

# Urban Engineering: Concepts and Challenges

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## 1. Introduction

The purpose of this chapter is to explain the concepts of urban engineering and to highlight some of the challenges faced by this discipline. The overall idea is to describe how urban engineering relates to other areas of engineering expertise, particularly within the context of civil engineering. To do this we have drawn mainly on our own professional and academic experience, fleshed out by an examination of the relevant literature available both in Brazil and further afield. At the outset it should be said that most of our observations focus on the city of São Paulo where our present professional concerns lie. However, in future works we hope to extend our approach beyond the confines of São Paulo in an effort to broaden and improve our understanding of the concepts underlying urban engineering as a necessary prelude to enable us to supply useful guidance for researchers, experts and students keen to work alongside the engineering professionals currently employed in our cities.

## 2. Urban engineering in São Paulo

### 2.1 Background

The first topographical survey of the city of São Paulo was completed in 1792. According to Toledo (1983) the survey was in effect the first 'master plan' for the city. In addition to being a straightforward survey it also provided certain guidelines as to how the city should deal with its future expansion from small village to larger urban center.

The above survey was carried out by Portuguese military engineers, cartographers and astronomers belonging to the Royal Corps of Engineers, who were also engaged in overseeing a variety of public works such as the building of hospitals, the laying down of water facilities and paved streets, as well as constructing barracks and other military-type installations.

It is perhaps worth recalling that, prior to the late 18th century, so-called public works such as the construction of bridges and the paving of roads and streets tended to be undertaken by ordinary people using makeshift building techniques and perishable materials such as mud reinforced with straw (adobe). The Portuguese military engineers introduced a series of new techniques, employing more durable materials such as stone and lime (infinitely more suited to large-scale works).

Military-trained engineers played an important role in the development of the city of São Paulo and its hinterland, moving on from mapping and surveying the then "province" to undertaking topographical surveys of the expanding urban area, designing roads and railways and being closely involved in the construction of bridges, fortifications and public buildings in general (Simões Jr., 1990).

The growing importance of these activities, which expanded in tandem with the population upsurge in the interior of the state of São Paulo as a result of the coffee boom, pointed to an urgent need to train more engineers. The latter began to be referred to, around this time, as "civil engineers" given that the majority of the public works required were increasingly of a non-military nature.

The Polytechnic School of São Paulo was established in 1893. This ran courses in civil, industrial and agricultural engineering as well as a supplementary course in mechanics. One year after its establishment the School was also able to offer courses in architecture and was entitled to award formal qualifications in accountancy, surveying and machinery operation for students who managed to complete only part of its engineering courses (Santos, 1985).

The first School of Engineering in Brazil to provide exclusively a course in civil engineering was the Polytechnic School of Rio de Janeiro, established in 1874. The School originated in 1792 with the creation of the Royal Academy of Artillery, Fortifications and Design in Rio de Janeiro, which later (in 1810) became known as the Royal Military Academy. The Academy was in the event staffed by the director and most of the members of the teaching corpus who had previously worked at the Portuguese Royal Naval Academy, having arrived in Brazil with the exiled Portuguese King João VI in 1808 (Pardal, 1985). The second school to be established was the Ouro Preto School of Mines (in 1876) which instituted a course on mining and metallurgical engineering.

Other schools soon followed: the Pernambuco Engineering School (1895), the Mackenzie Engineering Schools in São Paulo (1896), the Porto Alegre Engineering School (1896), the Bahia Polytechnic School (1897), the Belo Horizonte Free School of Engineering (1911), the Paraná Engineering School (1912), the Recife Polytechnic (1912), the Itajubá Electrical Engineering and Technical School (1913), the Juiz de Fora Engineering School (1914), the Military Engineering School in Rio de Janeiro (1928) and, finally, the Pará Engineering School in 1931 (Telles, 1993).

The above schools aimed to train civil engineers to work in the burgeoning cities, where they would be responsible for topographical surveys, all types and sizes of public and private buildings, road systems, canals, water and sewage networks, as well as for the conservation, planning and budgetary details involved in the public works that were an inevitable product of the growth of Brazil's urban areas.

## 2.2 Consolidation

In February 1911 Eng. Victor da Silva Freire gave a keynote address at the São Paulo Polytechnic School Guild in which he advanced a theoretical justification for the proposal which formed part of a series of *avant-garde* town planning projects submitted by the Municipal Works Management Division. This proposal focused on the need to respect fundamental artistic and traditional principles and the non-static nature of cities which, he believed, could be transformed by designing and applying specific street patterns (Freire, 1911). Freire, as Professor of Engineering at the São Paulo Polytechnic School, was a devotee

of the International Congresses for City Construction, which he attended regularly in Europe.

