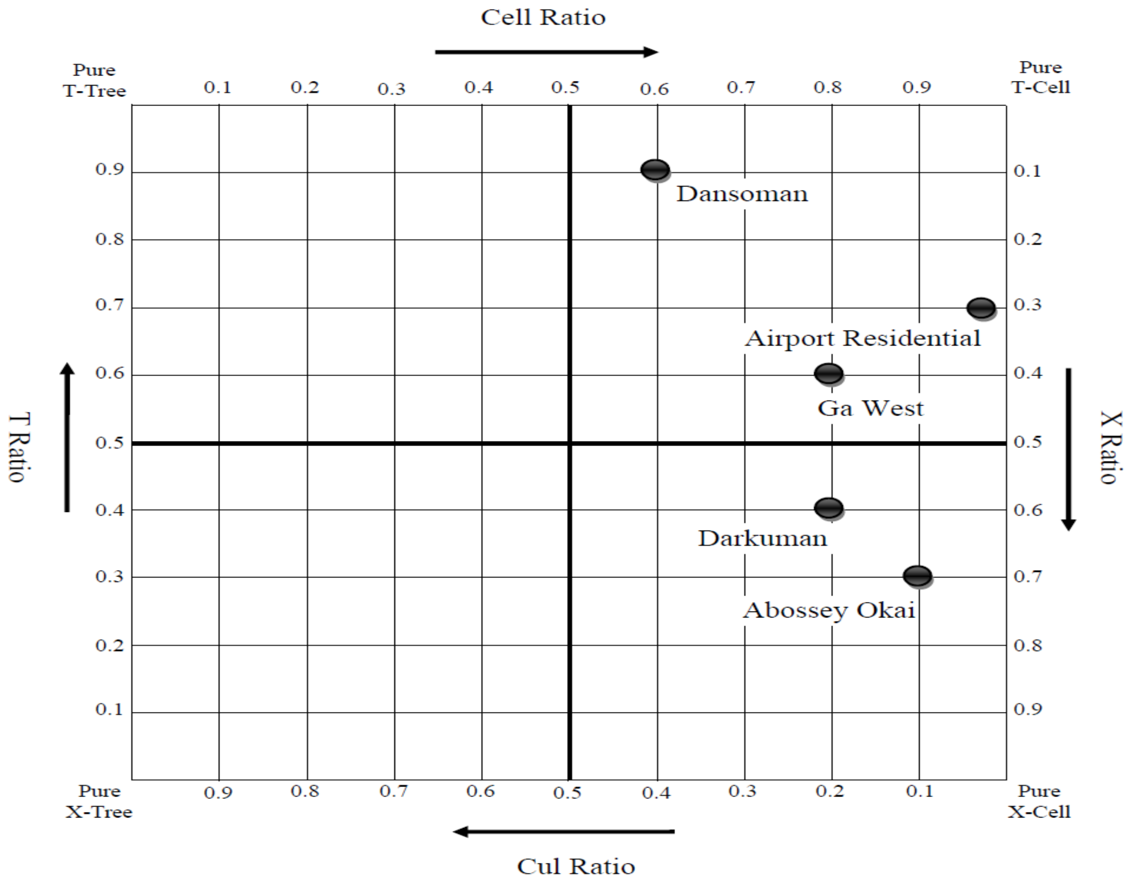


Figure 6.13 Combined Plot of T-X Ratio Against Cell-Cul Ratio of Selected Localities of Greater Accra Metropolitan Area

From the two-dimensional plot in Figure 6.13, it can be seen that the street pattern in GAMA is more cellular or griddy than dendritic. The Airport Residential and Dansoman localities, first and second class residential areas respectively, equally, reveal the same cellular street pattern as Darkuman and Abossey Okai, third and fourth class residential areas respectively. Airport Residential and Dansoman localities belonging to the high and medium income zones respectively, although cellular, have relatively a *T-cellular* street pattern. On the other hand, Darkuman and Abossey Okai belonging to the low income zones have also relatively an *X-cellular* street pattern. Obviously an *X-cellular* street pattern provides better accessibility as compared to *T-cellular* pattern. Usually, in the low income localities, walking forms a significant share of mobility and this appears to explain why the low income localities have an *X-cellular* street pattern as compared to the *T-cellular* pattern in the high income localities. The cul-ratio is slightly higher than what it should have been (See Table 6.5) in each locality, particularly Dansoman, due the truncation of roads at locality borders in the analysis. The Ga West location, formerly an outskirt of AMA, also indicates a griddy or cellular street pattern. This is in contrast with patterns at similar locations in most developed countries, particularly the U.S., where dendritic patterns ordinarily dominate.

Generally, apart from walking which is a significant transport mode in Ghana, other factors also help to explain the griddy or cellular street patterns in Ghana. Most of the residential developments at the suburbs are carried out informally and not undertaken by real estate developers. Real estate developers are usually concerned with the infrastructure costs and attractiveness of their sub-divisions and would thus opt for patterns that meet these objectives. The griddy or cellular pattern is also due to ease of sub-division as well as profit motives of land owners. In the absence of planners and landscape architects, traditional chiefs and families who own lands at the peripheries contract surveyors who simply carry out sub-divisions orthogonally.

6.4 Infrastructure costs modelling

6.4.1 The overview

This section of the study attempts to hold all other things constant and isolates the impact of street patterns and density on the infrastructure costs of alternative development patterns. The infrastructure cost, precisely, is the capital cost. This is done by modelling four residential neighbourhood patterns (See Figure 6.11) to reflect possible primary urban forms with respect to street patterns. The infrastructure costs for each neighbourhood pattern are then estimated and compared to ascertain the pattern which provides the least infrastructure cost. Generally, some infrastructure are less sensitive to street patterns. Point infrastructure (schools, hospitals, police stations, fire stations, sports centres, power generation stations, water treatment plants, waste water treatment plants, etc) are not, significantly, influenced by street patterns. Subsequently, the infrastructure under consideration are: water distribution network, electricity distribution network and road network. Assuming a flat topography, same engineering standards, same level of service and considering only the capital costs connotes the maintenance costs or cost-in-use for each neighbourhood pattern.

Each residential neighbourhood pattern accommodates a minimum of five thousand people, a threshold for a settlement to be considered urban in Ghana (Ghana Statistical Service, 2001). The five thousand people - the minimum population for a residential neighbourhood pattern - are housed with five persons per household, a reflection of the average household size in Ghana (Ghana Statistical Service, 2001).

6.4.2 Cost estimation methods

Different methods of estimating infrastructure costs of projects are available and in use today. The difference between the methods lies with the approach employed in arriving at the basic units of costs for the projects. The available details of the project, depending on the stage of project development, coupled with the available duration for estimation and the level of accuracy or certainty required determine which method to employ for any project. More detailed analysis and processes lead to accuracy and certainty of projects' cost estimates. Some of the methods are discussed below in the increasing certainty level.

6.4.2.1 Composite rate estimating

This method is considered to be an approximate and the least reliable approach to project cost estimation (State of Queensland, 2009; Gilleard, 2006). It involves the use of omnibus unit rates, usually, from historic database of projects similar to the project under consideration. The rates are obtained by relating the total costs of previous projects to some total capacities of those projects. A typical case is relating the total costs of a road project to the total lane length to obtain costs per lane kilometre of road or relating the total costs of a structure to the total gross floor area to obtain costs per square meter of that structure. Such "all-in" or "omnibus" unit rates could come from contractors' database or published by commercial services annually. The rates, usually, are for conventional or normal projects and may not take into accounts peculiarities (location, soil conditions, special materials, etc) that may be associated with the project under consideration. Hence adjustment factors and coefficients are necessary to enhance the reliability of the estimates. The adjusted "all-in" or "omnibus" unit rate is multiplied by some total capacities (total lane length of road, total gross area of structures, total capacity or volume of water, etc) to obtain the cost estimate of the new project. This approach has the advantages of simplicity and speed of estimating project costs. The composite rate estimate is expressed as:

$$Y = X.Q \qquad (1)$$

where Y = total cost; X = total capacity of interest; Q = omnibus unit rate or cost ratio

6.4.2.2 Parametric estimating

Parametric estimating as a tool for projects' costs estimation forecasts projects costs by virtue of their elements and parameters. It is a development of the composite rate estimating technique. At the kernel of parametric estimating technique are the cost estimating relationships (CERs) (Long, 2000; U.S., Department of Energy, 2011). A CER establishes a cost function which links cost as a dependent variable with the elements of the project as independent variables. In details, each element of the project could be further divided into components or parameters. The characteristics of the components or the parameters (cost drivers) influence the costs of the elements which subsequently influence the overall cost of the project. The CERs can be linear or non-linear and complexities increase as one moves from linear to non-linear (Long, 2000). This technique, just like the composite unit rate estimating, relies on collection and analysis of cost database of previous projects, similar to the project in question to forecast project cost. The cost database could be from contractors' project cost reports or from regular publications of engineering news journals. Adjustment of the historical cost data is still required to reflect the peculiarities of the project under consideration to improve the certainty of the cost estimate. The parametric estimating is expressed as:

$$Y = f_1 . E_1^{t1} + f_2 . E_2^{t2} \dots + f_n . E_n^{tn} \qquad (2)$$

where Y = total cost; f_1, f_2, f_n = cost estimating factors for cost elements of interest; E_1, E_2, E_n = cost elements of interest; t_1, t_2, t_n = exponents for transforming E_1, E_2, E_n

6.4.2.3 First principle or work package estimating

This estimating technique, sometimes referred to as "basic costs" estimating, is the calculation of project-specific costs based on detailed study of the resources required to undertake each activity of work involved in the project's work breakdown structure (State of Queensland, 2009). Unlike the first two techniques discussed above, this approach requires more detailed designs and specifications of the project. An experienced estimator or a collaboration between an estimator and the site production team is usually required to establish the work method as well as the production rate for each work package under the project. The work method coupled with the production rate reveals the resources and hence the cost for each work package in the work breakdown structure of the project. The bespoke nature of this technique ensures that specific and local conditions associated with the project are accounted for in the cost estimate of the project. This estimating technique requires more rigorous processes and hence provides better reliability with regard to project cost estimates. The first principle or work package estimating can be expressed in the following form:

$$Y = \sum_p \left[\sum_i Q_i \left((L_i . W_i) + M_i\right)\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where Y = total cost consisting *i* cost activities within *p* cost sections or packages (cost sections or packages are substructure, concrete works, etc while cost activities in a section or package "substructure" are trenching, earthworks support, backfilling, etc) ; Q_i= quantity of work in activity i; L_i= labour productivity rate for activity i; W_i= labour wage rate for activity i; M_i= Material unit price for activity *i*.

6.4.2.4 Probabilistic estimating

Probabilistic estimating as an estimating technique takes into account the fact that quantities measured can change, rates assumed can vary and risks with probable outcomes can occur on a project (State of Queensland, 2009). The cost estimate techniques discussed under sections 6.4.2.1-3 are all point estimates (single valued estimates) which usually do not predict a range of costs estimates. The reality of project costs variability is forcing project stakeholders to quantify the extent of variability. Recently, contractors are using probabilistic estimating techniques to ascertain the contingency levels in their bids while clients are employing the same approach to make "go-no-go" decisions (Diekmann, 1983).

The main goal in probabilistic estimating is the establishment of a probability distribution function (PDF) of the project's total cost (Touran, 1993). Generally, the mathematics required to generate the PDF is tedious and hence simulation methods are usually employed. One of the most effective and flexible simulation methods for establishing the PDF of the project total cost is the Monte Carlo simulation method (Diekmann, 1983; Touran, 1993). The probabilistic estimating technique as a dynamic estimating approach is not a replacement for the deterministic approaches earlier on discussed, but rather a complement.

6.4.3 Selecting the appropriate method

Loosely, estimating techniques can be categorised into detailed techniques and conceptual techniques (Diekmann, 1983). A detailed cost estimating technique (a typical case being the first principle or the work package estimating) requires sufficient design information while conceptual techniques (such as the composite rate estimating and parametric estimating) require some key parameters of the project for the estimation of the project total cost. The study under consideration is conceptual; however cost estimate accuracy is also required to support the validity of the conclusions of this study. To fulfil the cost reliability objective of the study, the first principle or work package estimating approach is employed.

6.4.4 Infrastructure cost functions and unit processes

The cost functions and unit processes highlight the components of the total direct construction costs of each infrastructure under consideration. The costs of these components consist material, labour and plant costs and are assumed for each residential sub-division pattern.

6.4.4.1 Water distribution system

Trench excavation

Trench excavation for pipe works is assumed in a sandy gravel type of soil. Due to the firmness of the soil type, there is no consideration for earthworks support. The average trench depth and width are 900mm and 450mm respectively.

Backfilling and bedding

The materials for backfilling are materials arising from trench excavation with 90% compaction. Fine sand of 150mm thick layer was considered for the bedding of the pipe works.

Pipe works

The pipe works costs consist the pipes, bends and fittings, thrust blocks, pressure testing and jointing materials. Generally, unplasticised polyvinyl chloride (uPVC) pipes with range of 100mm – 150mm nominal diameter are used for the distribution network.

Valves

Valves are placed at junctions and branches. Besides, no more than 180m of the water mains is located between isolating valves. Only control, isolating and blow-off valves are considered. Since a flat topography is considered in the study, air releasing valves are omitted in the cost model.

Fire hydrants

The main criteria for placing fire hydrants are as follows:

- Entrances and intersections of roads.
- No more than 150m access distance is allowed between fire hydrants.
- No house shall be more than 75m of fire access distance from the nearest fire hydrants.

Valve and hydrant chambers

Valve and hydrant chambers are in situ construction, consisting 150mm thick grade C20 mass concrete base, 150mm thick sandcrete blockwork and covered with 4mm thick heavy duty metal plate covers. The costs for the chambers include pits excavations and filling around. 600 X 600mm is considered for the chamber internal dimensions.

6.4.4.2 Electricity distribution system

Transformers and substation equipment

Cost for transformers is for pole mounted three phase units of the sealed tank type with oil immersed aluminium windings. The rating, generally, is assumed to be 315 kVA.

Poles and stay equipment

Poles for distribution are treated wooden poles and include the cost of mounting, shackles and insulators.

Conductors

Aluminium conductors are considered for both high voltage (11kV) and low voltage (0.4kV) networks. The cross section is assumed to be $120mm^2$. The high voltage lines are a three wire system while the low voltage lines are a four wire system.

6.4.4.3 Road network

A 13m right of way is assumed with 1.5m walkways on both sides of an 8m width carriageway.

Base

A fairly good soil is assumed and for each residential development pattern which takes away the need for several layers necessary for the structural integrity of the roads. The study assumes, only, a well compacted gravel base with a minimum thickness of 150mm.

Road surface material

A 20mm thick surface dressing is assumed to seal off the road surface. The cost of the road surface material is inclusive of the road markings.

Road kerbs

The kerbs are 250mm X 125mm chamfered precast concrete. The cost of the kerbs includes the concrete foundation and backing as well as the cement sand mortar jointing.

6.4.5 Costs model structure

The infrastructure cost model in this study is spreadsheet based. See appendices C and D for cost details. Figure 6.14 shows the estimating structure of the cost model.

6.4.5.1 Direct costs

The direct costs are outlays related to specific activities in the work breakdown structure (WBS) of the infrastructure development project. In estimating the direct costs, the amount of work under each activity in the WBS of the infrastructure development project was estimated and the corresponding resources (materials, plants and labour) required in executing each activity also estimated and costed. The cost of all resources (including quotations from sub-contractors for specialist works) for each activity is built into the unit rate for each activity.

6.4.5.2 Indirect costs

These are costs that cannot be related to any specific activity in the WBS of the infrastructure development project but are necessary and required for the proper execution of the project. For instance site visits and other costs the construction contractor incurs as part of mobilisation to move to site may not be tied to any specific activity in the main works. Again, cranes, scaffolding and general purpose machines for handling materials and aiding operations are usually indirect costs that must be accounted for in the total project costs. Also consumables such as fuel, grease among others are required for general purpose plants and site vehicles and are deemed as indirect costs. Site workshops, sanitary facilities, offices among other facilities for the construction contractors' project administrators and operatives are usually also not tied to specific activities in the main works but deemed as indirect costs of the project. Project supervision and management as well as transportation of construction workers to and from site must also be accounted for in the total costs of the project and many not necessarily be related to any specific activity in the main works. See Figure 6.14 for the components of indirect costs. The indirect costs were accounted for in the total costs of the infrastructure development project by surcharging 10% on the direct costs of each activity under the WBS of the infrastructure development project.

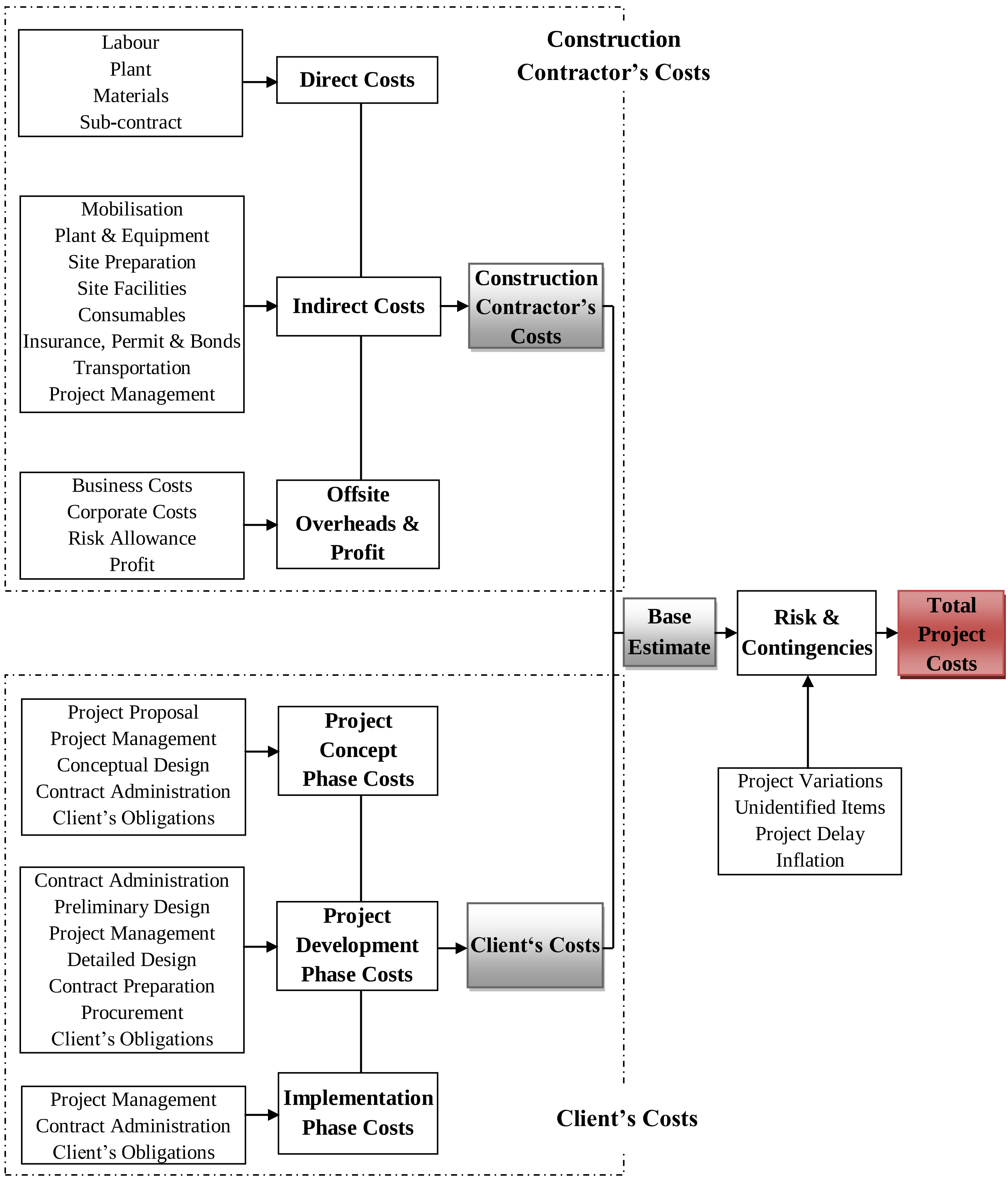


Figure 6.14 Estimation Structure of Infrastructure Costs Model

Source: Adapted from the State of Queensland's Department of Main Roads (2009)

The 10% surcharge for indirect costs is on the premise that historical records indicate that indirect costs of construction projects, though may vary with individual construction projects account for 6 - 10% of the total project cost in Ghana (P. Amoah, personal communication, December 21, 2011).

