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W107 - CONSTRUCTION IN DEVELOPING COUNTRIES

PAPERS AND POSTGRADUATE PAPERS FROM THE SPECIAL TRACK

The aim of this Commission is to study and effectively disseminate the possible ways and means by which the construction industry of developing countries can be continuously improved to enable them to fulfil the tasks required of them in the nations' drive to achieve social and economic progress. The objectives of the Commission include: to undertake research into areas relating to the construction industry in developing countries, in order to understand its nature, strengths, weaknesses and needs and possible improvement measures, to disseminate useful research findings and best practices and monitor and facilitate their implementation, to provide a forum for the exchange of experiences and information among construction researchers and administrators in developing countries and to serve as a link between construction researchers and administrators in developing countries and their counterparts in industrialised countries, as well as international agencies involved in the field of construction industry development.
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Initiatives to Reduce Labour Informality in Construction in Brazil

Abiko, A.
1-2 Escola Politécnica, University of São Paulo
(email: alex.abiko@poli.usp.br)

Pereira, P.M.S.
1-2 Escola Politécnica, University of São Paulo
(email: santiago.pereira@poli.usp.br)

Abstract

The construction industry plays an important role in the economy of developing countries such as Brazil. Given that it generates a substantial number of jobs the industry is also of major social importance. A 2007 survey revealed however that 71% of the people engaged in construction in Brazil are informal workers. This percentage is only surpassed by those employed in farming and agriculture (90%), personal services (79%) and as domestic servants (72%). Job informality presupposes among other things a lack of adequate protection in terms of social welfare benefits, retirement pensions and paid holidays as well as exposing workers to precarious health and safety conditions. This paper discusses whether a need exists to bring the informal labour in the construction industry into the mainstream economy and explores the possibility of introducing and implementing more proactive public policies in this respect. The paper is divided into two main sections: (i) a description of informal working in the construction sector in Brazil in qualitative and quantitative terms; and (ii) a discussion on the impact of a number of government programs and other initiatives which seek to contribute to reducing the scale of informality in Brazil.

Keywords: informality, construction industry, labour, Brazil
1. Construction and informality

The construction industry plays an important role in the economy of developing countries such as Brazil. Given that it generates a substantial number of jobs this industry is also of major social importance. However the existent labour informality impacts in a negative way this construction sector because it is considered as one of the main obstacles of the improvement of its quality, the increase of its productivity and the introduction of technological innovations.

The change in this situation is fundamental to the sustainable development process of the country and this paper discusses whether a need exists to bring the informal labour sector in the construction industry into the mainstream economy and explores the possibility of introducing and implementing more proactive public policies in this respect.

It is believed that as the Brazilian situation is quite similar to other developing and emergent countries this paper could contribute to understand aspects of the informality and discuss some initiatives to reduce them.

According to the 2007 Annual Construction Industry Survey (PAIC), conducted by the Brazilian Institute of Geography and Statistics (IBGE), the Brazilian construction sector is composed of 110,000 firms and 1.8 million workers (IBGE, 2007a). This universe consists predominantly of small firms, with 71.9% of them employing between one and four workers and 20.6% of them employing between 5 and 29 workers. According to the National Economic Activities Register (CNAE), the construction sector comprises three main divisions subdivided into nine groups, as follows (IBGE, 2007b):

- Buildings construction, with 51% of the firms involved in constructing buildings and real estate developments;

- Infrastructure development, with 14% of construction firms engaged in building roads, railways, urban civic and structural works as well as electricity, telecommunications, water, sewage and pipeline and other infrastructure works;

- Specialist building services involving 35% of the firms in demolition, site preparation, electric, hydraulic and other installations, finishing and other specialised building services.

According to the IBGE (2007c) Central Business Register, 2.65% of all Brazilian companies in 2007 were construction firms and according to the National Household Sample Survey (PNAD) carried out by IBGE in 2007, the construction sector in Brazil employs 6,107,000 workers, accounting for 6.73% of the country's total workforce of 90,786,000, out of an estimated population of around 184 million (IBGE, 2007d). Given that the people identified by the PAIC as working in the construction area were formal workers, the difference between the PNAD and PAIC figures (4,295,000) means that 70.3% of the total are effectively so-called informal workers.
Informality in the present article is understood as argued by Cacciamali (2000), by two different categories of workers: unregistered wage-earners and self-employed workers.

It is important to highlight the heterogeneous nature of the ‘self-employed’ category of workers, which includes workers engaged in an array of different activities who access employment opportunities in a variety of different ways and, among them, manifest a very substantial degree of economic inequality. In the specific case of the construction sector, autonomous, self-employed workers undertake a variety of tasks particularly in the area focused on small buildings and improvement/repair works. "In general, this class of workers remains outside the formal jobs market, dealing directly with consumers/property owners and possessing no properly formalised employment arrangement or link with these consumers. It follows that the social contributions by these workers would need to be made directly to the State in order to ensure that they have access to sickness and length of service/length of contribution retirement benefits, as well as proper accident insurance (DIESE, 2006)."