According to Simões Jr. (2004), Freire was the first to introduce the concept of town planning to Brazil. He was also the first engineer to treat this as a science rather than as a straightforward technical approach to street planning (as had hitherto been the case). Freire was the first to introduce a heightened theoretical approach to the subject – an approach which was becoming increasingly employed in other parts of the world.

The principal influences at the time were three European urban experts: Camillo Sitte (1843-1903, Austrian), Joseph Stübben (1845-1936, German) and Eugène Hénard (1849-1923, French). All these were considered to be the forerunners of modern 'urban science'. In addition to these three, the influence of the Englishman Raymond Unwin (1863-1940), was also notable. Unwin was responsible for Cia City in São Paulo (1912) built on the lines of the Garden Cities concept formulated by Ebenezer Howard. Ebenezer Howard (1850/1928) put forward the idea of building new cities with factories and gardens, The Garden Cities with houses built near to workplaces and the city center and within easy reach of green space. One of the main features of this design concept was the layout of the road and street systems which generally followed existing topography, however hilly or winding, thereby creating a more 'natural' environment.

Sitte, author of "Der Städtebau nach seinen künstlerischen Grundsätzen" (Building cities based on artistic principles) was a harsh critic of Haussmaniana (the 'grand monumentalist' approach), preferring to think in terms of irregular and more artistically- inspired patterns of streets and public squares. Baron Haussmann (1809/1891) was responsible for the rehabilitation of parts of the city of Paris by planning major thoroughfares, laying down fine parks and erecting a number of prestigious public buildings. Stübben, author of "Der Städtebau" (The building of cities) was, on the other hand, primarily concerned with questions of urban growth and issues touching on radial (spoke) and circumferential arterial road systems, as well as building healthy environments and promoting keener awareness of aesthetic factors. Hénard, author of "Études sur les transformations de Paris" (Studies on transforming Paris), produced a number of solutions for developing and improving cities in the course of his comparative work on the urban development of Paris, Moscow, London and Berlin.

The word "urbanism" was employed for the first time in Brazil by Freire (1916). This is a neologism of the French term *urbanisme* which emerged earlier in the century (in 1910) and which in turn was a translation of the English term 'town planning' (used for the first time in England in 1906). Similar terms had already been employed in Germany since the mid-19th century: *stadtplan* (city plans) and *stadtbau* (city building). Thus 'urbanism', or town planning, evolved into a modern urban science, reflecting the need to introduce a degree of planning discipline as the result of the major changes taking place in cities caused by industrialization and rapid population growth (Choay, 1965).

According to Freitag (2006), only with the advent of Le Corbusier (1887-1965) considered to be the founding father of modern town planning, could "urbanism" be considered to have become a universally accepted science, capable of providing practical solutions to the urban problems emerging in the context of 20th century industrial society.

The first 'urbanists' in São Paulo were civil and architectural engineers. These individuals left a clearly identifiable mark on the first examples of urban engineering in the growing city

despite opposition from local administrators schooled not in engineering but in the law such as João Theodoro, Antonio Prado and others.

This group of urban engineers was educated at the Polytechnic School (where a number of them also taught). They tended to align themselves with Victor Freire and his assistant - Eng. João Florence Ulhôa - who in 1924 conceived the idea of the "radial roads perimeter" and who in 1930 published, together with Eng. Francisco Prestes Maia, the first major street plan (the *Plano de Avenidas*) for the city of São Paulo. Eng. Prestes Maia, professor at the Polytechnic School, and Mayor of São Paulo on two occasions (27 April 1938 - 27 October 1945 and 10 April 1961-7 April 1965), was considered by Toledo (1996) to be a major proponent of town planning strategy and doctrine, with a reputation as a tough administrator.

It is also worth mentioning the important roles played by Arthur Saboya and Francisco Rodrigues Saturnino de Brito (the latter known primarily for his work as a public health specialist) and Luis Ignácio Romeiro de Anhaia Mello, who belonged to the new generation of engineers greatly influenced by the new approach to urbanism in the United States.