6.4.5.3 Offsite overheads and profit

These components of total infrastructure development project costs are due to the business operation and corporate costs as well as expected returns on investment for the construction contractor. In order to account for these costs components, an allowance of 25% was made and surcharged on the total costs of works (direct costs and indirect costs). These costs components, realistically, vary from one construction firm to the other, but in Ghana a range of 20 - 30% is common among many construction firms (P. Amoah, personal communication, December 21, 2011).

6.4.5.4 Client's costs

The client's costs are the costs the client needs to conceptualise, develop and implement the infrastructure project. See Figure 6.14 for components of client's costs. Client's costs in this study exclude the cost of land. The cost of land is held constant for all the four hypothetical residential neighbourhood patterns. From experience, client's cost for conceptualising, developing and implementing infrastructure projects ranges between 5 - 15% of the construction contractor's costs of the project in Ghana (P. Amoah, personal communication, December 21, 2011). However, 15% of the construction contractor's costs of the infrastructure project was assumed for client's cost.

6.4.5.5 Risk and contingencies

Every infrastructure development project comes with risk and unintended occurrences. The scope and functionality of the project, the specifications of materials and a lot of components of the project could be varied. Delays, inflation and omissions during the project development phase are issues that could threaten the accuracy of estimated infrastructure project costs. See Figure 6.14 for more details on risk and contingencies components of infrastructure project costs. Given normal conditions, the cost of these components of the total project cost ranges between 10 – 20% in Ghana (P. Amoah, personal communication, December 21, 2011). Hence 15% was allowed in the total costs of the infrastructure project.

6.5 Infrastructure costs implications with respect to street patterns

This section presents the infrastructure costs of water distribution network, electricity distribution network and road network to hypothetical residential neighbourhood patterns. Comparisons of infrastructure costs of the individual infrastructure are made with regard to the four hypothetical neighbourhood patterns – tributary, radial, grid and hybrid. The total area of each residential sub-division is 1.1km^2 and is required to settle a minimum of five thousand people with a household size of five persons per household. The analysis is to isolate the influence of street patterns on infrastructure costs. Hence, initially, density is considered constant and assumption made for only single family dwellings for all the alternative development patterns. A combined effect of street patterns and density on infrastructure costs is considered under section 6.6.

6.5.1 Water distribution network

The cost of a water distribution network is influenced by the demand, the type of system used and the connection to the mains by individual dwellings (Burchell, Downs, McCann, & Mukherji, 2005). The water consumption per capita in Ghana is 50 litres (Adombire, 2007). Water for fire was assumed as 48m^3/h for two hours of fire fighting. A hydraulic analysis was done using EPANET 2.0 to determine the pipe dimensions. See appendix A for the results and layout of the hydraulic analysis. The system of water supply is individual home connection to the mains as the water mains followed the street layout. However, since density is held constant initially, lot sizes and housing typology are also kept constant for all the alternative residential neighbourhood patterns, the costs of connections to the mains in the form of laterals were omitted in the estimate. The breakdown and details of the costs are shown in appendices C and D. The costs of water distribution network for the alternative residential neighbourhood patterns are indicated in Figure 6.15. The tributary pattern shows the lowest cost per dwelling (US$ 476) while the grid pattern indicates the highest cost per dwelling (US$ 642) in water distribution network. The radial and hybrid patterns present moderate costs per dwelling, US$ 582 and US$ 619 respectively. What accounted for a significant difference in costs among the alternative residential neighbourhood patterns are the pipes and attendant costs. Together, they account for a minimum of 60% of the total direct construction costs under each scenario. The costs of valves, hydrants and other appurtenances were somehow moderate in accounting for the cost variations.

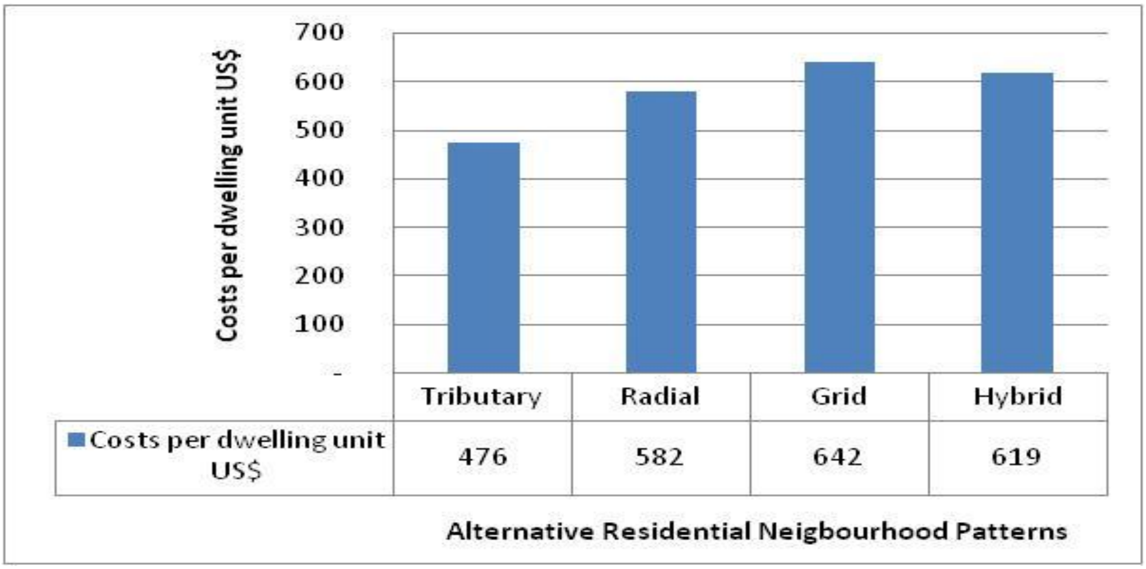


Figure 6.15 Capital Costs of Water Distribution Network for Alternative Neighbourhood Patterns

The tributary pattern indicates 35% cost savings per dwelling in comparison with the grid pattern. The costs savings in favour of the tributary pattern vis-a-vis the grid pattern are largely explained by the relative reduction in the length of pipes and related works. The radial pattern reveals a moderate 10% cost savings per dwelling compared to the grid pattern. The hybrid pattern only presents 4% savings compared to the grid pattern. The costs savings per dwelling by the radial and hybrid patterns in comparison with the grid pattern are, similarly, explained by the relative reduction in the length of pipes and related works. Among the linear infrastructure considered in this study, water distribution network appears to be lowest in cost per dwelling and accounts for 9% of the combined infrastructure costs.

6.5.2 Electricity distribution network

The cost of electricity distribution network is largely influenced by the demand, the type of system used and density of the built-up area. In this study, a maximum load demand of 4kVA was estimated for each household. See Table B.1 in appendix B for the composition of demand. A grid system was used for the primary distribution system while a radial system was employed for the secondary distribution system in all the scenarios. A spreadsheet based cost model, developed locally by the Electricity Company of Ghana, was run to estimate the direct costs of materials, labour and plants for the electricity distribution network for each residential neighbourhood pattern. See appendices C and D for details of the costs estimates. The costs per dwelling of electricity distribution network for the alternative residential neighbourhood patterns are presented in Figure 6.16.

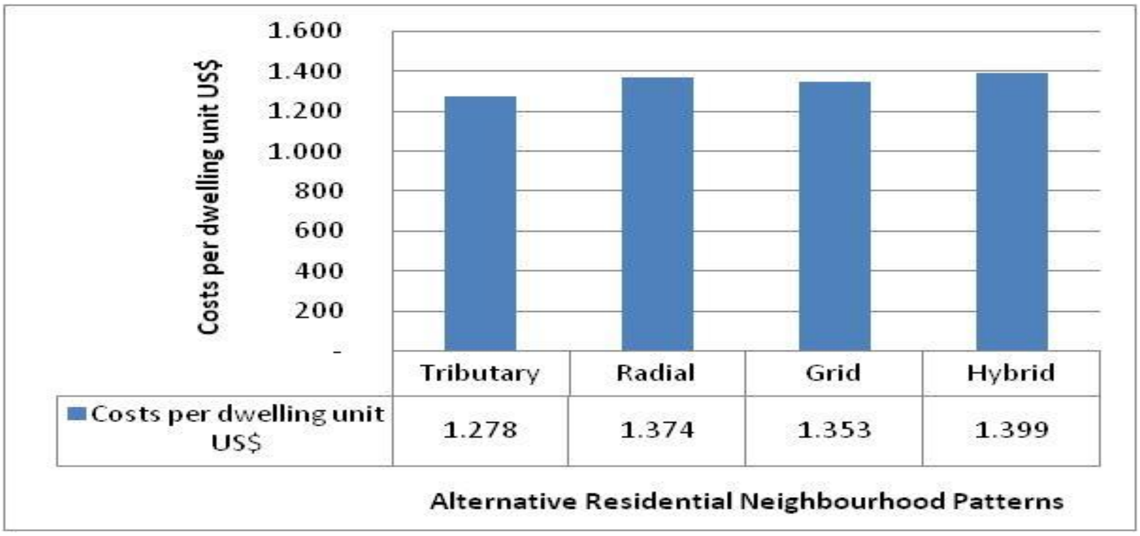


Figure 6.16 Capital Costs of Electricity Distribution Network for Alternative Neighbourhood Patterns

Clearly, it can be seen that the difference in costs per dwelling between the alternative residential neighbourhood patterns is marginal. The tributary pattern still remains the lowest in terms of cost (US$ 1,278) while the hybrid pattern turns out to be the most costly (US$ 1,399) in electricity distribution network. In comparison with the hybrid pattern, the tributary pattern saves 9% of electricity distribution costs. The radial and grid patterns save only 2% and 3% respectively in comparison with the hybrid pattern. The conductors, transformers and poles account for, averagely, 50%, 25% and 15% of the total direct construction costs respectively in all the four hypothetical patterns. The grid pattern seems to be benign on electricity distribution network costs after the tributary pattern. The savings that were made on conductors with the tributary pattern were to some extent offset by the increased costs of transformers and poles. Though density was held constant initially, the tributary pattern produced more lots in a sub-division as compared to the grid pattern (See Table 6.5). This resulted in higher transformer costs for the tributary pattern. Generally, with the exception of the pure tributary pattern, the radial pattern which is a kind of tributary and the hybrid pattern which has a component of tributary have higher costs of electricity distribution network in comparison with the grid pattern. The higher costs are accounted for by the relatively higher demand due to higher number of lots and the higher costs of poles necessitated by the higher number of termination and T-off poles which come with attendant costs for stay equipment. The costs of electricity distribution network seem to be the second lowest and account for 21% of the combined infrastructure costs. However, it appears other factors such as demand, density and type of distribution system other than the configuration of the street pattern influence the costs of electricity distribution network significantly. In this case, higher demand will necessitate higher ratings and numbers of transformers which has higher costs implications. Besides, when densities are low, the cost of conductors will rise as longer lengths will be required in a distribution system. The low densities will not only necessitate longer lengths of conductors, but will also lead to voltage drops which would have to be dealt with by increasing the number of step-up transformers. Consequently, in a sub-division, the lot size which has an implication on density must be one parameter that must be looked at critically as it influences the length of conductors and number of transformers which together account for about 75% of the direct construction costs of electricity distribution network.

6.5.3 Road network

Unlike the electricity distribution network, the road network of the alternative residential neighbourhoods indicated some costs differences (See Figure 6.17). Obviously the tributary pattern showed the lowest cost per dwelling while the grid pattern was highest in cost per dwelling. The radial pattern, a kind of tributary pattern, was moderate in costs after the tributary pattern. The hybrid pattern, which is fundamentally a grid pattern, had a slightly lower road network costs per dwelling in comparison with the pure grid. This might have been accounted for by the tributary component of the hybrid pattern. The tributary pattern provides a cost savings per dwelling of 33% in comparison with the grid pattern. The radial and hybrid patterns showed 12% and 5% savings, respectively, in road network costs in comparison with the grid pattern. Basically the costs savings of the tributary, radial and hybrid patterns vis-à-vis the grid pattern are explained by the, relatively, shorter lengths of roads with respect to the tributary, radial and hybrid patterns.

Clearly, the costs of road network is the highest and accounts for about 70% of the combined infrastructure costs. The significant share of the road network costs in relation to the combined infrastructure costs makes road infrastructure a critical cost component in alternative residential neighbourhood patterns. Hence decisions that affect the width and length of road network must be critically looked at as the costs implications are significant. This is in allusion to what Southworth & Ben-Joseph (2003) earlier pointed out that an increase in street width also increases construction and maintenance costs proportionately, lowers densities (assuming the same lot size and housing type), and increases travel times between points. As pointed out in section 6.3.1, the street patterns in Ghana are generally cellular or grid in form. However, the cost of sidewalks on both sides of the carriageway is

19% of the total direct construction cost of the road network across all the residential neighbourhood patterns. See appendices C and D for more details on road network costs. Therefore, since the tributary pattern provides costs savings of about 33% in comparison with the grid pattern, it seems to be economical for developing countries, especially Ghana, to consider dendritic street patterns in residential sub-divisions. Obviously, dendritic patterns have poor accessibilities. Coupled with this challenge is the low automobile ownership and dependency in Ghana as well as in most developing countries. This invariably will create mobility and accessibility problems.

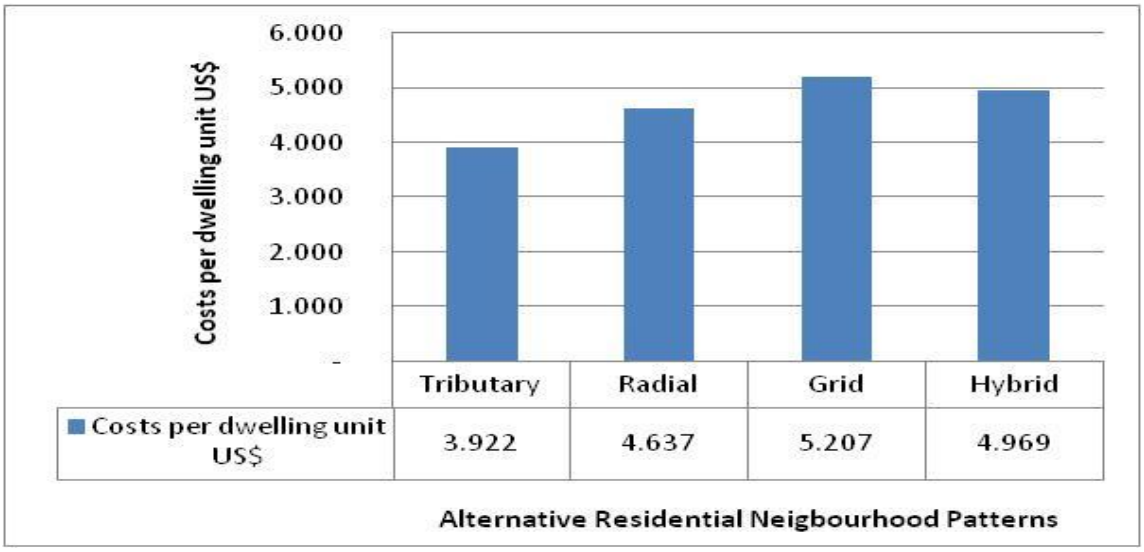


Figure 6.17 Capital Costs of Road Network for Alternative Neighbourhood Patterns

However, the accessibility dimension of the dendritic pattern could be enhanced or augmented by a carefully designed network of footpaths. This to some extent fits well into the mobility patterns of people in Ghana and most developing countries who usually rely on slow modes or walking. Again, in terms of net costs, the network of footpaths would ensure some savings in comparison with road network as the 33% costs savings with the tributary pattern could easily offset the slightly higher costs (19%) the network of footpaths may lead to.

6.5.4 Combined infrastructure costs

The total costs per dwelling of the three infrastructure (See Figure 6.18) reveal the tributary pattern as the most economical pattern in terms of the costs of linear infrastructure while the grid pattern is the least economical. The cost per dwelling (US$ 5,676) in the case of the tributary pattern shows a 27% costs savings over the costs of the grid pattern (US$ 7,202). The costs per dwelling of the radial and hybrid patterns also indicate 9% and 3% savings, respectively, in comparison with the grid pattern. With the exception of the tributary pattern, the radial and the hybrid patterns show marginal costs savings over the grid pattern. The radial pattern, though not a popular choice currently, appears to be economical in linear infrastructure costs in comparison with the hybrid and grid patterns. Clearly, the savings in linear infrastructure costs by the tributary, radial and hybrid patterns in comparison with the grid pattern largely resulted from savings in water distribution and road networks as the electricity distribution network showed minor costs difference.

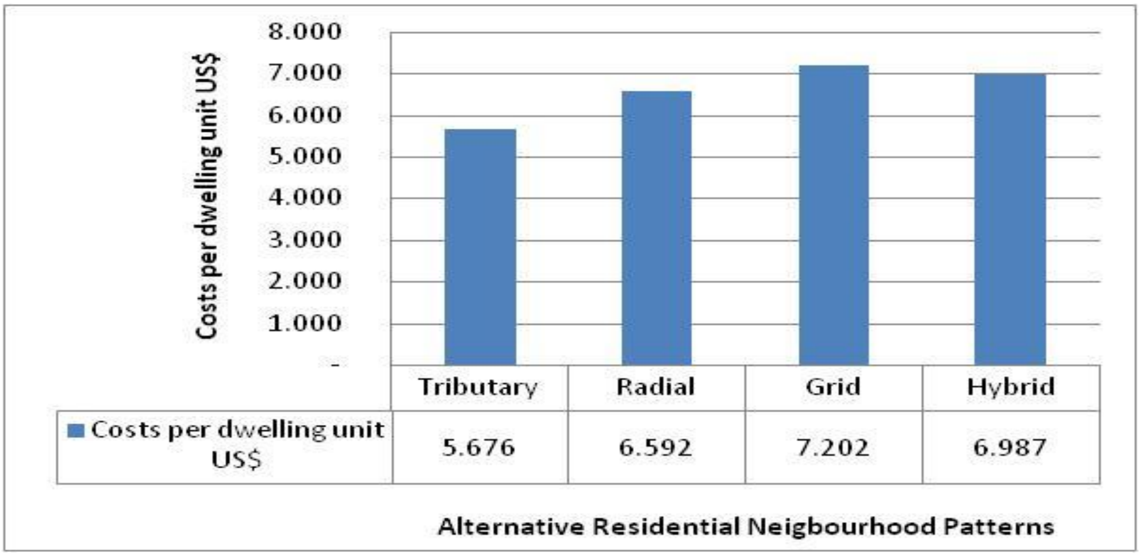


Figure 6.18 Combined Capital Costs of Alternative Neighbourhood Patterns

The costs per dwelling under the various hypothetical residential neighbourhood patterns show a gradual rise in cost as one moves from the pure tributary pattern towards the pure grid pattern. The radial pattern, as indicated earlier on, is a kind of tributary pattern while the hybrid pattern as configured in this study is, primarily, a grid pattern with components of a tributary pattern. The continuum of linear infrastructure costs, with respect to urban forms, (as shown in Figure 6.19) indicating the tributary and grid patterns at the extreme ends, provides the opportunity for costs optimisation with regard to street configurations.