Based on microdata obtained from the PNAD series, Kon (2002) describes the profile of self-employed workers according to their types of occupations: liberal professionals; others working in a management capacity; qualified workers, semi-qualified and unqualified workers.

Hirata and Machado (2007) attempt to classify different types of work with the aim of narrowing down, at least theoretically, the commonly accepted occupational categories within this group of self-employed workers. According to these authors, one formal sector and three informal sectors can be identified:

- 1st category: employers, wage earners possessing a CTPS (regular official personal work document - carteira de trabalho - issued by MTE, the Ministry of Labour, and signed/updated by the employer), and groups of self-employed workers who are specifically qualified (liberal professionals);
- 2nd category: domestic service;
- 3rd category: self-employed workers with no specific qualifications and working for ‘small’ employers;
- 4th category: all workers without an up to date CTPS, employed in any type of firm.

In the study undertaken by FGV Projetos (2006), informal construction firms are engaged in three main branches of activity. These activities are normally classified as building or ‘finishing’ works which can be categorised either by the end-purpose of the works or by the person or persons contracting such services:

- Works involving maintenance and repairs to buildings wholly carried out on existing properties;
• Construction and repair/rehabilitation of buildings which includes "self-help building". The latter involves contracting autonomous workers who are in general self-employed bricklayers (pedreiros) or small informal developers building residential properties for sale;

• Other informal works which include a further category of self-help building (undertaken by families themselves) and building or repair works subcontracted by formal construction firms. Normally the latter involves outsourcing to informal labour.

According to Kuhn (2007) "the smaller the building in terms of square metres the less likelihood of the existence of formal registration of workers in terms of contractual linkages".

It is not however possible, on the basis of available research, to distinguish the different types of self-employed professionals working in civil construction. The Monthly Employment Survey (PME), conducted by IBGE in six major metropolitan regions did however succeed in identifying (in March 2008) groups of pedreiros working on a self-employed basis (IBGE, 2008). These represented 15.9% of the total of self-employed workers (in other words a fairly high percentage).

To analyse informality in the civil construction sector in Brazil it is used as parameters the data produced by the PNAD survey and a selection of data from the PME, both undertaken by IBGE.

An analysis of the PNAD data for 2007 reveals that of all the people working in the construction sector only 32.57% contributed to the social protection system run by the Pensions and Social Security and Institute. According to the IBGE Synthesis of Indicators, the three largest categories of workers in percentage terms which fail to pay social protection contributions consist of people working in those occupations which "traditionally employ the largest numbers of self-employed workers" - agriculture (84.58%), domestic service (69.55%) and construction (67.43%). (IBGE, 2007e).

A survey conducted by Farrel (2004) reveals quite similar figures: 71% of the labour force in Brazil's construction industry is informal, a number only exceeded by people working informally in farming and agriculture (90%), the personal services sector (79%) and in domestic service (72%). This survey used the non-payment of social security contributions as an measure of informality.

If we consider as informal workers those employees without signed work papers plus self-employed workers, the total of informal workers in the construction sector amounts to 4,123,000. In other words, 67.5% of all the people working in the construction industry in Brazil are ‘informal’ workers, although some of these could well be actually working in or for formal firms. Although our calculation methodology is different, these figures nevertheless come close to those presented above.

The PME for 2008 shows that among the self-employed workers, those working as pedreiros and salespersons predominate, given their majority involvement in activities related to the construction industry (17.4%) and commerce (28%).
In March 2008, again according to the PME survey, 4.1 million self-employed workers were active in the six metropolitan regions surveyed (Belo Horizonte, Porto Alegre, Recife, Rio de Janeiro, Salvador and São Paulo), of which 1.6 million were employed in the construction sector. Of these, 15.9% were self-employed pedreiros.

Almost all the pedreiros in the above cities were men (99.6%), mainly in the age range from 35 to 49 years. With regard to race or colour, the vast majority of workers were either black or mestizo and, as far as educational levels were concerned, 63.5% of those self-employed in the construction sector had failed to finish primary school education.

With regard to pensions and social security contributions, the survey revealed that 9.4% of the self-employed workers contributed (i.e. 90.6% did not).

Different authors have argued that in general both casual and informal employment is "to a great extent unstable, badly paid, lacking career prospects, socially undervalued and involving people with few or no social rights" (AZEVEDO, 2009). Azevedo has drawn attention to the fact that "the consequences of the different types of contractual arrangements for labour in the construction sector vary greatly depending on the skills possessed by the professionals themselves" but that even among adequately remunerated qualified workers "being able to gain access to the benefits provided under Brazilian Labour legislation is an important aspect and makes a significant difference in their standard of living".