Anhaia Mello was the main force behind the creation of São Paulo's Architecture and Town Planning Faculty in 1948 - an independent academic facility which emerged from the engineering and architecture course previously run by the Polytechnic School. Mello was the first director of this faculty and was primarily responsible for perceiving the inter-related aspects of "urbanism" and "architecture" (hence the name of the new faculty). (Ficher, 2005).

At the time the above engineers were working in São Paulo (the first half of the 20<sup>th</sup> century), the city underwent a major period of expansion which, in turn, justified the increasing concern directed towards town planning matters. Table 1 contains population data for 1872-1950.

Year	São Paulo Municipality			Brazil	
	Population	Annual geometric growth rate	Urbanization rate (%)	Population	Annual geometric growth rate
1872	31,385		-	10,112,061	
		4.1			2.0
1890	64,934		-	14,333,915	
		14.0			1.9
1900	239,820		-	17,318,556	
		4.5			2.9
1920	579,033		-	30,635,605	
		4.2			1.5
1940	1,326,261		94.9	41,236,315	
		5.2			2.3
1950	2,198,096		93.4	51,944,397	

Table 1. Population figures (IBGE, Demographic Census)

Souza (2006) notes that throughout this period large numbers of São Paulo Polytechnic engineers occupied public positions in the various municipalities and public works/road and street planning secretariats, with the majority of them closely involved in urban engineering activities.

The aforementioned urban engineers tended to regard the city as a whole unit – an approach which in their view called for integrated interventions of a technical and aesthetic nature with regard both to buildings and traffic organization. They also paid strict attention to the public sanitation aspects of the city in their plans for city streets and squares. Furthermore, they took into account the administrative and management aspects of the city, resulting in the establishment of a number of bodies employing specialist professional staff concentrated specifically on town planning.

The above professionals were mainly ‘civil’ or ‘architectural’ engineers who on graduating were attracted by the prospect of interesting, well-paid and prestigious jobs in this area of expertise.

The term ‘urban engineering’ was employed by Francisco de Paula Dias de Andrade in his thesis dated 1966 (Chair (*Cátedra*) No. 12: Buildings construction; Notions of architecture; Urban engineering and urbanism), submitted as part of the qualification process for a senior professorship appointment at the Polytechnic School. Regardless of the fact that subsequent documents written by Professor Andrade fail to cast more precise light on the prospects for urban engineering in São Paulo, it is nevertheless evident that Andrade showed a keen pioneering approach with his creation in 1970 of a graduate course in construction and urban engineering at the University of São Paulo Polytechnic School devoted specifically to training engineers at Masters and Doctoral level in those fields of knowledge.

### 3. Urban engineering

According to Martinard (1986), urban engineering can be described as "the art of conceiving, undertaking, managing and coordinating the technical aspects of urban systems. The term ‘urban technical systems’ has two meanings: the first conveys the ‘physical’ dimension of an infrastructural ‘support’ network, while the second can be construed as a supporting ‘services’ network". For example, while the water supply system of any city possesses a ‘physical’ dimension insofar as the actual physical distribution of water is concerned (pipes, water capture machinery, treatment equipment etc), it is vital to take into consideration, in addition, the number and quality of the services required to operate and maintain the networks and their various equipments, to ensure appropriate billing, charging and cost recovery mechanisms for the payment of services rendered and the need for water quality control and supervision of the multifarious aspects of systems management.

It could be argued that the responsibility for the purely technical aspects of water supply falls to civil engineers specializing in hydraulic and sanitation engineering – a speciality widely recognized as one of the most traditional branches of engineering. However, although this particular class of engineer is certainly qualified to deal with and resolve problems in his chosen area of expertise (hydraulics and sanitation) it is difficult to attribute to him the title of ‘urban engineer’.

A further example is that of the civil engineer specializing in transport engineering. This branch of engineering involves dealing with land, maritime, river and air transport, as well

as the infrastructure needed to keep abreast of developments in these specialist areas. It is equally difficult to describe this transport specialist an 'urban engineer'.

Both the above examples point to the need to identify a more precise definition of the 'urban technical systems' mentioned by Martinard, given that there is no clear distinction made in current day-to-day practice between specialist civil engineering fields and those specifically associated with 'urban engineering'.

A further definition of the term is provided by EIVP, the École des Ingénieurs de la Ville de Paris (City of Paris Engineering School, <http://www.eivp-paris.fr/>), founded in 1959, which runs an undergraduate course in urban engineering. For the EIPV urban engineering deals with the 'conception, construction and management of cities', while simultaneously playing close attention to the need for 'sustainable development'.