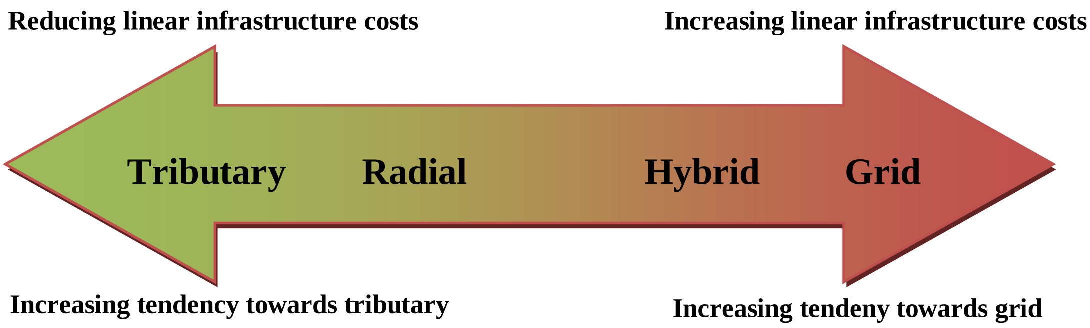


Figure 6.19 A Continuum of Linear Infrastructure Costs with Respect to Urban Forms

6.6 Infrastructure costs implications with respect to street patterns and density

In addition to street patterns, the effect of density was also isolated on urban infrastructure costs. Density as referred to in the analysis is net density. The density for each hypothetical residential pattern was raised in three equal successions and the respective infrastructure costs estimated. The dwelling space per household ($150m^2$) was assumed same for the various densities across the hypothetical residential patterns. The dwellings were assumed as one-storey, two-storey, three-storey and four-storey per lot for the density scenarios respectively. In isolating the effect of street patterns on capital costs of the linear infrastructure under consideration, density was initially assumed constant. Hence the capital costs of households' connections to the main infrastructure were omitted. Therefore, to ensure consistency and equal bases for comparison, the capital costs of household connections to the main infrastructure were omitted in isolating the effect of density on the capital costs of the linear infrastructure. The results are shown in Figures 6.20 – 6.23 for water distribution network, electricity distribution network, roads and combined infrastructure respectively.

6.6.1 Water distribution network

The isolation of the effect of density on the capital costs of water distribution network can be seen from Figure 6.20. Initially, as density increases, the capital costs of water distribution network per dwelling for all the hypothetical residential patterns reduce sharply (as indicated by a steep slope), reach a minimum at density 40 DPH and begin to rise marginally. See also Tables E.1 and E.2 in appendix E for details of figures. With the same length of water distribution network for all the hypothetical residential patterns, it is required that the capital costs per dwelling reduce with increasing density. However, capital costs per dwelling seem to rise after a density of 40 DPH. The rise in capital costs per dwelling is accounted for by the increment in the dimensions of the pipes and other appurtenances, particularly diameters, as density increases. Until the density of 53 DPH, with the exception of the tributary pattern, a 100mm diameter pipe sufficed for all the hypothetical residential patterns and capital costs per dwelling decreased with increasing density. However, at density 53 DPH, to maintain a minimum pressure of 3.0 bar (30 Mwc) in the distribution network, the pipe diameter was increased to 125mm. This resulted in a marginal rise in capital costs per dwelling as indicated in Figure 6.20. See also Tables E.1 and E.2 in appendix E for details of figures.

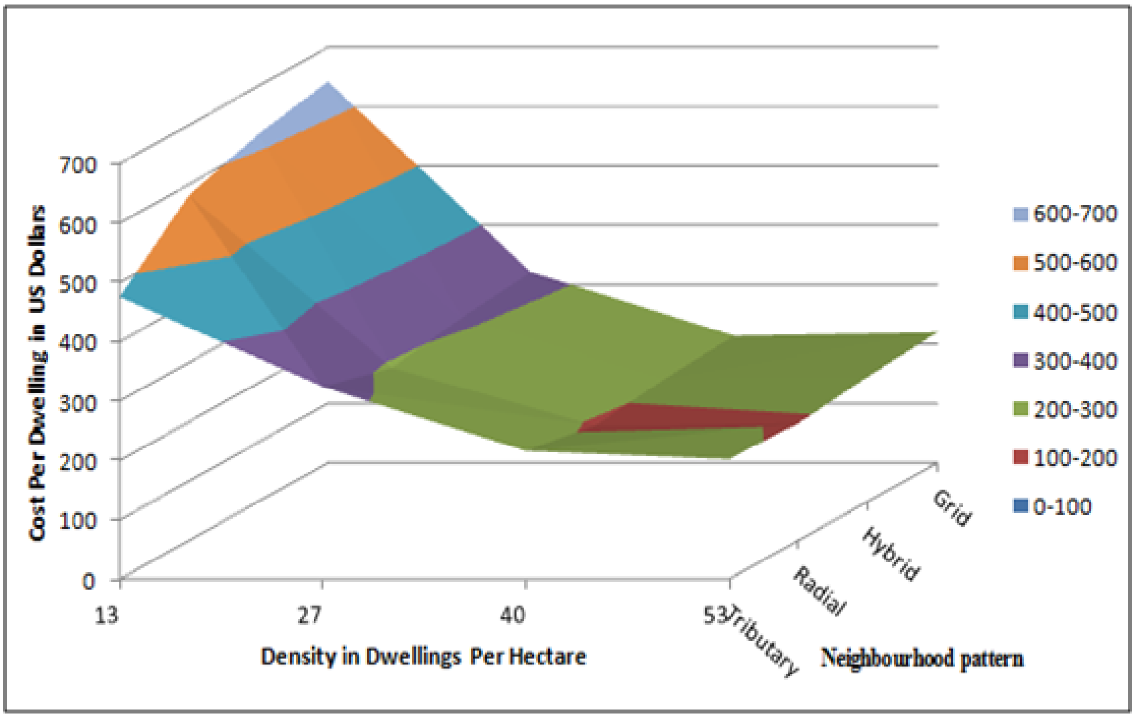


Figure 6.20 Effect of Density on Capital Costs of Water Distribution Network

This finding supports an earlier work by Ladd (1992) which indicates that except within a range of very low densities, the per capita public services costs of infrastructure increase with higher densities, depicting a "U" shaped curve. Moreover, it appears although capital costs per dwelling of water distribution network decrease with increasing density, increasing density beyond a particular threshold warrants bigger diameter of pipes and appurtenances. This increases costs excessively and erodes the gains by increasing density. Besides, although the tributary pattern saves on the length of water distribution network, relatively bigger pipe diameters pipe are required to maintain the minimum pressure (3.0 bar) in the network. For instance, while a 100mm diameter pipe sufficed for the radial, grid and hybrid patterns at densities 27 DPH and 40 DPH, the tributary pattern required a pipe diameter of 125mm for the respective densities. Again, at density 53 DPH, a pipe diameter of 125mm sufficed for all the patterns except the tributary pattern which required a pipe diameter of 150mm. Therefore, at higher densities, the tributary pattern becomes less economical with respect to capital costs per dwelling due to the increasing sizes of pipes and other appurtenances. Clearly, the radial pattern seems to, relatively, benefit from increasing density as it presents the lowest capital costs per dwelling for water distribution network as indicated in Figure 6.20 by the depression along the density axis. This is partly explained by the fact that the radial pattern, relatively closer to the tributary pattern in terms of configuration, similarly economises on the length of pipeworks. However, unlike the tributary, the radial pattern does not – for hydraulic purposes – require overly big dimensions of pipes and other appurtenances as density increases. This eventually ensures that the radial pattern leverages on its economy of pipe length to reduce capital costs as density increases. Again, from Figure 6.20 and particularly along the neighbourhood pattern axis, it can be seen that the capital costs per dwelling for water distribution network increase gradually as one moves from the tributary pattern to the grid pattern. It is also worth noting that the relatively steep slope along the density axis in comparison with the gentle slope along the neighbourhood pattern axis indicate that density seems to influence capital costs of water distribution network more than street patterns or configuration.

6.6.2 Electricity distribution network

Similar to the water distribution network, the effect of density on electricity distribution network is indicated in Figure 6.21. Again, initially as density rises, the capital costs of electricity distribution network for all the hypothetical patterns decrease suddenly and thereafter decrease marginally with further increment in density (See phenomenon along density axis). This presupposes that further increment in density will not guarantee further reduction in capital costs of electricity per dwelling forever.

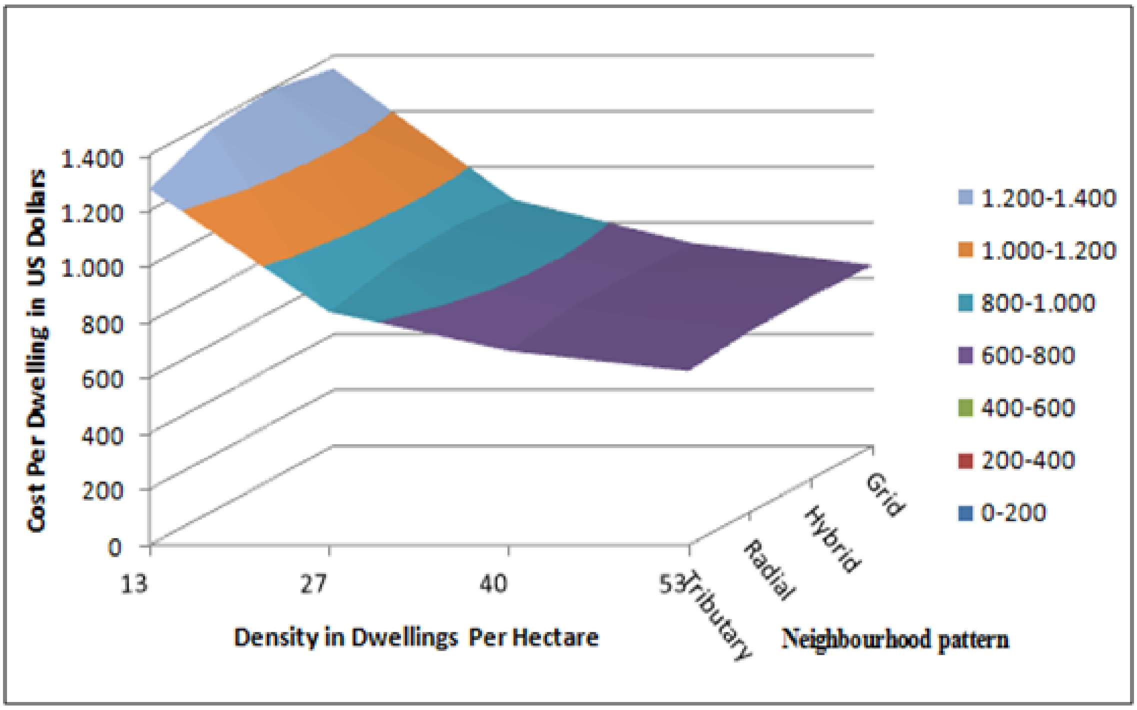


Figure 6.21 Effect of Density on Capital Costs of Electricity Distribution Network

A density threshold would be reached where the capital costs of electricity will begin to rise. Such a rise in capital costs per dwelling, with increasing density, will be warranted by higher technical standards (necessitating higher costs) that come with higher densities. Besides, along the neighbourhood pattern axis, the tributary pattern indicates the lowest capital costs of electricity distribution network (See Figure 6.21). Hence, the tributary pattern, however, appears to be relatively cheaper on capital costs of electricity distribution network as density increases. This relative economy is justified by the savings in the costs of conductors which constitute, approximately, 50% of the total direct costs of electricity distribution network.

6.6.3 Road network

The capital costs per dwelling for the alternative hypothetical residential patterns as in the case of water and electricity distribution networks, similarly, decrease sharply, in the case of road network, with increasing density at the initial stage and later decrease marginally with further increment in density (See phenomenon along density axis). The marginal reduction in capital costs of the road network with increasing density is justified by the higher road standards associated with higher density and traffic volumes.

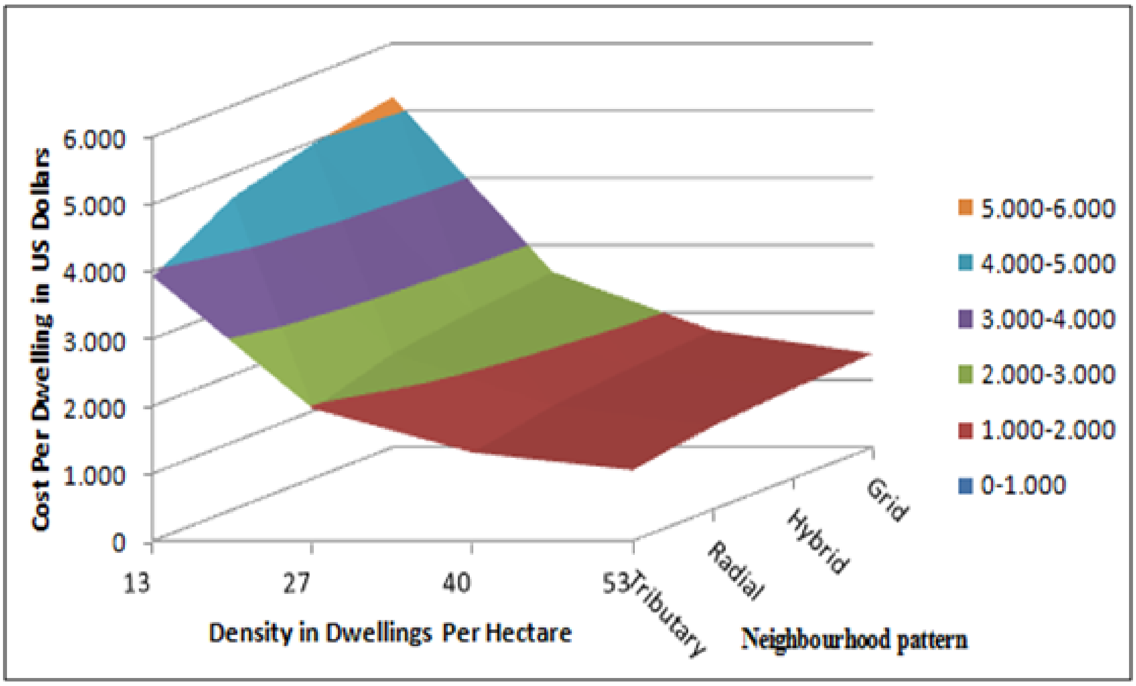


Figure 6.22 Effect of Density on Capital Costs of Road Network

The higher road standards associated with higher densities which, invariably, increase the capital costs of the road network are particularly related to the strength and structural integrity of the road. Hence the tributary pattern which saves on the total road length still reveals a, relatively, lower capital costs of road network per dwelling with increasing density. See Figure 6.22 – along the neighbourhood pattern axis – for a rising capital cost per dwelling as one moves from the tributary pattern towards the grid pattern.

6.6.4 Combined infrastructure costs

The combined infrastructure costs reveal the summation of the capital costs per dwelling of water and electricity distribution networks and roads vis-à-vis density and street pattern (See Figure 6.23). Once again the capital costs per dwelling for linear infrastructure decrease with increasing density (See phenomenon along density axis). The decrease in capital costs per dwelling is very drastic, initially, when density is increased and decreases marginally with further increment in density. Trajectories along both density (See also Tables E.7 and E.8 in appendix E for details of density figures) and neighbourhood axes indicate that the tributary pattern still remains, relatively, cheaper and the grid pattern the most expensive with respect to linear infrastructure under increasing density (See Figure 6.23).

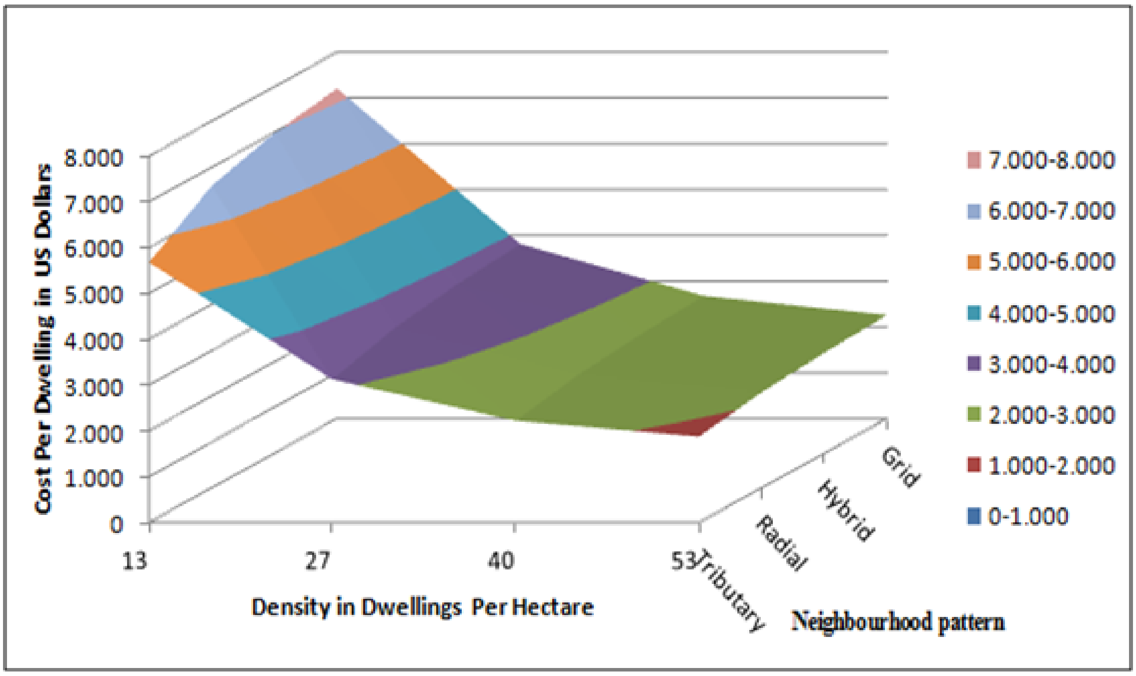


Figure 6.23 Effect of Density on Combined Capital Costs of Linear Infrastructure

From Figure 6.23, a density from 13 DPH to 53 DPH means approximately a 300% increment in density. However, the corresponding decrease in capital costs per dwelling for linear infrastructure is about 68% across the alternative hypothetical residential patterns. This means that although a rise in density decreases the capital costs of linear infrastructure to an extent, there is a clear evidence of "diminishing returns". Hence, it is necessary to ascertain the justification for further increasing density beyond a particular threshold with regard to capital costs of linear infrastructure. Again, it can be clearly seen from Figure 6.23 (particularly along the neighbourhood pattern axis) that differences in capital costs per dwelling for the alternative street patterns do not show any significant variation as density increases. This is seen in the, still, gentle slope along the neighbourhood pattern axis. Hence, it suggests that as density increases, other factors other than street pattern are significant to costs. The costs as stated here is with emphasis on economic and environmental costs. The economic and environmental costs could manifest in time loss due to traffic congestion and vehicular pollution, respectively, among other costs factors as density increases. Though not the focus of this study, it is worth noting for a balanced and transparent decision in the quest for an efficient urban form.