In Anglo-Saxon countries, particularly in the United Kingdom, Canada and the United States, the term "municipal engineering" has a similar meaning to "urban engineering". Municipal engineering includes all the civil and environmental engineering services related to the complex problems generated by infrastructural and environmental problems and land use that confront municipal governments on a daily basis (see <http://www.nlja.com/municipal.html>). In our view, this more precise definition gives a clearer idea of the practical scope of urban engineering and of the activities undertaken by urban engineers.

Based on this definition, urban engineering can more properly be described as the branch of engineering that covers all the civil and environmental engineering services related to the range of complex problems associated with infrastructure, services, buildings, environmental and land-use issues generally encountered in urban areas.

### 3.1 The systemic approach

The 'urban engineer' operates in a broad and systemic manner, given that his field of activity is multifaceted and complex, involving many different social, economic, political, environmental and technological factors. This generally means that a large number of interests and stakeholders are involved.

Systemic (or systems) thinking is a framework based on the belief that the component parts or properties of an organism or living system can best be understood in the context of relationships with each other and with other systems rather than in isolation. These properties are the product of a variety of interactions and relationships between the separate parts and it follows that the only way to fully understand why a problem occurs and persists is to understand the part in relation to the whole (Ackoff, 1974).

This approach is of crucial importance if we wish to understand our cities and find ways of tackling the problems incurred in and by these cities. The many problems, for example, encountered in cities linked to water and energy supply, transport, etc cannot be seen in isolation. Rather they need to be understood systemically within the context of an overarching, broader urban context.

Applying this approach is a complex task given that urban engineering touches on a wide range of activities, including:

- water resources engineering, the collection and treatment of sewage, solid waste management, collection and disposal, energy distribution, drainage, urban transport, telecommunications, etc;

- different areas of activity requiring coordination, including initial planning and detailed design, project execution, ongoing operation, maintenance and management;
- a variety of stakeholders: public authorities at the several levels (local, municipal, regional, metropolitan, state and national), plus para-statal sectors, private sector involvement, NGOs and community representatives.

### 3.2 The urban space

One key aspect worthy of consideration is the relationship between the urban engineer and his territorial preserve – which amounts in reality to the entire "urban space". This particular space is not merely an area of land distinguishable from the "rural space" around the city but also a political space which also provides a home for members of the workforce (Castells, 1983).

However we believe that the urban and rural territorial spaces are in fact closely integrated and cannot be viewed as totally independent entities. In an urban engineering context it is thus vital to employ the 'systemic' approach in an effort to understand the mutually dependent relationship between the city and the surrounding country areas (and vice versa).

We also need to remember that any definition of what exactly is "urban space" tends to be fairly arbitrary. In Brazil, areas defined in municipal law (based upon the National Taxation Code) are considered to be 'urban areas'. The National Taxation Code defines those areas which can be considered as 'urban'. This definition is directly related to the IPTU (urban property rates) revenue. It is not necessary for these areas to be occupied by a minimum number of inhabitants or to possess a minimum population density. Other criteria have of course been adopted in other countries according to their homegrown political, geographic or cultural circumstances (Jenkins et al., 2007)

In the United States, for example, an area is considered to be "urban" when it has a minimum of 2,500 inhabitants, with a minimum population density of 1,000 persons other per square mile (386 persons per km<sup>2</sup> (one square mile = approx. 2.59km<sup>22</sup> is the norm. In Mexico an urban space requires at least 2,500 inhabitants but no density requirement. On the other hand, in Peru any area demarcated formally as "urban" has to possess *in situ* at least 100 dwelling units.

According to Veiga (2002) if the criteria of population size were combined with local and demographic density, the urban part of Brazil would represent 57% of the total population of the country (in 2,000) - not 81.2%, as stated by the Brazilian Statistics Institute IBGE.

## 4. The challenges

Practitioners of urban engineering are currently faced by the highly complex situation outlined above. Cities of different sizes and social/political weight are crying out for specialized and competent engineers possessing broad managerial expertise combined with a systemic approach to the tasks in hand. Cities are complicated environments requiring the involvement of fully qualified professional staff capable of confronting the many challenges, particularly in the cities of the developing world.