6.7 Development costs and fiscal implications

Development cost is a function of land costs, infrastructure costs and structure costs. These components eventually influence the costs of homes or dwelling units. However, since the structure costs are usually private costs, they are of less concern to governments and local authorities in developing countries. In developed countries, the infrastructure costs are usually included in the final price the home owners pay for the homes. However, in Ghana, except a few real estate companies which take care of infrastructure costs of developments through this means, most linear infrastructure are provided by parastatals. These parastatals incur the costs of the infrastructure either after settlement of households or during the settlement process and recoup their capital through connection fees and tariffs. Therefore any residential neighbourhood pattern which imposes excessive infrastructure costs on the parastatals not only strains the budget of the government but also raises the tariffs of utilities to the general public who consume the services of the parastatals. For instance, assuming a constant density at 13 DPH and analysis made for the implication of street patterns on capital costs of linear infrastructure, as shown in Table 6.6 – for the same size of development tract (1.1km^2) – the tributary pattern provides total costs savings of US$ 1,209,036 in comparison with the grid pattern.

Table 6.6 Combined Capital Costs of Linear Infrastructure of Alternative Residential Neighbourhood Patterns with Respect to Street Patterns

	Alternative Residential Neighbourhood Patterns			
	Tributary	Radial	Grid	Hybrid
Total costs (US$)	6,532,896	7,297,584	7,741,932	7,601,409
Costs per dwelling unit (US$)	5,676	6,592	7,202	6,987

The radial and hybrid patterns also indicate total costs savings of US$ 444,348 and US$ 140,523, respectively, in comparison with the grid pattern.

Land is deemed to be a very vital commodity to every government or local authority. The way governments and local authorities choose to invest their lands affects their fiscal outlooks. More land being devoted to infrastructure increases public services costs while reducing available land for other revenue generating purposes.

Table 6.7 Efficiency of Alternative Residential Neighbourhood Patterns

Indicators	Tributary	Radial	Grid	Hybrid
Total land area (km^2)	1.1	1.1	1.1	1.1
Number of lots	1,151	1,107	1,075	1,088
Area of streets (%)	22	25	27	26
Buildable area (%)	78	75	73	74
Street length (m)	18,399	20,920	22,814	22,033

Again, with the same development size ($1.1km^2$) as seen in Table 6.7, the tributary pattern devotes 22% of the total land area to road network while the grid pattern devotes 27%. The radial and hybrid patterns devote 25% and 26% of their total land areas, respectively, to road networks and attendant infrastructure. Clearly, the public services costs of the tributary pattern will be lowest in comparison with the rest of the patterns while the grid pattern appears to be most expensive. Besides, governments or local authorities stand to gain more revenue from lands sales as well as property tax when more productive lands are available. The tributary pattern has the most lots (1,151) from the same development area while the grid pattern has the least number of lots (1,075).

6.8 Efficiency analysis of the development process

It is important that the infrastructure development process is seen as a system. The various components of the development process must be efficient in order to yield the desired overall efficiency which eventually translates into minimum infrastructure costs. The final price of every product comprises the costs and the profits of the manufacturer. Similarly, the price of infrastructure can also be separated into costs and profits. Adapting the costs estimation structure (See Figure 6.14) employed in this study, an infrastructure development economics model is presented in Figure 6.24. The development process works in a system and the effect of one constituent affects the other. However, it appears most costs-of-sprawl studies, including this study, constantly seek to focus on urban development features (density, lot size, lot shape, location of development, dispersion of development and street configuration) in attempts to point out development patterns which are more efficient. The goal of such studies is to reduce the amount of resources and costs required in the development process and, primarily, targets the direct and indirect costs of construction (See Figure 6.24).

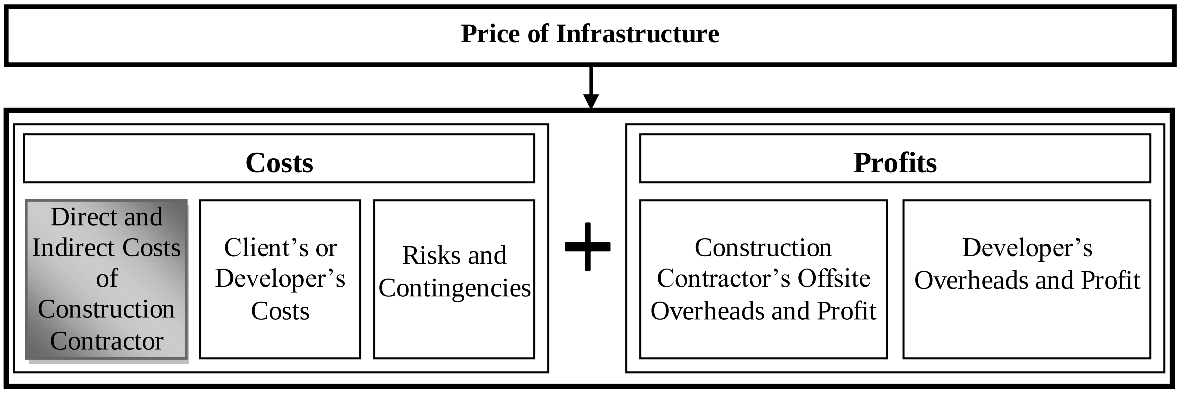


Figure 6.24 Infrastructure Development Economics Model

However, the components of client or developer's costs, risks and contingencies can be quite significant, especially in Ghana. Therefore, the strategies that the client or developer employs in engaging consultants and construction contractors must ensure that there is value for money. That will also require that administrative and institutional inefficiencies are minimised as much as possible. Clearly, in Ghana and most developing countries, attention to details is – relatively – low at the design stage of infrastructure projects. This coupled with ill-project identification and preparation gives rise to numerous project variations, delays and other price escalation factors.

The component of profits in the price of infrastructure projects is also one area that must be looked at in the efficiency analysis of the development process. How profits affect the users of infrastructure and its perception in both developed and developing countries appear to be different. The development process in developed countries usually requires a developer to fully bear the costs of the development and later recoup its costs together with a profit margin through the sales of the products. Moreover, the final prices of the products do not, necessarily, depend on the actual costs, but also on the demand and supply forces and other hedonic factors. Therefore, where the demand is extremely high, the price is likely to shoot up and the profit margin would be quite significant. In such an environment, some critics may opine that the costs of the products to the home buyers are private costs and home buyers have preference as to whether or not to consume expensive products. However, in Ghana and some developing countries, developers are usually not at the forefront of infrastructure development and provision. Most infrastructure, particularly the linear infrastructure, are developed by the parastatals. This makes the final price of infrastructure a public cost to the user since, as indicated earlier on, the parastatals recoup their investments through connection fees and tariffs. Hence, governments or parastatals engaging the services of construction contractors in delivering linear infrastructure could negotiate on the profit margins of the construction contractors so as to minimise the overall costs of infrastructure to users. Besides, governments or parastatals alone are finding it increasingly difficult to meet the infrastructure supply requirements in most developing countries. This is paving way for public-private partnerships in infrastructure delivery in most developing countries. For instance in Ghana, the government sometimes donates land and private developers carry out the development works. In such cases, there is the need for governments or local authorities to ascertain and negotiate on the profit margins of the developers in order to reduce the eventual costs of the infrastructure to the user.

7. CONCLUSIONS AND OUTLOOK

The importance of infrastructure to human settlement cannot be underestimated. Again, the infrastructure costs concerns vis-à-vis urban forms have generated a lot of debates among practitioners and theorists for over three decades now as to which development pattern is the most cost efficient. However, the conclusions are still fuzzy and not clear. Interestingly, most planning authorities rarely know and consider the costs of alternative development patterns in their decision making process. Besides, studies on infrastructure costs efficiency of alternative developments have constantly focused on developed countries without any attention to developing countries. This study then sought to contribute to the debate from developing countries' perspective by reviewing the current urban development in developing countries – urban sprawl – as well as analysing the relationship between infrastructure costs and urban forms with the quest to ascertain the development pattern that is infrastructure costs efficient. This study concludes by giving an overview of the findings, how the study contributes to knowledge, the limitations of the study, recommendations for future research and finally the relevance of the study to policy.

7.1 Overview of research findings

The study found out that, generally, there are major factors that drive the current urban development patterns – urban sprawl – in both developing and developing countries. However, the level of development of those drivers in both developing and developed countries determines the level of urban dispersion potential in the different economic regions of the world which, subsequently, have implications on infrastructure costs. It appears the level of development of the drivers in developed countries is higher in comparison with developing countries and therefore possesses a higher urban dispersion potential. Hence, relating the potential of urban dispersion to infrastructure costs, developed countries are likely to have higher infrastructure costs as compared to developing countries. Again, the higher development levels of the drivers of urban sprawl in developed countries, in comparison with developing countries, have partly occasioned a multiple nuclei model of urban form in developed countries. The, relatively, lower development levels of the drivers of urban sprawl in developing countries have also led to continuously unlimited expansion of urban areas in developing countries. In view of this, infrastructure costs concerns vis-à-vis urban forms in the case of developed countries must concentrate on inter-city infrastructure costs while in the case of developing countries, emphasis should be on intra-city infrastructure costs.

Furthermore, urban sprawl is perceived to be occasioned by market distortions and failures. Residents and businesses that locate to the suburban areas are not paying the full costs of their choices and the services they benefit from and are being subsidised by residents and businesses in consolidated areas. This situation, in part, is caused by the scheme of infrastructure costs financing – cost-sharing approach. Hence, to correct this inefficiency and to internalise all the externalities generated by urban sprawl, in a bid to ensure more efficient urban forms, a marginal cost pricing scheme (which is implemented through impact-fee approach) is being touted recently. This highlights the significance of fiscal tools of cities in shaping urban forms. Hence, attempts to ensure efficient urban forms must not only look at planning tools, but also fiscal tools. The two (planning and fiscal tools) must not seek to work against each other, but must ensure complementary efforts.

The phenomenon of urban sprawl albeit evident in developing counties (particularly Ghana), does not fit exactly into the developed countries' scheme of urban sprawl – both in causes and impacts. This requires urban sprawl to be partly dealt with by developing countries, both in causes and impacts, in a more local or indigenous way other than addressing it – completely – with policies from developed countries. Hence, it is deemed that a national planning or development strategy which seeks to reduce the disparities in national development would help to check urban sprawl (predominantly in the primate cities) and subsequently alleviate the infrastructure costs associated with such an undesirable development pattern. Again, such a national planning or development strategy should greatly take inspiration from the local values of Ghanaians.

The urban structures of both developing and developed countries are different and have implications on the costs of infrastructure development and financing. While infrastructure development was optimised in developed countries by the concurrent evolution of development patterns and infrastructure, developing countries (particularly Third World Countries) inherited and elaborated the colonial urban structures which promoted *dual cities*. The *dual cities'* structure makes infrastructure development, particularly extension of conventional infrastructure from the European space to the indigenous space, extremely expensive as structural threshold is usually reached. Again, the result of the investigation shows that in most developed countries, the rich and the high income groups locate further away from the central business districts (CBDs) to the urban peripheries, while the same location is inhabited by the poor and low income groups in developing countries due to high costs of living in the city centres. This revealed one caveat when borrowing and interpreting policies that emanate from studies done on infrastructure costs of alternative development patterns in developed countries by developing countries. The general traditional approach in infrastructure financing is the average cost scheme. However, with increasing suburbanisation in most developed countries, there is a call to introduce marginal cost financing schemes which ensure that suburban dwellers cover the increase in infrastructure costs caused by them. This approach may be fair in developed countries, but its implementation in most developing countries may be unrealistic and may not be deemed as an efficient infrastructure financing scheme due to the urban structure and income distribution of population in developing countries, particularly Ghana.

The study also found out that there is a relationship between urban forms and infrastructure costs. However, the relationship is not a single relationship but rather a multiple one. Previous studies which attempted to relate urban forms to infrastructure costs tried to relate one or more urban development features to infrastructure costs. Some of the urban development features that have been related to infrastructure costs (in literature) are density, lot size, lot shape, location of development and dispersion of development. Density and lot shape index are inversely related to infrastructure costs while lot size, location and dispersion of developments are directly related to infrastructure costs. The intrinsic purpose of these relationships is independent of the socio-economic situation of any particular region. Hence, these studies which are primarily done in developed countries are, presumably, applicable in developing countries as well. However, since the assumptions of the standard of service and the duration of the construction of the infrastructure in studies from developed countries differ from that of developing countries, the real values of infrastructure costs cannot be borrowed by developing countries directly.

One obvious finding from this study is the significant agreement in literature that compact developments are less expensive in comparison with conventional or sprawling developments. The main parameter that underpins this conclusion is density. However, assumptions on density by the previous studies either fail to or deliberately ignore the real costs of density. Ladd (1992) argues that the real cost of density must include both the capital and the services costs of developments that densities are related to. Elaborating on true accounting of the services costs, Ladd (1992) posits a distinction between a direct output cost and final output cost. Public sector cost such as police petrol against crime (direct output cost) may not necessarily measure up to the value of protection against crime (final output cost) by citizens. Besides, harsher environments require more direct output costs to produce a given level of final output. However, local authorities may respond sluggishly, leading to – in most cases – deteriorated services. Ladd (1992) further argues that although much planning literature focuses on the capital costs of development, the services costs is quantitatively much larger than the capital costs (See Figure 5.4). Therefore, in view of the fact that (after a particular density) services costs increase with increasing density, conclusions in literature appear to be misleading with regard to the fiscal effects of density (Ladd, 1992).

It has also been shown in this study that apart from density, lot size, lot shape, location and dispersion of developments, street pattern or configuration relates to and has influence on infrastructure costs, particularly linear infrastructure. The total capital costs of the three infrastructure (roads, water and electricity distribution networks) reveal the tributary pattern as the most economical pattern in terms of the capital costs of linear infrastructure while the grid pattern is the least economical. This also has connotation of public services costs of infrastructure. In isolating the effect of street patterns on linear infrastructure costs, the capital costs per dwelling (US$ 5,676) in the case of the tributary pattern showed a 27% costs savings over the costs of the grid pattern (US$ 7,202). The capital costs per dwelling of the radial (US$ 6,592) and hybrid (US$ 6,985) patterns also indicated 9% and 3% savings, respectively, in comparison with the grid pattern. Clearly, the savings in network infrastructure costs by the tributary, radial and hybrid patterns in comparison with the grid pattern largely resulted from savings in water distribution and road networks. The study showed that other factors such as demand, density and type of distribution system other than the configuration of the street pattern influence the costs of electricity distribution network significantly. The capital costs per dwelling showed a gradual rise in cost as one moved from the pure tributary pattern towards the pure grid pattern. The continuum of linear infrastructure costs, with respect to urban forms, indicating the tributary and grid patterns at the extreme ends, provides the opportunity for costs optimisation with regard to street configurations. Again, the general street pattern in Ghana is the cellular or grid type. This is largely necessitated by the heavy dependence of majority of the people on slow modes with regard to mode of transport. However, in terms of linear infrastructure, this pattern is expensive.

Besides, in analysing the influence of density on linear infrastructure costs, it was realised that although density increment reduces the capital costs of linear infrastructure per dwelling for all the alternative hypothetical residential patterns, the reduction in capital costs is sharp initially as density is increased and thereafter reduce marginally with further density increments. The reason appears to be as density is increased, it necessitates higher technical standards of linear infrastructure which, subsequently, increase the capital costs and hence erode the gains by density increment. Again, a density from 13 DPH to 53 DPH means approximately a 300% increment in density. However, the corresponding decrease in capital costs per dwelling for linear infrastructure is about 68% across the alternative hypothetical residential patterns. This means that although a rise in density decreases the capital costs of linear infrastructure to an extent, there is a clear evidence of “diminishing returns”. Hence, it is necessary to ascertain the justification for further increasing density beyond a particular threshold with regard to capital costs of linear infrastructure, since density beyond that particular threshold does not only refuse to ensure capital costs benefits but is also loathed by residents. Furthermore, as density increased, the capital costs per dwelling of linear infrastructure did not indicate any significant differences among the alternative street patterns. This presupposes that other factors other than street patterns are significant to costs as density increases. Those factors are both economic and environmental costs concerns as density increases. These costs, although not the focus of this study, are required to be pointed out to ensure a balanced and transparent decision in the quest for an efficient urban form.

Passing a general conclusion on infrastructure costs effectiveness of alternative development patterns based on one urban development feature may not be convincing enough. The best approach is to consider costs effectiveness from a specific urban development feature’s point of view. On the other hand, a good compromise will be to seek a collective minimisation of infrastructure costs to development with respect to all the urban development features discussed in this study.

7.2 Contribution of study to knowledge

In literature, the significant agreement on density as a major decision criterion in concluding that compact developments are less expensive in comparison with sprawling developments is somehow debatable. The cost of development is a function of the population that will benefit from the development. Therefore, if the development costs were related to a common denominator of the human beings, it is the required or equal space by each human being that would be the most appropriate criterion for determining development costs. However, studies on alternative development patterns that emphasise density as a criterion for determining cost-effective urban forms usually lower the space and standards per capita for the compact developments to bring about some costs savings. This makes comparison very difficult. A typical case is the "The Costs of Sprawl" study by the Real Estate Research Corporation in the United States in 1974. Again, the real costs of higher densities in public services costs are either deliberately ignored or not accounted for in those studies. Therefore, approaches that hold density constant and focus on urban design and configuration are likely to ensure fairness and unbiased comparison with regard to the debate on costs of alternative development patterns. Studies by Suen (2005) and Speir & Stephenson (2002) which focused on lot shape and development location and dispersion, respectively, are in the right direction. The current study contributes to the body of literature on the influence of urban configuration on infrastructure costs by relating the configuration of streets (the main cost driver together with density) to infrastructure costs.

7.3 Limitations of study

It is important to note that the current study has a number of limitations. Firstly, the study presents a theoretical basis instead of an empirical evidence. Secondly, the lack of complete data on public services costs in Ghana made the estimation of the costs-in-use (services costs) component of the infrastructure, considered in the study, challenging and hence omitted. Thirdly, point infrastructure were not considered in the study because they were deemed to be less sensitive to urban configuration, particularly street patterns.

7.4 Recommendations for future work

Clearly, this study does not end the debate on the costs of alternative development patterns. Considerably more work would need to be done to refine and enhance decisions and conclusions on the most economical urban form. This study suggests a few areas which require further research. Though this study considered only monetary costs, it would be helpful, if future studies are able to account for non-monetary costs such as environmental costs in their analyses. Again, some studies considered both capital and public services costs in their analyses. However, a lot more studies omitted the public services costs, including the present study. These costs are very significant with regard to the total costs of the infrastructure during its life span. Hence, future studies need not only account for these costs, but must also refine the methods of estimations to ensure accuracy in results. The relationship between density and infrastructure costs requires further research. The focus should be on a critical estimation of the real costs of density, especially as it increases. Only few studies, such as Biermann (2000), attempted to consider the effects of topography on infrastructure costs. Thus, more investigations may be required as to the role that topography plays in determining the infrastructure costs of urban forms. With the exception of Ladd (1992) who attempted to consider a dynamic scenario with regard to public services costs of infrastructure, most studies considered static development patterns. However, with some development patterns such as urban sprawl deemed to be a moment of time, it would be needful for future studies to consider dynamic scenarios with regard to costs of alternative development patterns. Literature on alternative development patterns, particularly the nature of urban sprawl in developing countries, is inadequate. More studies are requested in this area with special emphasis on differences and similarities in both developing and developed countries. Besides, an empirical approach would still be required to engage the conclusions tendered in this study as to how street configurations influence urban infrastructure costs, particularly linear infrastructure. Finally, an empirical study that would look at a combined relationship between all the urban features (density, lot size, lot shape, location and dispersion of developments, street pattern or configuration) and infrastructure costs, with particular emphasis on how much each variable contributes to infrastructure costs under the same assumptions and conditions would be helpful. A regression analysis tool promises to be useful in this regard.

7.5 Recommendations for policy

The findings of this study requires that policy, especially in developing countries, does not consider only density in taking decisions as to which development pattern is the most economical in terms of infrastructure costs. Though a arise in density decreases the capital costs of linear infrastructure to an extent, it is important for decision makers in Ghana and developing countries to ascertain the threshold beyond which any further increment in density does not occasion any further reduction in the costs of linear infrastructure per dwelling. Again, the issues of urban forms concerning land uses and remoteness are less important in developing countries, especially Ghana. Therefore, much attention should be focused on urban configurations in developing countries so as to reduce infrastructure costs. The reduction in infrastructure costs must be pursued by optimising the urban development features that influence infrastructure costs. Besides, due to the unique urban structure and income distribution of households in developing countries, infrastructure financing policies that seek to adapt to the current financial capabilities, as well as maximising the net incomes, of the low income households at the urban peripheries would be deemed efficient policies. Such financing policies could be reflected in low costs infrastructure technologies which, importantly, have inherent mechanisms for upgrading to sophisticated standards in the future. The possibility of future upgrading to sophisticated standards will depend on the economic health of households as well as the nation.

Furthermore, since most developing countries have fiscal challenges, urban configurations which reduce infrastructure costs and enhance revenues would be more appropriate. Thus, as shown by this study, the tributary pattern appears to fulfil this goal. However, as also shown by this study, urban configurations (with respect to street patterns) which seek to minimise infrastructure costs invariably compromise on accessibility. Hence, a good approach will be to ensure an optimisation of the infrastructure costs concerns and accessibility. One of such optimisation measures is to augment the accessibility shortfalls of patterns, which minimise infrastructure costs but poor on accessibility, with carefully designed network of footpaths. This, to some extent, fits into the Ghanaian or developing countries' mode of transport – slow mode or walking. Again, the optimisation approach should resort to the use of geometry. Geometry could provide the tool to optimise the values of infrastructure costs minimisation and accessibility enhancement. The fused grid, a new neighbourhood layout model, seeks to combine the geometries of both the grid and the tributary patterns. Essentially, such a fusion tries to retain the best characteristics of the original patterns and none of the disadvantages of each (See Grammenos, Craig, Pollard, & Guerrera (2008) for more discussions on the fused grid layout). Such innovations through geometry offer opportunities for more nuanced models of efficient urban forms.

Besides, the price of infrastructure comprises costs and profits. Hence, an approach like urban configuration which seeks to reduce the costs is not enough. Other factors or areas which also influence the price of infrastructure to the user should also be considered. Such areas are developer or client's costs, risks and contingencies related to the infrastructure development and profit margin of the construction contractor or developer. Administrative or institutional inefficiencies can, significantly, swell up developer or client's costs in developing countries and should be minimised. In Ghana and most developing countries, attention to details is – relatively – low at the design stage of infrastructure projects. This coupled with ill-project identification and preparation gives rise to numerous project variations, delays and other price escalation factors which eventually increase the risk and contingencies' component of infrastructure costs. Policy should target the reduction of this cost component in developing countries. The profit margins of construction contractors working for parastatals, in developing countries, should be negotiated down during the procurement process in order to reduce the overall infrastructure costs. In the case of public-private partnership, policy must seek to limit or minimise the developer's profit margin.

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APPENDIX A: HYDRAULIC ANALYSIS OF WATER DISTRIBUTION NETWORK WITH FOCUS ON STREET PATTERNS

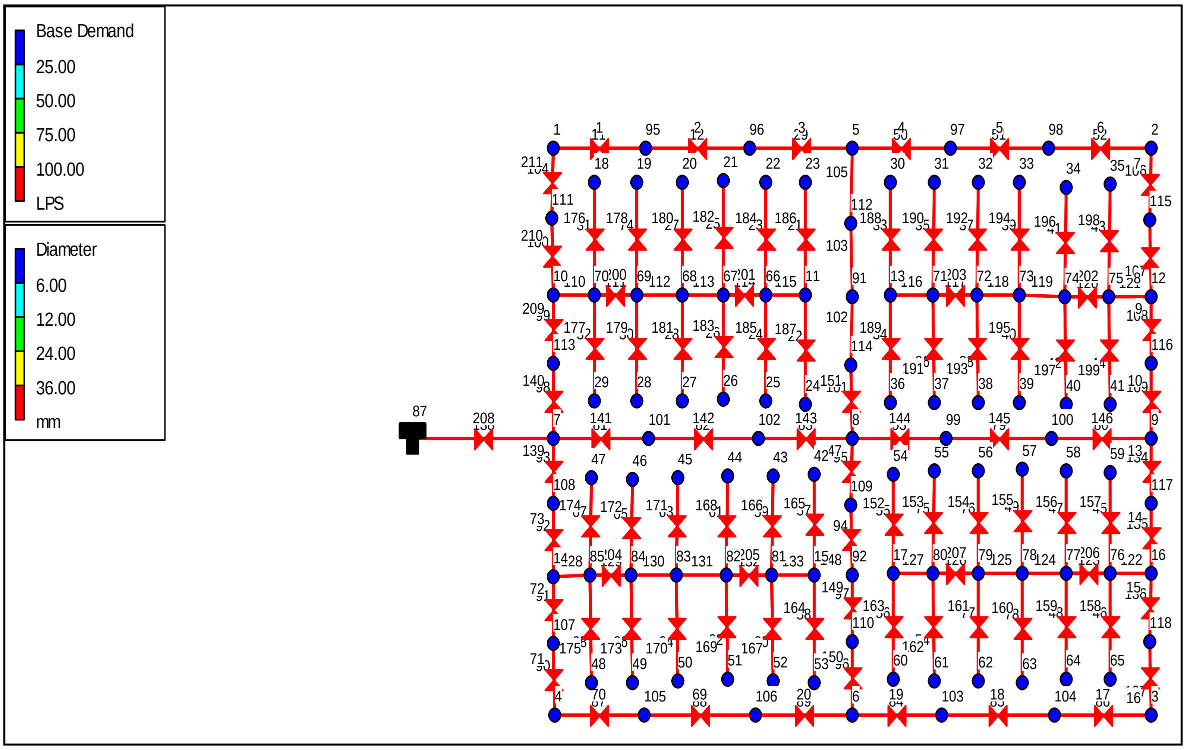

Figure A.1: Water Distribution Network Map of Tributary Pattern

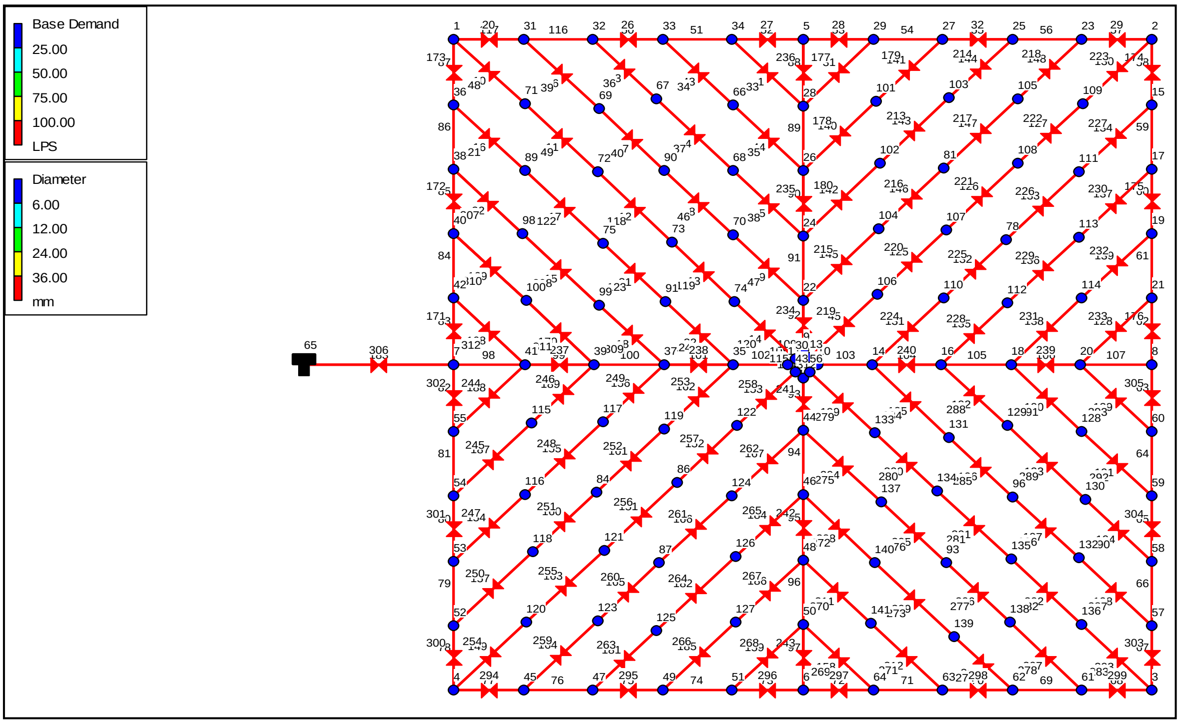

Figure A.2: Water Distribution Network Map of Radial Pattern

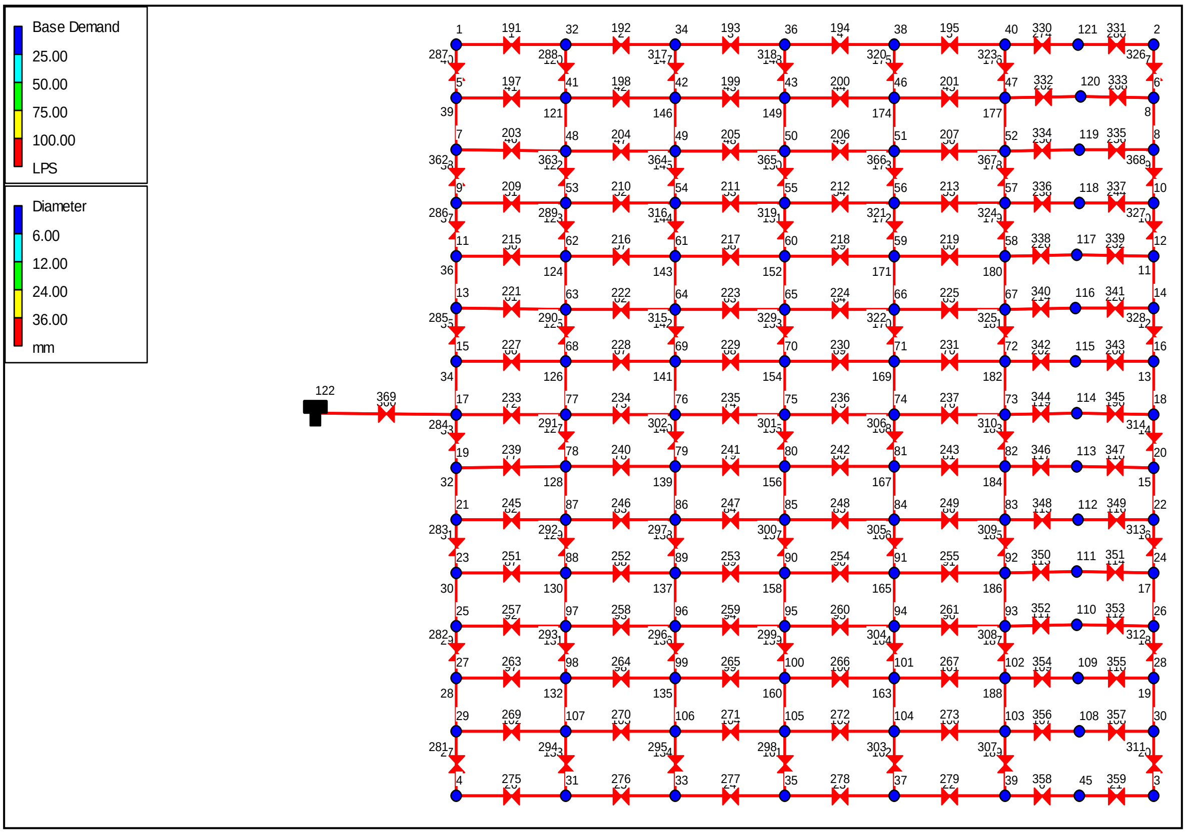

Figure A.3: Water Distribution Network Map of Grid Pattern

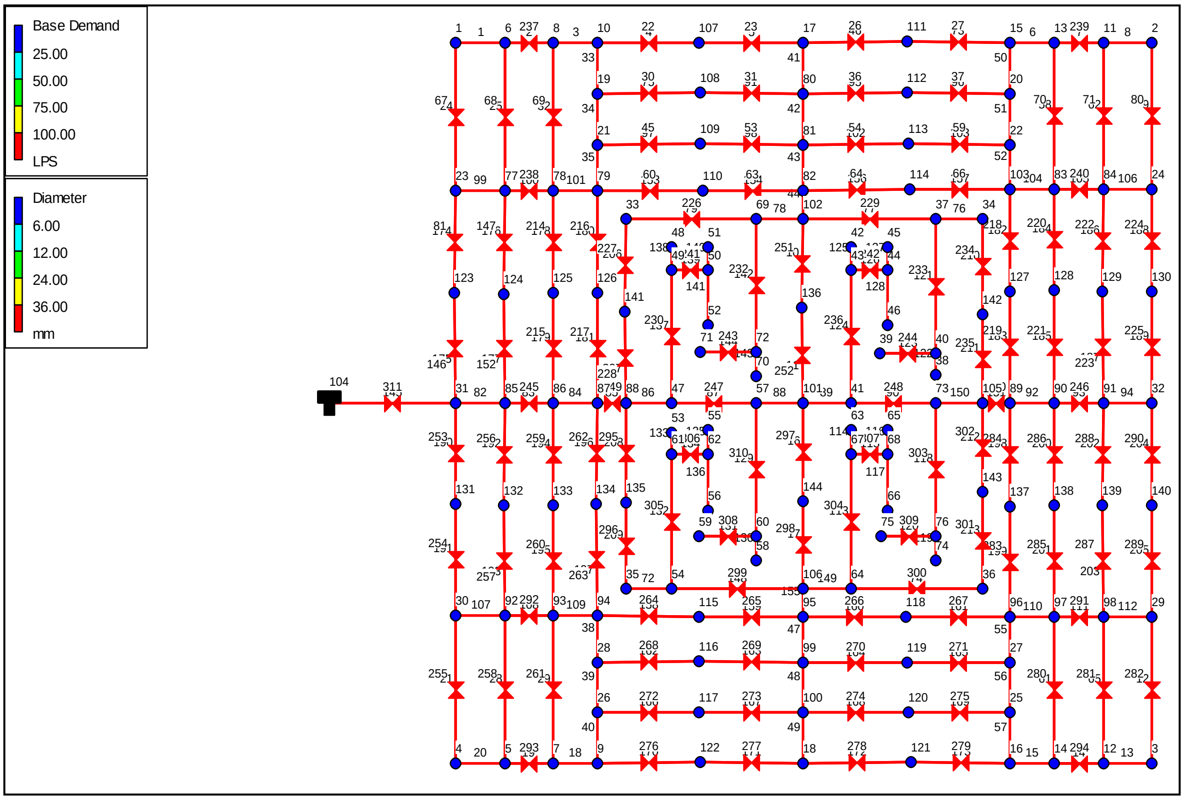

Figure A.4: Water Distribution Network Map of Hybrid Pattern

Table A.1: Water Distribution Network Node Table for Tributary Pattern

	Elevation	**Demand**	**Head**	**Pressure**
Node ID	m	LPS	m	m
Junc 1	100	0.13	141.97	41.97
Junc 2	100	0.13	140.49	40.49
Junc 3	100	0.13	140.49	40.49
Junc 4	100	0.13	141.97	41.97
Junc 5	100	0.21	141.28	41.28
Junc 6	100	0.21	141.28	41.28
Junc 7	100	-15.91	144.36	44.36
Junc 8	100	0.26	141.38	41.38
Junc 9	100	0.19	140.29	40.30
Junc 10	100	0.15	142.41	42.41
Junc 11	100	0.22	141.92	41.92
Junc 12	100	0.15	140.17	40.17
Junc 13	100	0.22	139.68	39.68
Junc 14	100	0.15	142.41	42.41
Junc 15	100	0.22	141.92	41.92
Junc 16	100	0.15	140.17	40.17
Junc 17	100	0.22	139.68	39.68
Junc 18	100	0.19	142.22	42.22
Junc 19	100	0.19	142.09	42.09
Junc 20	100	0.19	142.00	42.00
Junc 21	100	0.19	141.95	41.95
Junc 22	100	0.19	141.92	41.92
Junc 23	100	0.19	141.92	41.92
Junc 24	100	0.19	141.92	41.92
Junc 25	100	0.19	141.92	41.92
Junc 26	100	0.19	141.95	41.95
Junc 27	100	0.19	142.00	42.00
Junc 28	100	0.19	142.09	42.09
Junc 29	100	0.19	142.22	42.22
Junc 30	100	0.19	139.68	39.68
Junc 31	100	0.19	139.69	39.69
Junc 32	100	0.19	139.71	39.71
Junc 33	100	0.19	139.77	39.77
Junc 34	100	0.19	139.86	39.86
Junc 35	100	0.19	139.99	39.99
Junc 36	100	0.19	139.68	39.68
Junc 37	100	0.19	139.69	39.69
Junc 38	100	0.19	139.71	39.71
Junc 39	100	0.19	139.77	39.77
Junc 40	100	0.19	139.86	39.86
Junc 41	100	0.19	139.99	39.99
Junc 42	100	0.19	141.92	41.92
Junc 43	100	0.19	141.92	41.92
Junc 44	100	0.19	141.95	41.95

Junc 45	100	0.19	142.00	42.00
Junc 46	100	0.19	142.09	42.09
Junc 47	100	0.19	142.22	42.22
Junc 48	100	0.19	142.22	42.22
Junc 49	100	0.19	142.09	42.09
Junc 50	100	0.19	142.00	42.00
Junc 51	100	0.19	141.95	41.95
Junc 52	100	0.19	141.92	41.92
Junc 53	100	0.19	141.92	41.92
Junc 54	100	0.19	139.68	39.68
Junc 55	100	0.19	139.69	39.69
Junc 56	100	0.19	139.71	39.71
Junc 57	100	0.19	139.77	39.77
Junc 58	100	0.19	139.86	39.86
Junc 59	100	0.19	139.99	39.99
Junc 60	100	0.19	139.68	39.68
Junc 61	100	0.19	139.69	39.69
Junc 62	100	0.19	139.71	39.71
Junc 63	100	0.19	139.77	39.77
Junc 64	100	0.19	139.86	39.86
Junc 65	100	0.19	139.99	39.99
Junc 66	100	0.25	141.93	41.93
Junc 67	100	0.25	141.95	41.95
Junc 68	100	0.25	142.00	42.00
Junc 69	100	0.25	142.09	42.09
Junc 70	100	0.25	142.22	42.22
Junc 71	100	0.25	139.69	39.69
Junc 72	100	0.25	139.72	39.72
Junc 73	100	0.25	139.77	39.77
Junc 74	100	0.25	139.86	39.86
Junc 75	100	0.25	139.99	39.99
Junc 76	100	0.25	139.99	39.99
Junc 77	100	0.25	139.86	39.86
Junc 78	100	0.25	139.77	39.77
Junc 79	100	0.25	139.72	39.72
Junc 80	100	0.25	139.69	39.69
Junc 81	100	0.25	141.93	41.93
Junc 82	100	0.25	141.95	41.95
Junc 83	100	0.25	142.00	42.00
Junc 84	100	0.25	142.09	42.09
Junc 85	100	0.25	142.22	42.22
Junc 91	100	0.11	141.32	41.32
Junc 92	100	0.11	141.32	41.32
Junc 95	100	0.15	141.72	41.72
Junc 96	100	0.15	141.49	41.49
Junc 97	100	0.15	140.99	40.99
Junc 98	100	0.15	140.73	40.73