University-level urban engineering teaching in Brazil has traditionally been carried out at graduate level. The following urban engineering graduate courses were registered according to their original date of introduction: 1970, USP Polytechnic School; 1994, Federal University of São Carlos; 2000, Federal University of Paraíba; 2002, Federal University of Uberlândia and Federal University of Passo Fundo; 2005, Federal University of Bahia; 2006, Federal University of Maringá; 2008, Federal University of Rio de Janeiro and Rio de Janeiro Catholic University. Two undergraduate courses have also come to our notice: one at the Federal University of São Carlos and the other at the ABC Federal University. We need to train and qualify our urban engineers to face, inter-ally, the following challenges:

- (a) ever-growing urban population pressure on existing infrastructure and public services. As can be seen in Table 2, "macro-regions" throughout the world have recorded continuing urban demographic growth in both absolute and percentage terms;

	Population (millions)			Urban population (millions)			Urban population (%)		
	1950	2005	2030	1950	2005	2030	1950	2005	2030
World	2,535	6,464	8,200	735	3,148	4,912	29.0	48.7	59.9
Africa	224	922	1,518	33	353	770	14.7	38.3	50.7
Asia	1,410	3,938	4,931	237	1,567	2,668	16.8	39.8	54.1
Europe	548	731	707	277	528	554	50.5	72.2	78.3
LA & Caribbean	168	558	713	71	432	601	42.0	77.4	84.3
North America	171	332	405	109	268	351	63.9	80.7	86.7
Oceania	13	33	43	8	23	32	62.0	70.8	73.8

Table 2. Demographic change by macro-region (UN World Population Prospects, 2006)

- (b) in spite of this growth, what have been observed is that in general the quality of living in cities improves as increases the urbanization rate, particularly in developing countries. As an example of this phenomena, Figure 1 shows that as the urbanization process advances, the infant mortality rate which is a largely adopted social indicator, decreases. It is quite logical that this kind of situation occurs because population will have more access to health care, education and information in cities even if these services are not so well delivered. This situation leads to an approach which understands cities not only as a problem but the solution, or at least an important part of it.

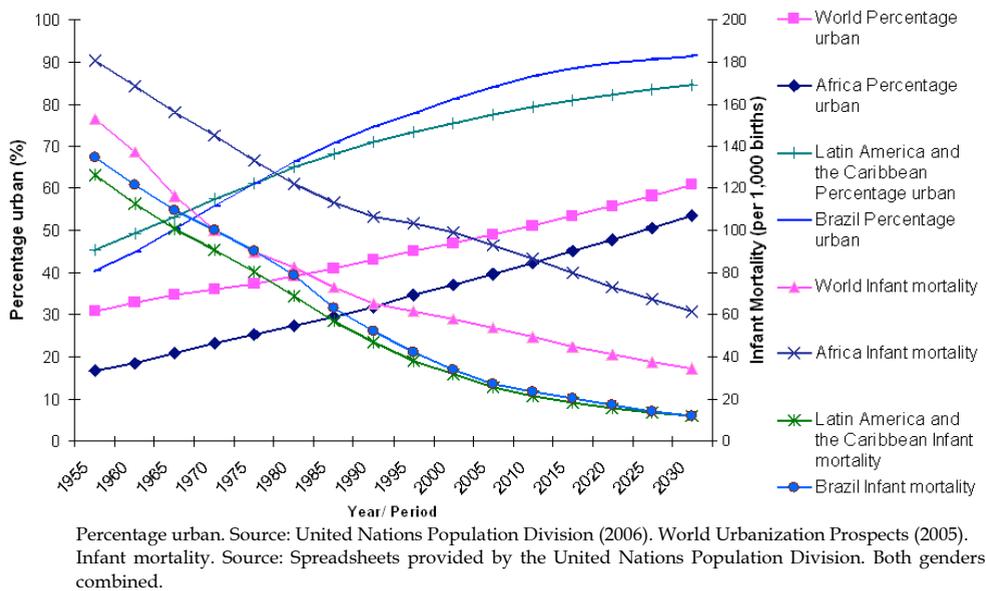


Figure 1. Percentage urban versus Infant mortality in World, Africa, Latin America and Caribbean, and Brazil

- (c) urban population growth has tended to be concentrated on the metropolitan regions, given that these attract incoming workers to available employment opportunities. Brazil's 'metropolitan regions' possess formal and legal status but they are not in reality 'political' entities as such, able to exclusively benefit from government resources while undertaking appropriate responsibilities and commitments. This creates serious administrative difficulties since problem-solving is often not confined to the territorial boundaries of a particular municipality but calls for intervention at a wider regional level. A prime example of this situation is the whole question of the final disposal of solid waste;
- (d) the deterioration and obsolescence of existing infrastructure networks and the need to introduce new technical solutions in keeping with the physical and population growth of the cities. In this respect many new, lighter and more durable materials have come onto the market but these have often not been properly tested in real situations. Moreover, the higher building densities in the urban areas ("verticalization") generally mean that infrastructure and services networks need upscaling in order to meet new demands;
- (e) the introduction of new technologies such as cellphones and the internet and the rapid evolution of increasingly more efficient, accessible and cost-effective information management, access and retrieval systems such as those based on geo-processing;