Junc 99	100	0.15	140.99	40.99
Junc 100	100	0.15	140.63	40.63
Junc 101	100	0.15	143.32	43.32
Junc 102	100	0.15	142.33	42.33
Junc 103	100	0.15	140.99	40.99
Junc 104	100	0.15	140.73	40.73
Junc 105	100	0.15	141.72	41.72
Junc 106	100	0.15	141.49	41.49
Junc 107	100	0.11	142.18	42.18
Junc 108	100	0.11	143.37	43.37
Junc 109	100	0.11	141.34	41.34
Junc 110	100	0.11	141.29	41.29
Junc 111	100	0.11	142.18	42.18
Junc 112	100	0.11	141.29	41.29
Junc 113	100	0.11	143.37	43.37
Junc 114	100	0.11	141.34	41.34
Junc 115	100	0.11	140.32	40.32
Junc 116	100	0.11	140.23	40.23
Junc 117	100	0.11	140.23	40.23
Junc 118	100	0.11	140.32	40.32
Tank 87	140	-4.42	146.00	6.00

Table A.2: Water Distribution Network Node Table for Radial Pattern

	Elevation	Demand	Head	Pressure
Node ID	m	LPS	m	m
Junc 1	100	0.13	144.01	44.01
Junc 2	100	0.13	143.76	43.76
Junc 3	100	0.13	143.76	43.76
Junc 4	100	0.13	144.01	44.01
Junc 5	100	0.12	143.78	43.78
Junc 6	100	0.12	143.78	43.78
Junc 7	100	-15.78	146.00	46.00
Junc 8	100	0.12	143.73	43.73
Junc 9	100	0.04	143.84	43.84
Junc 10	100	0.04	143.82	43.82
Junc 11	100	0.04	143.89	43.89
Junc 12	100	0.04	143.84	43.84
Junc 13	100	0.10	143.83	43.83
Junc 14	100	0.18	143.76	43.76
Junc 15	100	0.14	143.75	43.75
Junc 16	100	0.20	143.74	43.74
Junc 17	100	0.14	143.74	43.74
Junc 18	100	0.20	143.73	43.73
Junc 19	100	0.14	143.73	43.73

Junc 20	100	0.20	143.73	43.73
Junc 21	100	0.14	143.73	43.73
Junc 22	100	0.18	143.81	43.81
Junc 23	100	0.14	143.77	43.77
Junc 24	100	0.20	143.79	43.79
Junc 25	100	0.14	143.77	43.77
Junc 26	100	0.20	143.78	43.78
Junc 27	100	0.14	143.78	43.78
Junc 28	100	0.20	143.78	43.78
Junc 29	100	0.14	143.78	43.78
Junc 30	100	0.10	143.87	43.87
Junc 31	100	0.14	143.88	43.88
Junc 32	100	0.14	143.81	43.81
Junc 33	100	0.14	143.79	43.79
Junc 34	100	0.14	143.78	43.78
Junc 35	100	0.18	144.24	44.24
Junc 36	100	0.14	144.28	44.28
Junc 37	100	0.20	144.64	44.64
Junc 38	100	0.14	144.64	44.64
Junc 39	100	0.20	145.06	45.06
Junc 40	100	0.14	145.06	45.06
Junc 41	100	0.20	145.51	45.51
Junc 42	100	0.14	145.51	45.51
Junc 43	100	0.10	143.87	43.87
Junc 44	100	0.18	143.81	43.81
Junc 45	100	0.14	143.88	43.88
Junc 46	100	0.20	143.79	43.79
Junc 47	100	0.14	143.81	43.81
Junc 48	100	0.20	143.78	43.78
Junc 49	100	0.14	143.79	43.79
Junc 50	100	0.20	143.78	43.78
Junc 51	100	0.14	143.78	43.78
Junc 52	100	0.14	144.28	44.28
Junc 53	100	0.14	144.64	44.64
Junc 54	100	0.14	145.06	45.06
Junc 55	100	0.14	145.51	45.51
Junc 56	100	0.10	143.83	43.83
Junc 57	100	0.14	143.75	43.75
Junc 58	100	0.14	143.74	43.74
Junc 59	100	0.14	143.73	43.73
Junc 60	100	0.14	143.73	43.73
Junc 61	100	0.14	143.77	43.77
Junc 62	100	0.14	143.77	43.77
Junc 63	100	0.14	143.78	43.78
Junc 64	100	0.14	143.78	43.78
Junc 75	100	0.11	144.25	44.25
Junc 78	100	0.11	143.75	43.75

Junc 81	100	0.11	143.78	43.78
Junc 84	100	0.11	144.25	44.25
Junc 86	100	0.11	143.91	43.91
Junc 87	100	0.11	143.83	43.83
Junc 90	100	0.11	143.83	43.83
Junc 93	100	0.11	143.78	43.78
Junc 96	100	0.11	143.75	43.75
Junc 66	100	0.11	143.78	43.78
Junc 67	100	0.11	143.80	43.80
Junc 68	100	0.11	143.79	43.79
Junc 69	100	0.11	143.85	43.85
Junc 70	100	0.11	143.82	43.82
Junc 71	100	0.11	143.97	43.97
Junc 72	100	0.11	143.93	43.93
Junc 73	100	0.11	143.91	43.91
Junc 74	100	0.11	143.88	43.88
Junc 89	100	0.11	144.26	44.26
Junc 91	100	0.11	144.24	44.24
Junc 98	100	0.11	144.64	44.64
Junc 99	100	0.11	144.64	44.64
Junc 100	100	0.11	145.06	45.06
Junc 101	100	0.11	143.78	43.78
Junc 102	100	0.11	143.78	43.78
Junc 103	100	0.11	143.78	43.78
Junc 104	100	0.11	143.79	43.79
Junc 105	100	0.11	143.77	43.77
Junc 106	100	0.11	143.81	43.81
Junc 107	100	0.11	143.79	43.79
Junc 108	100	0.11	143.78	43.78
Junc 109	100	0.11	143.77	43.77
Junc 110	100	0.11	143.75	43.75
Junc 111	100	0.11	143.75	43.75
Junc 112	100	0.11	143.74	43.74
Junc 113	100	0.11	143.74	43.74
Junc 114	100	0.11	143.73	43.73
Junc 115	100	0.11	145.06	45.06
Junc 116	100	0.11	144.64	44.64
Junc 117	100	0.11	144.64	44.64
Junc 118	100	0.11	144.26	44.26
Junc 119	100	0.11	144.24	44.24
Junc 120	100	0.11	143.97	43.97
Junc 121	100	0.11	143.93	43.93
Junc 122	100	0.11	143.88	43.88
Junc 123	100	0.11	143.85	43.85
Junc 124	100	0.11	143.82	43.82
Junc 125	100	0.11	143.80	43.80
Junc 126	100	0.11	143.79	43.79

Junc 127	100	0.11	143.78	43.78
Junc 128	100	0.11	143.73	43.73
Junc 129	100	0.11	143.74	43.74
Junc 130	100	0.11	143.74	43.74
Junc 131	100	0.11	143.75	43.75
Junc 132	100	0.11	143.75	43.75
Junc 133	100	0.11	143.81	43.81
Junc 134	100	0.11	143.79	43.79
Junc 135	100	0.11	143.78	43.78
Junc 136	100	0.11	143.77	43.77
Junc 137	100	0.11	143.79	43.79
Junc 138	100	0.11	143.77	43.77
Junc 139	100	0.11	143.78	43.78
Junc 140	100	0.11	143.78	43.78
Junc 141	100	0.11	143.78	43.78
Tank 65	140	-0.30	146.00	6.00

Table A.3: Water Distribution Network Node Table for Grid Pattern

	Elevation	**Demand**	**Head**	**Pressure**
Node ID	m	LPS	m	m
Junc 1	100	0.10	145.23	45.23
Junc 2	100	0.08	145.20	45.20
Junc 3	100	0.09	145.20	45.20
Junc 4	100	0.09	145.23	45.23
Junc 5	100	0.11	145.24	45.24
Junc 6	100	0.11	145.20	45.20
Junc 7	100	0.11	145.24	45.24
Junc 8	100	0.11	145.20	45.20
Junc 9	100	0.11	145.26	45.26
Junc 10	100	0.11	145.20	45.20
Junc 11	100	0.11	145.30	45.30
Junc 12	100	0.11	145.20	45.20
Junc 13	100	0.11	145.38	45.38
Junc 14	100	0.11	145.20	45.20
Junc 15	100	0.11	145.54	45.54
Junc 16	100	0.11	145.20	45.20
Junc 17	100	-15.29	145.97	45.97
Junc 18	100	0.11	145.20	45.20
Junc 19	100	0.11	145.55	45.55
Junc 20	100	0.11	145.20	45.20
Junc 21	100	0.11	145.38	45.38
Junc 22	100	0.11	145.20	45.20
Junc 23	100	0.11	145.30	45.30
Junc 24	100	0.11	145.20	45.20

Junc 25	100	0.11	145.26	45.26
Junc 26	100	0.11	145.20	45.20
Junc 27	100	0.11	145.24	45.24
Junc 28	100	0.11	145.20	45.20
Junc 29	100	0.11	145.24	45.24
Junc 30	100	0.12	145.20	45.20
Junc 31	100	0.14	145.23	45.23
Junc 32	100	0.14	145.23	45.23
Junc 33	100	0.14	145.23	45.23
Junc 34	100	0.14	145.23	45.23
Junc 35	100	0.14	145.22	45.22
Junc 36	100	0.14	145.22	45.22
Junc 37	100	0.14	145.21	45.21
Junc 38	100	0.14	145.21	45.21
Junc 39	100	0.15	145.20	45.20
Junc 40	100	0.15	145.20	45.20
Junc 41	100	0.16	145.23	45.23
Junc 42	100	0.16	145.23	45.23
Junc 43	100	0.16	145.22	45.22
Junc 46	100	0.16	145.21	45.21
Junc 47	100	0.18	145.20	45.20
Junc 48	100	0.16	145.24	45.24
Junc 49	100	0.16	145.23	45.23
Junc 50	100	0.16	145.22	45.22
Junc 51	100	0.16	145.21	45.21
Junc 52	100	0.18	145.20	45.20
Junc 53	100	0.16	145.26	45.26
Junc 54	100	0.16	145.24	45.24
Junc 55	100	0.16	145.22	45.22
Junc 56	100	0.16	145.21	45.21
Junc 57	100	0.18	145.20	45.20
Junc 58	100	0.18	145.20	45.20
Junc 59	100	0.16	145.21	45.21
Junc 60	100	0.16	145.23	45.23
Junc 61	100	0.16	145.25	45.25
Junc 62	100	0.16	145.28	45.28
Junc 63	100	0.16	145.32	45.32
Junc 64	100	0.16	145.27	45.27
Junc 65	100	0.16	145.23	45.23
Junc 66	100	0.16	145.21	45.21
Junc 67	100	0.18	145.20	45.20
Junc 68	100	0.16	145.37	45.37
Junc 69	100	0.16	145.28	45.28
Junc 70	100	0.16	145.23	45.23
Junc 71	100	0.16	145.21	45.21
Junc 72	100	0.18	145.20	45.20
Junc 73	100	0.18	145.20	45.20

Junc 74	100	0.16	145.21	45.21
Junc 75	100	0.16	145.23	45.23
Junc 76	100	0.16	145.28	45.28
Junc 77	100	0.16	145.40	45.40
Junc 78	100	0.16	145.37	45.37
Junc 79	100	0.16	145.28	45.28
Junc 80	100	0.16	145.23	45.23
Junc 81	100	0.16	145.21	45.21
Junc 82	100	0.18	145.20	45.20
Junc 83	100	0.18	145.20	45.20
Junc 84	100	0.16	145.21	45.21
Junc 85	100	0.16	145.23	45.23
Junc 86	100	0.16	145.27	45.27
Junc 87	100	0.16	145.32	45.32
Junc 88	100	0.16	145.28	45.28
Junc 89	100	0.16	145.25	45.25
Junc 90	100	0.16	145.23	45.23
Junc 91	100	0.16	145.21	45.21
Junc 92	100	0.18	145.20	45.20
Junc 93	100	0.18	145.20	45.20
Junc 94	100	0.16	145.21	45.21
Junc 95	100	0.16	145.22	45.22
Junc 96	100	0.16	145.24	45.24
Junc 97	100	0.16	145.26	45.26
Junc 98	100	0.16	145.24	45.24
Junc 99	100	0.16	145.23	45.23
Junc 100	100	0.16	145.22	45.22
Junc 101	100	0.16	145.21	45.21
Junc 102	100	0.18	145.20	45.20
Junc 103	100	0.19	145.20	45.20
Junc 104	100	0.16	145.21	45.21
Junc 105	100	0.16	145.22	45.22
Junc 106	100	0.16	145.23	45.23
Junc 107	100	0.16	145.23	45.23
Junc 45	100	0.10	145.20	45.20
Junc 108	100	0.10	145.20	45.20
Junc 109	100	0.10	145.20	45.20
Junc 110	100	0.10	145.20	45.20
Junc 111	100	0.10	145.20	45.20
Junc 112	100	0.10	145.20	45.20
Junc 113	100	0.10	145.20	45.20
Junc 114	100	0.10	145.20	45.20
Junc 115	100	0.10	145.20	45.20
Junc 116	100	0.10	145.20	45.20
Junc 117	100	0.10	145.20	45.20
Junc 118	100	0.10	145.20	45.20
Junc 119	100	0.10	145.20	45.20

Junc 120	100	0.10	145.20	45.20
Junc 121	100	0.10	145.20	45.20
Tank 122	140	-1.42	146.00	6.00

Table A.4: Water Distribution Network Node Table for Hybrid Pattern

	Elevation	**Demand**	**Head**	**Pressure**
Node ID	m	LPS	m	m
Junc 1	100	0.10	145.16	45.16
Junc 2	100	0.10	144.87	44.87
Junc 3	100	0.10	144.87	44.87
Junc 4	100	0.10	145.16	45.16
Junc 5	100	0.13	145.13	45.13
Junc 6	100	0.13	145.13	45.13
Junc 7	100	0.13	145.07	45.07
Junc 8	100	0.13	145.07	45.07
Junc 9	100	0.16	144.99	44.99
Junc 10	100	0.16	144.99	44.99
Junc 11	100	0.13	144.87	44.87
Junc 12	100	0.13	144.87	44.87
Junc 13	100	0.13	144.87	44.87
Junc 14	100	0.13	144.87	44.87
Junc 15	100	0.16	144.88	44.88
Junc 16	100	0.16	144.88	44.88
Junc 17	100	0.13	144.91	44.91
Junc 18	100	0.13	144.91	44.91
Junc 19	100	0.10	144.97	44.97
Junc 20	100	0.10	144.88	44.88
Junc 21	100	0.10	144.97	44.97
Junc 22	100	0.10	144.88	44.88
Junc 23	100	0.15	145.25	45.25
Junc 24	100	0.15	144.86	44.86
Junc 25	100	0.10	144.88	44.88
Junc 26	100	0.10	144.97	44.97
Junc 27	100	0.10	144.88	44.88
Junc 28	100	0.10	144.97	44.97
Junc 29	100	0.15	144.86	44.86
Junc 30	100	0.15	145.25	45.25
Junc 31	100	-15.36	146.00	46.00
Junc 32	100	0.13	144.86	44.86
Junc 33	100	0.11	144.90	44.90
Junc 34	100	0.11	144.87	44.87
Junc 35	100	0.11	144.90	44.90
Junc 36	100	0.11	144.87	44.87
Junc 37	100	0.14	144.87	44.87

Junc 38	100	0.01	144.87	44.87
Junc 39	100	0.03	144.87	44.87
Junc 40	100	0.11	144.87	44.87
Junc 41	100	0.16	144.87	44.87
Junc 42	100	0.01	144.87	44.87
Junc 43	100	0.09	144.87	44.87
Junc 44	100	0.06	144.87	44.87
Junc 45	100	0.01	144.87	44.87
Junc 46	100	0.02	144.87	44.87
Junc 47	100	0.16	144.91	44.91
Junc 48	100	0.01	144.91	44.91
Junc 49	100	0.09	144.91	44.91
Junc 50	100	0.06	144.91	44.91
Junc 51	100	0.01	144.91	44.91
Junc 52	100	0.02	144.91	44.91
Junc 53	100	0.01	144.89	44.89
Junc 54	100	0.16	144.89	44.89
Junc 55	100	0.01	144.89	44.89
Junc 56	100	0.02	144.89	44.89
Junc 57	100	0.14	144.89	44.89
Junc 58	100	0.01	144.89	44.89
Junc 59	100	0.03	144.89	44.89
Junc 60	100	0.11	144.89	44.89
Junc 61	100	0.09	144.89	44.89
Junc 62	100	0.06	144.89	44.89
Junc 63	100	0.01	144.88	44.88
Junc 64	100	0.16	144.88	44.88
Junc 65	100	0.01	144.88	44.88
Junc 66	100	0.02	144.88	44.88
Junc 67	100	0.09	144.88	44.88
Junc 68	100	0.06	144.88	44.88
Junc 69	100	0.14	144.89	44.89
Junc 70	100	0.01	144.89	44.89
Junc 71	100	0.03	144.89	44.89
Junc 72	100	0.11	144.89	44.89
Junc 73	100	0.14	144.87	44.87
Junc 74	100	0.01	144.87	44.87
Junc 75	100	0.03	144.87	44.87
Junc 76	100	0.11	144.87	44.87
Junc 77	100	0.17	145.18	45.18
Junc 78	100	0.17	145.08	45.08
Junc 79	100	0.15	144.99	44.99
Junc 80	100	0.15	144.91	44.91
Junc 81	100	0.15	144.91	44.91
Junc 82	100	0.14	144.90	44.90
Junc 83	100	0.17	144.87	44.87
Junc 84	100	0.17	144.87	44.87

Junc 85	100	0.15	145.34	45.34
Junc 86	100	0.15	145.11	45.11
Junc 87	100	0.14	144.99	44.99
Junc 88	100	0.13	144.93	44.93
Junc 89	100	0.26	144.87	44.87
Junc 90	100	0.15	144.87	44.87
Junc 91	100	0.15	144.86	44.86
Junc 92	100	0.17	145.18	45.18
Junc 93	100	0.17	145.08	45.08
Junc 94	100	0.15	144.99	44.99
Junc 95	100	0.14	144.90	44.90
Junc 96	100	0.15	144.87	44.87
Junc 97	100	0.17	144.87	44.87
Junc 98	100	0.17	144.87	44.87
Junc 99	100	0.15	144.90	44.90
Junc 100	100	0.15	144.91	44.91
Junc 101	100	0.24	144.88	44.88
Junc 102	100	0.20	144.89	44.89
Junc 103	100	0.15	144.87	44.87
Junc 105	100	0.13	144.87	44.87
Junc 106	100	0.20	144.89	44.89
Junc 107	100	0.10	144.95	44.95
Junc 108	100	0.10	144.94	44.94
Junc 109	100	0.10	144.94	44.94
Junc 110	100	0.10	144.94	44.94
Junc 111	100	0.10	144.89	44.89
Junc 112	100	0.10	144.89	44.89
Junc 113	100	0.10	144.89	44.89
Junc 114	100	0.10	144.88	44.88
Junc 115	100	0.10	144.94	44.94
Junc 116	100	0.10	144.94	44.94
Junc 117	100	0.10	144.94	44.94
Junc 118	100	0.10	144.88	44.88
Junc 119	100	0.10	144.89	44.89
Junc 120	100	0.10	144.89	44.89
Junc 121	100	0.10	144.89	44.89
Junc 122	100	0.10	144.95	44.95
Junc 123	100	0.10	145.61	45.61
Junc 124	100	0.10	145.26	45.26
Junc 125	100	0.10	145.10	45.10
Junc 126	100	0.10	144.99	44.99
Junc 127	100	0.10	144.87	44.87
Junc 128	100	0.10	144.87	44.87
Junc 129	100	0.10	144.86	44.86
Junc 130	100	0.10	144.86	44.86
Junc 131	100	0.10	145.61	45.61
Junc 132	100	0.10	145.26	45.26

Junc 133	100	0.10	145.10	45.10
Junc 134	100	0.10	144.99	44.99
Junc 135	100	0.09	144.91	44.91
Junc 136	100	0.09	144.89	44.89
Junc 137	100	0.10	144.87	44.87
Junc 138	100	0.10	144.87	44.87
Junc 139	100	0.10	144.86	44.86
Junc 140	100	0.10	144.86	44.86
Junc 141	100	0.09	144.92	44.92
Junc 142	100	0.09	144.87	44.87
Junc 143	100	0.09	144.87	44.87
Junc 144	100	0.09	144.89	44.89
Tank 104	140	0.01	146.00	6.00

APPENDIX B: LOAD DEMAND OF HOUSEHOLDS FOR ELECTRICITY DISTRIBUTION NETWORK WITH FOCUS ON STREET PATTERNS

Table B.1: Load demand of households

Use	Demand (kVA)
Water heating	0.5
Refrigeration	0.5
Ironing	1.0
Lightening	1.0
Air conditioning[2]	0.6
Miscellaneous	0.4
Total[3]	**4**

[2] One air conditioner is considered in each household.
[3] The total load demand of 4kVA is usually the design load per household used by Electricity Company of Ghana.

APPENDIX C: DIRECT COSTS OF LINEAR INFRASTRUCTURE WITH FOCUS ON STREET PATTERNS

Costs reference:

1. The costs estimates are based on 2011 construction costs in Ghana
2. The Cedi (local currency) Dollar exchange rate was based on the Bank of Ghana Interbank Exchange Rate of **Gh¢1.56 = US$1**
   Source: http://www.bog.gov.gh/index1.php?linkid=139 – Last accessed 17/12/2011

Table C.1: Direct Costs of Road Network Under Tributary Pattern

Item	Description	Qty	Unit	Rate (US$)	Amount (US$)
A	150mm thick gravel base	22.079	m^3	18,75	413.981,25
B	20mm thick surface dressing	147.192	m^2	6,40	942.028,80
C	200 x 100mm chamfered precast concrete kerbs	36.798	m	15,38	565.953,24
D	1.5m wide sidewalks	55.197	m^2	8,28	457.031,16
	Total direct costs carried to Grand Summary				**2.378.994,45**

Table C.2: Direct Costs of Road Network Under Radial Pattern

Item	Description	Qty	Unit	Rate (US$)	Amount (US$)
A	150mm thick gravel base	25.104	m^3	18,75	470.700,00
B	20mm thick surface dressing	167.360	m^2	6,40	1.071.104,00
C	200 x 100mm chamfered precast concrete kerbs	41.840	m	15,38	643.499,20
D	1.5m wide sidewalks	62.760	m^2	8,28	519.652,80
	Total direct costs carried to Grand Summary				**2.704.956,00**

Table C.3: Direct Costs of Road Network Under Grid Pattern

Item	Description	Qty	Unit	Rate (US$)	Amount (US$)
A	150mm thick gravel base	27.377	m^3	18,75	513.318,75
B	20mm thick surface dressing	182.512	m^2	6,40	1.168.076,80
C	200 x 100mm chamfered precast concrete kerbs	45.628	m	15,38	701.758,64
D	1.5m wide sidewalks	68.442	m^2	8,28	566.699,76
	Total direct costs carried to Grand Summary				**2.949.853,95**

Table C.4: Direct Costs of Road Network Under Hybrid Pattern

Item	Description	Qty	Unit	Rate (US$)	Amount (US$)
A	150mm thick gravel base	26.440	m^3	18,75	495.750,00
B	20mm thick surface dressing	176.264	m^2	6,40	1.128.089,60
C	200 x 100mm chamfered precast concrete kerbs	44.066	m	15,38	677.735,08
D	1.5m wide sidewalks	66.099	m^2	8,28	547.299,72
	Total direct costs carried to Grand Summary				**2.848.874,40**

Table C.5: Direct Costs of Water Distribution Network Under Tributary Pattern

Item	Description	Qty	Unit	Rate (US$)	Amount (US$)
A	Trench excavation	4.968	m3	2,96	14.705,28
B	Backfilling and embedment	4.823	m3	3,53	17.025,19
C	100mm diameter uPVC pipes	18.399	m	8,14	149.767,86
D	100mm diameter valves	96	No.	128,85	12.369,60
E	Fire hydrants	111	No.	358,97	39.845,67
F	Valve and hydrant chambers	207	No.	265,38	54.933,66
	Total direct costs carried to Grand Summary				**288.647,26**

Table C.6: Direct Costs of Water Distribution Network Under Radial Pattern

Item	Description	Qty	Unit	Rate (US$)	Amount (US$)
A	Trench excavation	5.648	m3	2,96	16.718,08
B	Backfilling and embedment	5.484	m3	3,53	19.358,52
C	100mm diameter uPVC pipes	20.920	m	8,14	170.288,80
D	100mm diameter valves	135	No.	128,85	17.394,75
E	Fire hydrants	128	No.	358,97	45.948,16
F	Valve and hydrant chambers	263	No.	265,38	69.794,94
	Total direct costs carried to Grand Summary				**339.503,25**

Table C.7: Direct Costs of Water Distribution Network Under Grid Pattern

Item	Description	Qty	Unit	Rate (US$)	Amount (US$)
A	Trench excavation	6.160	m3	2,96	18.233,60
B	Backfilling and embedment	5.981	m3	3,53	21.112,93
C	100mm diameter uPVC pipes	22.814	m	8,14	185.705,96
D	100mm diameter valves	162	No.	128,85	20.873,70
E	Fire hydrants	120	No.	358,97	43.076,40
F	Valve and hydrant chambers	282	No.	265,38	74.837,16
	Total direct costs carried to Grand Summary				**363.839,75**

Table C.8: Direct Costs of Water Distribution Network Under Hybrid Pattern

Item	Description	Qty	Unit	Rate (US$)	Amount (US$)
A	Trench excavation	5.949	m3	2,96	17.609,04
B	Backfilling and embedment	5.776	m3	3,53	20.389,28
C	100mm diameter uPVC pipes	22.033	m	8,14	179.348,62
D	100mm diameter valves	123	No.	128,85	15.848,55
E	Fire hydrants	143	No.	358,97	51.332,71
F	Valve and hydrant chambers	266	No.	265,38	70.591,08
	Total direct costs carried to Grand Summary				**355.119,28**

Table C.9: Direct Costs of Electricity Distribution Network Under Tributary Pattern

Item	Code	Description	Qty	Unit	Rate (US$)	Amount (US$)
		Overhead Line Hardware(11kV & 33kV)				
1	1115027	11 KV Intermediate angle iron crossarm (2.0m) C/W, Tie Straps (2No), M20 x 40mm Bolts, Nuts & Washers (2No.).	89	set	73,90	6.577,10
2	1115028	11KV Intermediate angle iron crossarm (2.0m Long)	12	ea	73,90	886,80
3	1117006	11KV Pin Insulator C/W Spindle (Glass)	223	ea	5,63	1.255,49
4	1117046	11KV Strain Insulator Porcelain	120	ea	17,57	2.108,40
5	1115067	Fittings for strain Insulator consisting of ball, Clevis, hook, Section Strap, M20X40mm bolt/nut/washer and Anchor Clamp for 120sq.mm conductor.	60	set	12,05	723,00
6	1118017	Wood pole 11m	81	ea	422,29	34.205,49
		Substation Equipments and Materials				
7	3121018	11 kV expulsion type fuselink 25A	57	ea	2,40	136,80
8	3112105	11/0.433 kV PMT 315 KVA	19	ea	11.002,97	209.056,43
9	3119002	11KV Expulsion type fusegear - single pole	57	ea	137,40	7.831,80
10	1115035	Ancilliary Channel crossarm for 11KV 1.6m Long	95	ea	75,83	7.203,85
11	1115058	L-Bracket Attachment to Fusegear/Lighting Arrestor	57	ea	1,29	73,53
12	1121008	Lightning Arrestor - 11 KV	57	ea	73,93	4.214,01
13	3121175	LV HRC Fuselink with blade contacts 100A	228	ea	4,59	1.046,52
14	1112058	LV pvc insulated, pvc sheathed Cu. Conductor 70 sq. mm	1140	m	6,17	7.033,80
15	1115060	Transformer Mounting Bracket	38	pr	6,86	260,68
16	3121291	Wedge type fuse carrier 92mm (LV Aerial Fuse Unit)	228	ea	50,88	11.600,64
		To Collection (1)				**294.214,34**

Item	Code	Description	Qty	Unit	Rate (US$)	Amount (US$)
		Low Voltage Overhead Line Hardware				
17	1115051	D Iron C/W Pin (99mm x 120mm x 6mm) large	448	ea	1,90	851,20
18	1115061	D-Iron Bracket Extension Strap C/W pins	48	pair	1,65	79,20
19	1117107	LV Shackle Insulator - Porcelain (76mm height)	1780	ea	2,53	4.503,40
20	1118008	Wood pole 9m	385	ea	258,72	99.607,20
		Overhead Line Conductors & Binding Wire				
21	1119012	11kV Aluminium Binding Stirrups	219	pr.	1,20	262,80
22	1113030	Hard drawn Aluminium bare stranded conductor (AAC) 120 sq.mm	94662	m	3,72	352.142,64
23	1119003	Soft Aluminium Binding Wire	2431	m	0,07	170,17
		Stay Equipments				
24	1120116	11Kv Stay Insulator	32	ea	6,66	213,12
25	1120115	L V Stay Insulator	64	ea	4,40	281,60
26	1120105	Stay Equipment C/W Rod & Plate, Bow, 2NO. Brackets & 2nO. thimbles and M16 X 40mm bolt & nuts.	96	set	36,99	3.551,04
27	1120100	Stay Wire 7/ 4 SWG	1024	m	1,14	1.167,36
28	1120110	Wooden Stay Block	96	ea	18,39	1.765,44
		Earthing Materials				
29	1123134	Bimetallic tap-off clamp (bolted type) 120Al/16Cu	48	ea	6,96	334,08
30	1116140	Copper Earth Rod C/W Clamp	238	ea	12,55	2.986,90
31	1114005	Hard drawn bare stranded Cu. conductor 16 sq.mm	380	m	3,27	1.242,60
32	1114015	Hard drawn bare stranded Cu. conductor 35 sq.mm	665	m	6,83	4.541,95
33	1112057	LV pvc insulated, pvc sheathed Cu. Conductor 16 sq. mm	670	m	1,57	1.051,90
		To Collection (2)				**474.752,60**

Item	Code	Description	Qty	Unit	Rate (US$)	Amount (US$)
34	1119023	Plastic staple for cables up to 16sq.mm	380	ea	0,08	30,40
		Bolts, Nuts, Washers and Connectors				
35	1123151	Al. tap-off clamp (bolted type)	48	ea	1,73	83,04
36	1123149	Al. tap-off clamp (bolted type) 120 / 120	93	ea	1,61	149,73
37	1125032	Bolt, Nut & Washers M16 x 220mm	272	ea	1,53	416,16
38	1125035	Bolt, Nut & Washers M16 x 260mm	1284	ea	1,53	1.964,52
39	1125045	Bolt, Nut & Washers M20 x 280mm	362	ea	1,85	669,70
40	1125052	Bolt, Nut & Washers M16 X 300mm (Double Arm)	24	ea	3,49	83,76
41	1125092	Bolt, Nut & Washers M16 x 40mm	171	ea	0,46	78,66
42	1124006	Cu. Compression cable lug 70 sq.mm	760	ea	3,70	2.812,00
		To Collection (3)				**6.287,97**
		COLLECTION				
		Collection (1)				294.214,34
		Collection (2)				474.752,60
		Collection (3)				6.287,97
		Total direct costs carried to Grand Summary				**775.254,91**

Table C.10: Direct Costs of Electricity Distribution Network Under Radial Pattern

Item	Code	Description	Qty	Unit	Rate (US$)	Amount (US$)
		Overhead Line Hardware(11kV & 33kV)				
1	1115027	11 KV Intermediate angle iron crossarm (2.0m) C/W, Tie Straps(2No), M20 x 40mm Bolts, Nuts & Washers(2No.).	149	set	73,90	11.011,10
2	1115028	11KV Intermediate angle iron crossarm (2.0m Long)	8	ea	73,90	591,20
3	1117006	11KV Pin Insulator C/W Spindle (Glass)	235	ea	5,63	1.323,05
4	1117046	11KV Strain Insulator Porcelain	264	ea	17,57	4.638,48
5	1115067	Fittings for strain Insulator consisting of ball, Clevis, hook, Section Strap, M20X40mm bolt/nut/washer and Anchor Clamp for 120sq.mm conductor.	132	set	12,05	1.590,60
6	1118017	Wood pole 11m	68	ea	422,29	28.715,72
		Substation Equipments and Materials				
7	3121018	11 kV expulsion type fuselink 25A	54	ea	2,40	129,60
8	3112105	11/0.433 kV PMT 315 KVA	18	ea	11.002,97	198.053,46
9	3119002	11KV Expulsion type fusegear - single pole	54	ea	137,40	7.419,60
10	1115035	Ancilliary Channel crossarm for 11KV 1.6m Long	90	ea	75,83	6.824,70
11	1115058	L-Bracket Attachment to Fusegear/Lighting Arrestor	54	ea	1,29	69,66
12	1121008	Lightning Arrestor - 11 KV	54	ea	73,93	3.992,22
13	3121175	LV HRC Fuselink with blade contacts 100A	216	ea	4,59	991,44
14	1112058	LV pvc insulated, pvc sheathed Cu. Conductor 70 sq. mm	1080	m	6,17	6.663,60
15	1115060	Transformer Mounting Bracket	36	pr	6,86	246,96
16	3121291	Wedge type fuse carrier 92mm (LV Aerial Fuse Unit)	216	ea	50,88	10.990,08
		To Collection (1)				**283.251,47**

Item	Code	Description	Qty	Unit	Rate (US$)	Amount (US$)
		Low Voltage Overhead Line Hardware				
17	1115051	D Iron C/W Pin (99mm x 120mm x 6mm) large	144	ea	1,90	273,60
18	1115061	D-Iron Bracket Extension Strap C/W pins	128	pair	1,65	211,20
19	1117107	LV Shackle Insulator - Porcelain (76mm height)	1620	ea	2,53	4.098,60
20	1118008	Wood pole 9m	373	ea	258,72	96.502,56
		Overhead Line Conductors & Binding Wire				
21	1119012	11kV Aluminium Binding Stirrups	231	pr.	1,20	277,20
22	1113030	Hard drawn Aluminium bare stranded conductor (AAC) 120 sq.mm	105730	m	3,72	393.315,60
23	1119003	Soft Aluminium Binding Wire	1851	m	0,07	129,57
		Stay Equipments				
24	1120116	11Kv Stay Insulator	80	ea	6,66	532,80
25	1120115	L V Stay Insulator	36	ea	4,40	158,40
26	1120105	Stay Equipment C/W Rod & Plate, Bow, 2NO. Brackets & 2nO. thimbles and M16 X 40mm bolt & nuts.	116	set	36,99	4.290,84
27	1120100	Stay Wire 7/ 4 SWG	1320	m	1,14	1.504,80
28	1120110	Wooden Stay Block	116	ea	18,39	2.133,24
		Earthing Materials				
29	1116140	Copper Earth Rod C/W Clamp	180	ea	12,55	2.259,00
30	1114005	Hard drawn bare stranded Cu. conductor 16 sq.mm	360	m	3,27	1.177,20
31	1114015	Hard drawn bare stranded Cu. conductor 35 sq.mm	630	m	6,83	4.302,90
32	1112057	LV pvc insulated, pvc sheathed Cu. Conductor 16 sq. mm	180	m	1,57	282,60
33	1119023	Plastic staple for cables up to 16sq.mm	360	ea	0,08	28,80
		To Collection (2)				**511.478,91**

Item	Code	Description	Qty	Unit	Rate (US$)	Amount (US$)
		Bolts, Nuts, Washers and Connectors				
34	1123151	Al. tap-off clamp (bolted type)	128	ea	1,73	221,44
35	1123149	Al. tap-off clamp (bolted type) 120 / 120	174	ea	1,61	280,14
36	1125032	Bolt,Nut & Washers M16 x 220mm	180	ea	1,53	275,40
37	1125035	Bolt,Nut & Washers M16 x 260mm	1348	ea	1,53	2.062,44
38	1125045	Bolt,Nut & Washers M20 x 280mm	458	ea	1,85	847,30
39	1125052	Bolt,Nut & Washers M16 X 300mm (Double Arm)	80	ea	3,49	279,20
40	1125092	Bolt,Nut & Washers M16 x 40mm	162	ea	0,46	74,52
41	1124006	Cu. Compression cable lug 70 sq.mm	720	ea	3,70	2.664,00
		To Collection (3)				**6.704,44**
		COLLECTION				
		Collection (1)				283.251,47
		Collection (2)				511.478,91
		Collection (3)				6.704,44
		Total direct costs carried to Grand Summary				**801.434,82**

Table C.11: Direct Costs of Electricity Distribution Network Under Grid Pattern

Item	Code	Description	Qty	Unit	Rate (US$)	Amount (US$)
		Overhead Line Hardware(11kV & 33kV)				
1	1115027	11 KV Intermediate angle iron crossarm (2.0m) C/W, Tie Straps(2No), M20 x 40mm Bolts, Nuts & Washers(2No.).	75	set	73,90	5.542,50
2	1115028	11KV Intermediate angle iron crossarm (2.0m Long)	8	ea	73,90	591,20
3	1117006	11KV Pin Insulator C/W Spindle (Glass)	133	ea	5,63	748,79
4	1117046	11KV Strain Insulator Porcelain	144	ea	17,57	2.530,08
5	1115067	Fittings for strain Insulator consisting of ball, Clevis, hook, Section Strap, M20X40mm bolt/nut/washer and Anchor Clamp for 120sq.mm conductor.	72	set	12,05	867,60
6	1118017	Wood pole 11m	47	ea	422,29	19.847,63
		Substation Equipments and Materials				
7	3121018	11 kV expulsion type fuselink 25A	51	ea	2,40	122,40
8	3112105	11/0.433 kV PMT 315 KVA	17	ea	11.002,97	187.050,49
9	3119002	11KV Expulsion type fusegear - single pole	51	ea	137,40	7.007,40
10	1115035	Ancilliary Channel crossarm for 11KV 1.6m Long	85	ea	75,83	6.445,55
11	1115058	L-Bracket Attachment to Fusegear/Lighting Arrestor	51	ea	1,29	65,79
12	1121008	Lightning Arrestor - 11 KV	51	ea	73,93	3.770,43
13	3121175	LV HRC Fuselink with blade contacts 100A	204	ea	4,59	936,36
14	1112058	LV pvc insulated, pvc sheathed Cu. Conductor 70 sq. mm	1020	m	6,17	6.293,40
15	1115060	Transformer Mounting Bracket	34	pr	6,86	233,24
16	3121291	Wedge type fuse carrier92mm (LV Aerial Fuse Unit)	204	ea	50,88	10.379,52
		To Collection (1)				**252.432,38**