- (f) complex, decentralized and automated administrative and governmental systems requiring efficient and coherent coordination and follow-up. Financial resources are under massive pressure everywhere, calling for the development of efficient 'allocation and usage' criteria by urban management practitioners. The need for maintaining good lines of communication with members of society and organized economic sectors is also important. While it is obvious that the interests of these urban stakeholders have to be taken into proper consideration, the broader interests of society as a whole need to be respected in the short and, above all, the longer term, with due attention paid to the relevant strategic planning processes;
- (g) increased community participation demanding a higher level of transparency on the part of the public authorities. Communities have begun to protect their own interests at the neighborhood and city block level by employing direct action, as well as through indirect pressure exerted by social organizations. Communities have also expanded the scope of their activities and are currently in a better position to influence, for example, master plans and other urban planning laws at the initial stages. It is also worth mentioning that professional and corporate associations are increasingly involved in pressuring local authorities to undertake appropriate action. The latter, for their part, are increasingly obliged to engage their interlocutors in sensible dialogue;
- (h) increasing involvement by the private sector through concessions and permits which call for complex bidding, tendering, contracting, control and remuneration systems. The so-called Public Private Partnerships (PPPs) currently provide new opportunities for service provision and the sharing of responsibility between public-sector and private bodies;
- (i) the growing need for the processes and products developed and used in cities to comply with environmental requirements. These requirements, apart from conforming to new compulsory environmental legislation, are also the outcome of a series of social demands presented by NGOs, community groups and by the many proactive voluntary approaches by private service delivery organizations. Also on the environmental level, it is worth noting the increasing inroads made by systems that govern the rational use of water and energy contributing to reducing global warming. In this aspect it is important to register the importance of the urban transportation as one of the main responsible for the environmental problems which affect contemporary cities.

A further crucial challenge exists in many developing countries: problems arising from the contiguity of conventional, "formal" cities with "clandestine", "informal" cities. Given their size, the latter - consisting mainly of *favelas* (slums) and irregular subdivisions - can no longer be considered as illegal settlements, mainly on account of their large size. According to Benevolo (2006), past attempts to suppress the informal areas of cities (replacing them with planned developments and/or relocating the inhabitants) have met with limited success. It is now generally accepted that in the longer term the best way to approach this situation is to introduce incremental improvements and to stabilize the original irregular land occupations by introducing basic infrastructure and services to the poorer areas in question.

In Brazil this approach is perhaps best illustrated by the slum upgrading ('urbanization of favelas') initiatives that are being taken forward in the majority of our large cities. Moves are afoot to retain the resident populations in the already-occupied areas while improving living conditions by introducing better street layouts, eliminating risk areas, installing water supply and sewage/storm-water collection systems and electricity/telephone distribution networks, street-lighting etc. A range of other public services and complementary facilities such as income generation and post-works social monitoring programs have frequently gone hand in hand with public works in these problematic areas (Abiko, 2007). Some of the *favelas* have in fact become 'real' cities, in view of their enormous size and number of inhabitants (Marques (2007) has produced an interesting survey of "precarious settlements" in Brazil).

The *favela* upgrading developments have involved the participation of architects, lawyers, social workers, doctors and engineers, together with other professionals working in interdisciplinary teams. It is now obvious that in housing interventions of this nature the involvement of the *urban engineer*, possessing a clear understanding of systemic urban requirements and an ability to act accordingly, is paramount. The services of the urban engineer are vital not only at the project design, planning and execution level but also at the technical and 'social' levels - two specific areas of expertise that go beyond the traditional narrow confines of the qualified civil engineer's job description.

To conclude, it is clear that engineers with a broad, systemic approach rooted in the historic efforts of the pioneering urban engineers at the beginning of the last century, have an extremely important future role to play in our cities. Although the urban engineering pioneers labored in totally different circumstances a century ago they nevertheless continue to serve as examples of clear-sightedness and dedication in the quest for a better quality of life for the inhabitants of our cities.

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