Item	Code	Description	Qty	Unit	Rate (US$)	Amount (US$)
		Low Voltage Overhead Line Hardware				
17	1115051	D Iron C/W Pin (99mm x 120mm x 6mm) large	160	ea	1,90	304,00
18	1115061	D-Iron Bracket Extension Strap C/W pins	144	pair	1,65	237,60
19	1117107	LV Shackle Insulator - Porcelain (76mm height)	1404	ea	2,53	3.552,12
20	1118008	Wood pole 9m	315	ea	258,72	81.496,80
		Overhead Line Conductors & Binding Wire				
21	1119012	11kV Aluminium Binding Stirrups	129	pr.	1,20	154,80
22	1113030	Hard drawn Aluminium bare stranded conductor (AAC) 120 sq.mm	109922	m	3,72	408.909,84
23	1119003	Soft Aluminium Binding Wire	1533	m	0,07	107,31
		Stay Equipments				
24	1120116	11Kv Stay Insulator	40	ea	6,66	266,40
25	1120115	L V Stay Insulator	40	ea	4,40	176,00
26	1120105	Stay Equipment C/W Rod & Plate, Bow, 2NO. Brackets & 2nO. thimbles and M16 X 40mm bolt & nuts.	80	set	36,99	2.959,20
27	1120100	Stay Wire 7/ 4 SWG	880	m	1,14	1.003,20
28	1120110	Wooden Stay Block	80	ea	18,39	1.471,20
		Earthing Materials				
29	1116140	Copper Earth Rod C/W Clamp	170	ea	12,55	2.133,50
30	1114005	Hard drawn bare stranded Cu. conductor 16 sq.mm	340	m	3,27	1.111,80
31	1114015	Hard drawn bare stranded Cu. conductor 35 sq.mm	595	m	6,83	4.063,85
32	1112057	LV pvc insulated, pvc sheathed Cu. Conductor 16 sq. mm	170	m	1,57	266,90
33	1119023	Plastic staple for cables up to 16sq.mm	340	ea	0,08	27,20
		To Collection (2)				**508.241,72**

Item	Code	Description	Qty	Unit	Rate (US$)	Amount (US$)
		Bolts, Nuts, Washers and Connectors				
34	1123151	Al. tap-off clamp (bolted type)	144	ea	1,73	249,12
35	1123149	Al. tap-off clamp (bolted type) 120 / 120	111	ea	1,61	178,71
36	1125032	Bolt,Nut & Washers M16 x 220mm	200	ea	1,53	306,00
37	1125035	Bolt,Nut & Washers M16 x 260mm	1100	ea	1,53	1.683,00
38	1125045	Bolt,Nut & Washers M20 x 280mm	302	ea	1,85	558,70
39	1125052	Bolt,Nut & Washers M16 X 300mm (Double Arm)	40	ea	3,49	139,60
40	1125092	Bolt,Nut & Washers M16 x 40mm	153	ea	0,46	70,38
41	1124006	Cu. Compression cable lug 70 sq.mm	680	ea	3,70	2.516,00
		To Collection (3)				**5.701,51**
		COLLECTION				
		Collection (1)				252.432,38
		Collection (2)				508.241,72
		Collection (3)				5.701,51
		Total direct costs carried to Grand Summary				**766.375,61**

Table C.12: Direct Costs of Electricity Distribution Network Under Hybrid Pattern

Item	Code	Description	Qty	Unit	Rate (US$)	Amount (US$)
		Overhead Line Hardware(11kV & 33kV)				
1	1115027	11 KV Intermediate angle iron crossarm (2.0m) C/W, Tie Straps(2No), M20 x 40mm Bolts, Nuts & Washers(2No.).	68	set	73,90	5.025,20
2	1115028	11KV Intermediate angle iron crossarm (2.0m Long)	8	ea	73,90	591,20
3	1117006	11KV Pin Insulator C/W Spindle (Glass)	136	ea	5,63	765,68
4	1117046	11KV Strain Insulator Porcelain	120	ea	17,57	2.108,40
5	1115067	Fittings for strain Insulator consisting of ball, Clevis, hook, Section Strap, M20X40mm bolt/nut/washer and Anchor Clamp for 120sq.mm conductor.	60	set	12,05	723,00
6	1118017	Wood pole 11m	48	ea	422,29	20.269,92
		Substation Equipments and Materials				
7	3121018	11 kV expulsion type fuselink 25A	54	ea	2,40	129,60
8	3112105	11/0.433 kV PMT 315 KVA	18	ea	11.002,97	198.053,46
9	3119002	11KV Expulsion type fusegear - single pole	54	ea	137,40	7.419,60
10	1115035	Ancilliary Channel crossarm for 11KV 1.6m Long	90	ea	75,83	6.824,70
11	1115058	L-Bracket Attachment to Fusegear/Lighting Arrestor	54	ea	1,29	69,66
12	1121008	Lightning Arrestor - 11 KV	54	ea	73,93	3.992,22
13	3121175	LV HRC Fuselink with blade contacts 100A	216	ea	4,59	991,44
14	1112058	LV pvc insulated, pvc sheathed Cu. Conductor 70 sq. mm	1080	m	6,17	6.663,60
15	1115060	Transformer Mounting Bracket	36	pr	6,86	246,96
16	3121291	Wedge type fuse carrier92mm (LV Aerial Fuse Unit)	216	ea	50,88	10.990,08
		To Collection (1)				**264.864,72**

Item	Code	Description	Qty	Unit	Rate (US$)	Amount (US$)
		Low Voltage Overhead Line Hardware				
17	1115051	D Iron C/W Pin (99mm x 120mm x 6mm) large	384	ea	1,90	729,60
18	1115061	D-Iron Bracket Extension Strap C/W pins	208	pair	1,65	343,20
19	1117107	LV Shackle Insulator - Porcelain (76mm height)	1820	ea	2,53	4.604,60
20	1118008	Wood pole 9m	383	ea	258,72	99.089,76
		Overhead Line Conductors & Binding Wire				
21	1119012	11kV Aluminium Binding Stirrups	132	pr.	1,20	158,40
22	1113030	Hard drawn Aluminium bare stranded conductor (AAC) 120 sq.mm	109984	m	3,72	409.140,48
23	1119003	Soft Aluminium Binding Wire	2132	m	0,07	149,24
		Stay Equipments				
24	1120116	11Kv Stay Insulator	32	ea	6,66	213,12
25	1120115	L V Stay Insulator	76	ea	4,40	334,40
26	1120105	Stay Equipment C/W Rod & Plate, Bow, 2NO. Brackets & 2nO. thimbles and M16 X 40mm bolt & nuts.	108	set	36,99	3.994,92
27	1120100	Stay Wire 7/ 4 SWG	1144	m	1,14	1.304,16
28	1120110	Wooden Stay Block	108	ea	18,39	1.986,12
		Earthing Materials				
29	1123134	Bimetallic tap-off clamp (bolted type) 120Al/16Cu	20	ea	6,96	139,20
30	1116140	Copper Earth Rod C/W Clamp	200	ea	12,55	2.510,00
31	1114005	Hard drawn bare stranded Cu. conductor 16 sq.mm	360	m	3,27	1.177,20
32	1114015	Hard drawn bare stranded Cu. conductor 35 sq.mm	630	m	6,83	4.302,90
33	1112057	LV pvc insulated, pvc sheathed Cu. Conductor 16 sq. mm	380	m	1,57	596,60
		To Collection (2)				**530.773,90**

Item	Code	Description	Qty	Unit	Rate (US$)	Amount (US$)
34	1119023	Plastic staple for cables up to 16sq.mm	360	ea	0,08	28,80
		Bolts, Nuts, Washers and Connectors				
35	1123151	Al. tap-off clamp (bolted type)	208	ea	1,73	359,84
36	1123149	Al. tap-off clamp (bolted type) 120 / 120	102	ea	1,61	164,22
37	1125032	Bolt,Nut & Washers M16 x 220mm	360	ea	1,53	550,80
38	1125035	Bolt,Nut & Washers M16 x 260mm	1228	ea	1,53	1.878,84
39	1125045	Bolt,Nut & Washers M20 x 280mm	296	ea	1,85	547,60
40	1125052	Bolt,Nut & Washers M16 X 300mm (Double Arm)	32	ea	3,49	111,68
41	1125092	Bolt,Nut & Washers M16 x 40mm	162	ea	0,46	74,52
42	1124006	Cu. Compression cable lug 70 sq.mm	720	ea	3,70	2.664,00
		To Collection 83)				**6.380,30**
		COLLECTION				
		Collection (1)				264.864,72
		Collection (2)				530.773,90
		Collection (3)				6.380,30
		Total direct costs carried to Grand Summary				**802.018,92**

APPENDIX D: GRAND SUMMARY OF COSTS WITH FOCUS ON STEET PATTERNS

Table D.1: Grand Summary of Road Costs Under Tributary Pattern

Item	Description		Amount (US$)	Amount (US$)
A	Total direct costs brought to Grand Summary		2.378.994	
B	Allow for indirect costs (10% of direct costs)	10%	237.899	
C	Allow for offsite overheads & profit (25% of sum of items A & B)	25%	654.223	
D	Construction contractor's cost			3.271.117
E	Allow for client's costs (15% of construction contractor's costs)	15%		490.668
F	Base Estimate			3.761.785
G	Allow for risk & contingency (20% of base Estimate)	20%		752.357
H	**Total Project Costs**			**4.514.142**

Table D.2: Grand Summary of Road Costs Under Radial Pattern

Item	Description		Amount (US$)	Amount (US$)
A	Total direct costs brought to Grand Summary		2.704.956	
B	Allow for indirect costs (10% of direct costs)	10%	270.496	
C	Allow for offsite overheads & profit (25% of sum of items A & B)	25%	743.863	
D	Construction contractor's cost			3.719.315
E	Allow for client's costs (15% of construction contractor's costs)	15%		557.897
F	Base Estimate			4.277.212
G	Allow for risk & contingency (20% of base Estimate)	20%		855.442
H	**Total Project Costs**			**5.132.654**

Table D.3: Grand Summary of Road Costs Under Grid Pattern

Item	Description		Amount (US$)	Amount (US$)
A	Total direct costs brought to Grand Summary		2.949.854	
B	Allow for indirect costs (10% of direct costs)	10%	294.985	
C	Allow for offsite overheads & profit (25% of sum of items A & B)	25%	811.210	
D	Construction contractor's cost			4.056.049
E	Allow for client's costs (15% of construction contractor's costs)	15%		608.407
F	Base Estimate			4.664.457
G	Allow for risk & contingency (20% of base Estimate)	20%		932.891
H	**Total Project Costs**			**5.597.348**

Table D.4: Grand Summary of Road Costs Under Hybrid Pattern

Item	Description		Amount (US$)	Amount (US$)
A	Total direct costs brought to Grand Summary		2.848.874	
B	Allow for indirect costs (10% of direct costs)	10%	284.887	
C	Allow for offsite overheads & profit (25% of sum of items A & B)	25%	783.440	
D	Construction contractor's cost			3.917.202
E	Allow for client's costs (15% of construction contractor's costs)	15%		587.580
F	Base Estimate			4.504.783
G	Allow for risk & contingency (20% of base Estimate)	20%		900.957
H	**Total Project Costs**			**5.405.739**

Table D.5: Grand Summary of Water Distribution Network Costs Under Tributary Pattern

Item	Description		Amount (US$)	Amount (US$)
A	Total direct costs brought to Grand Summary		288.647	
B	Allow for indirect costs (10% of direct costs)	10%	28.865	
C	Allow for offsite overheads & profit (25% of sum of items A & B)	25%	79.378	
D	Construction contractor's cost			396.890
E	Allow for client's costs (15% of construction contractor's costs)	15%		59.533
F	Base Estimate			456.423
G	Allow for risk & contingency (20% of base Estimate)	20%		91.285
H	**Total Project Costs**			**547.708**

Table D.6: Grand Summary of Water Distribution Network Costs Under Radial Pattern

Item	Description		Amount (US$)	Amount (US$)
A	Total direct costs brought to Grand Summary		339.503	
B	Allow for indirect costs (10% of direct costs)	10%	33.950	
C	Allow for offsite overheads & profit (25% of sum of items A & B)	25%	93.363	
D	Construction contractor's cost			466.817
E	Allow for client's costs (15% of construction contractor's costs)	15%		70.023
F	Base Estimate			536.840
G	Allow for risk & contingency (20% of base Estimate)	20%		107.368
H	**Total Project Costs**			**644.207**

Table D.7: Grand Summary of Water Distribution Network Costs Under Grid Pattern

Item	Description		Amount (US$)	Amount (US$)
A	Total direct costs brought to Grand Summary		363.840	
B	Allow for indirect costs (10% of direct costs)	10%	36.384	
C	Allow for offsite overheads & profit (25% of sum of items A & B)	25%	100.056	
D	Construction contractor's cost			500.280
E	Allow for client's costs (15% of construction contractor's costs)	15%		75.042
F	Base Estimate			575.322
G	Allow for risk & contingency (20% of base Estimate)	20%		115.064
H	**Total Project Costs**			**690.386**

Table D.8: Grand Summary of Water Distribution Network Costs Under Hybrid Pattern

Item	Description		Amount (US$)	Amount (US$)
A	Total direct costs brought to Grand Summary		355.119	
B	Allow for indirect costs (10% of direct costs)	10%	35.512	
C	Allow for offsite overheads & profit (25% of sum of items A & B)	25%	97.658	
D	Construction contractor's cost			488.289
E	Allow for client's costs (15% of construction contractor's costs)	15%		73.243
F	Base Estimate			561.532
G	Allow for risk & contingency (20% of base Estimate)	20%		112.306
H	**Total Project Costs**			**673.839**

Table D.9: Grand Summary of Electiricty Distribution Network Costs Under Tributary Pattern

Item	Description		Amount (US$)	Amount (US$)
A	Total direct costs brought to Grand Summary		775.255	
B	Allow for indirect costs (10% of direct costs)	10%	77.525	
C	Allow for offsite overheads & profit (25% of sum of items A & B)	25%	213.195	
D	Construction contractor's cost			1.065.976
E	Allow for client's costs (15% of construction contractor's costs)	15%		159.896
F	Base Estimate			1.225.872
G	Allow for risk & contingency (20% of base Estimate)	20%		245.174
H	**Total Project Costs**			**1.471.046**

Table D.10: Grand Summary of Electiricty Distribution Network Costs Under Radial Pattern

Item	Description		Amount (US$)	Amount (US$)
A	Total direct costs brought to Grand Summary		801.435	
B	Allow for indirect costs (10% of direct costs)	10%	80.143	
C	Allow for offsite overheads & profit (25% of sum of items A & B)	25%	220.395	
D	Construction contractor's cost			1.101.973
E	Allow for client's costs (15% of construction contractor's costs)	15%		165.296
F	Base Estimate			1.267.269
G	Allow for risk & contingency (20% of base Estimate)	20%		253.454
H	**Total Project Costs**			**1.520.723**

Table D.11: Grand Summary of Electiricty Distribution Network Costs Under Grid Pattern

Item	Description		Amount (US$)	Amount (US$)
A	Total direct costs brought to Grand Summary		766.376	
B	Allow for indirect costs (10% of direct costs)	10%	76.638	
C	Allow for offsite overheads & profit (25% of sum of items A & B)	25%	210.753	
D	Construction contractor's cost			1.053.766
E	Allow for client's costs (15% of construction contractor's costs)	15%		158.065
F	Base Estimate			1.211.831
G	Allow for risk & contingency (20% of base Estimate)	20%		242.366
H	**Total Project Costs**			**1.454.198**

Table D.12: Grand Summary of Electiricty Distribution Network Costs Under Hybrid Pattern

Item	Description		Amount (US$)	Amount (US$)
A	Total direct costs brought to Grand Summary		802.019	
B	Allow for indirect costs (10% of direct costs)	10%	80.202	
C	Allow for offsite overheads & profit (25% of sum of items A & B)	25%	220.555	
D	Construction contractor's cost			1.102.776
E	Allow for client's costs (15% of construction contractor's costs)	15%		165.416
F	Base Estimate			1.268.192
G	Allow for risk & contingency (20% of base Estimate)	20%		253.638
H	**Total Project Costs**			**1.521.831**

APPENDIX E: CAPITAL COSTS OF LINEAR INFRASTRUCTURE WITH FOCUS ON DENSITY

Table E.1: Total Capital Costs of Water Distribution Network Under Varying Density Levels

Density (DPH)	Tributary (US$)	Radial (US$)	Grid (US$)	Hybrid (US$)
13	547.708	644.207	690.386	673.839
27	747.174	644.207	690.386	673.839
40	747.174	644.207	690.386	673.839
53	932.103	874.796	944.018	913.881

Table E.2: Capital Costs Per Dwelling of Water Distribution Network Under Varying Density Levels

Density	Tributary (US$)	Radial (US$)	Grid (US$)	Hybrid (US$)
13	476	582	642	619
27	325	291	321	310
40	216	194	214	206
53	202	198	220	210

Table E.3: Total Capital Costs of Electricity Distribution Network Under Varying Density Levels

Density	Tributary (US$)	Radial (US$)	Grid (US$)	Hybrid (US$)
13	1.471.046	1.520.723	1.454.198	1.521.831
27	1.927.448	1.965.872	1.900.732	1.964.775
40	2.406.994	2.433.651	2.342.523	2.406.566
53	2.874.636	2.875.442	2.784.314	2.848.357

Table E.4: Capital Costs Per Dwelling of Electricity Distribution Network Under Varying Density Levels

Density	Tributary (US$)	Radial (US$)	Grid (US$)	Hybrid (US$)
13	1.278	1.374	1.353	1.399
27	837	888	884	903
40	697	733	726	737
53	624	649	648	654

Table E.5: Total Capital Costs of Road Network Under Varying Density Levels

Density	Tributary (US$)	Radial (US$)	Grid (US$)	Hybrid (US$)
13	4.514.142	5.132.654	5.597.348	5.405.739
27	4.514.142	5.132.654	5.597.348	5.405.739
40	4.514.142	5.132.654	5.597.348	5.405.739
53	4.819.951	5.480.388	5.976.543	5.771.967

Table E.6: Capital Costs Per Dwelling of Road Network Under Varying Density Levels

Density	Tributary (US$)	Radial (US$)	Grid (US$)	Hybrid (US$)
13	3.922	4.637	5.207	4.969
27	1.961	2.318	2.603	2.484
40	1.307	1.546	1.736	1.656
53	1.047	1.238	1.390	1.326

Table E.7: Total Combined Capital Costs of Linear Infrastructure Under Varying Density Levels

Density	Tributary (US$)	Radial (US$)	Grid (US$)	Hybrid (US$)
13	6.532.896	7.297.584	7.741.932	7.601.409
27	7.188.764	7.742.733	8.188.466	8.044.353
40	7.668.310	8.210.512	8.630.257	8.486.144
53	8.626.690	9.230.626	9.704.875	9.534.205

Table E.8: Total Combined Capital Costs Per Dwelling of Linear Infrastructure Under Varying Density Levels

Density	Tributary (US$)	Radial (US$)	Grid (US$)	Hybrid (US$)
13	5.676	6.592	7.202	6.987
27	3.123	3.497	3.809	3.697
40	2.221	2.472	2.676	2.600
53	1.874	2.085	2.257	2.191