The participants at the first meeting of CIB Task Group 29 (now Work Commission 107), Construction in Developing Countries held in Tanzania in 1998 summarized all the above concepts by defining the informal sector of the construction industry as: “unregulated and unprotected individuals and enterprises engaged in economic activities in construction, including the supply of labor and production of building materials and components for both the formal construction sector and directly in response to client needs” (WELLS, 2007).

2. Policies on reduction of informality in construction

Federal public policies seeking to reduce informality can be grouped under three main headings (MTE, 2002; OLÍMPIA, ROLIM, 2000): (a) policies targeted at increasing the number of jobs, at generating income and at re-employing workers who have lost their jobs due to structural changes; (b) policies designed to enforce compliance with legislation and ensure that arrangements between employer and employee are formalised; and (c) measures aimed at bringing labour legislation up to date.

With regard to the policies for increasing the number of jobs, enhancing income generation and bringing back into the employment market workers who have lost their jobs because of structural changes, a programme known as Credit for the Development and Generation of Employment and Income, is aimed at “encouraging the social and economic development of the country through the democratisation of productive credit for generating jobs, work and income”. The target public for this
program consists of micro and small enterprises, workers’ associations and co-operatives, liberal professionals, small entrepreneurs, firms working in priority sectors determined by government development policies, in local manufacturing initiatives or in labour-intensive sectors. One of the initiatives pursued under this programme was Credit for Promoting Civil Construction (MTE, 2009).

Another program is known as the Social and Professional Qualification Programme which aims to "promote social and professional upgradation, provide initial and ongoing training and undertake a series of integrated actions aimed at providing professional guidance and certification in tandem with insertion of individuals into the world of work, actions to improve educational levels and socio-economic and environmental development initiatives, as part of the effort to construct a national public professional training system involving initiatives by the public authorities to bolster employment, working conditions and workers' incomes". The latter has as its target both males and female workers, the unemployed and those at risk of losing their jobs, with emphasis on the most vulnerable sectors of the population (MTE, 2009). This program encompasses three different initiatives: (i) the Territorial Qualification Plans (PlanTeQs) involving states and municipalities with over 300,000 inhabitants; (ii) the Special Qualification Projects (ProEsQs); and, finally, (iii) the Sectoral Qualification Plans (PlanSeQs), focused on social actors in a specific area of the country.

As foreseen by IPEA (2006) some, albeit slow, progress can already be detected in the context of the national system, where tentative discussions have begun to take place focused on increasing the scope and application of public employment and income policies: "The credit, labour force recruitment, professional qualification enhancement programs (jobs and income generation programmes) have been widely accepted by workers who have no contractual or other links with the formal job market".

As for the policies designed to enforce compliance with current legislation and to formalise current informal contractual arrangements, Simão (2009), in her study on the impact of the surveillance and enforcement of labour laws between 1999 and 2007 on labour formalisation in Brazil, concluded that the efforts of the MTE, Ministry of Labour, had produced a number of positive effects on employment generation, leading to a significant increase in the number of registered workers both in absolute and relative terms. According to this author "the steps taken to ensure compliance with the rules has generated an increase in formal jobs of approximately 11.3% in agriculture, 7.4% in the construction sector, 5.9% in industry, 4.6% in the commercial sector and 4.25% in the services sector", and, significantly, "the results show that closer inspection has produced more substantial outcomes in the agricultural and construction sectors, both of which have been traditionally more vulnerable to precarious contractual arrangements".

With regard to the measures for modernising Brazil's labour legislation, Pastore (2000) states that in terms of increased formalisation of employer-employee contracts, Brazil has taken two significant steps which have resulted in firms saving 19% on the usual costs involved in contracting formal labour: the Simples contract and the Time-bound contract.

Other measures that have been adopted include the introduction of a simple dispute resolution device, Mesa de Entendimento, whereby the employer is committed to solving possible problems arising from
non-compliance with the rules, as well as with Law No. 9.958/2000 establishing the Prior Conciliation Commission (Simão, 2009).

With a view to further promoting formality in the labour market and enhancing its attractions for different categories of professionals, including those working in the construction sector such as electricians, plumbers, painters etc, Complementary Law No. 128 of 2008 (Individual Microentrepreneurs) is designed to facilitate the legalisation of self-employed workers with a turnover of up to US$ 21,200 per annum, by introducing a monthly payment by these of US$ 34 to the National Social Security Institute (INSS), of the Tax on Goods Circulation and Services Provision (ICMS) and of the Tax on Services (ISS) when these are due. In return, such people are exempted from all other taxes and contributions and, furthermore, they are given rightful access to a series of legally established benefits including a CNPJ number (National Cadastre of Legal Firms) and authorisation to issue regular invoices, Notas Fiscais.

Other authors present wider systemic suggestions for combating informality, which are shared by the International Labour Organisation in its publication Cities at Work. The latter argues that reducing informality calls for efforts on several fronts simultaneously, focused on local and sectorial issues which need addressing under an all-encompassing joint strategy (ILO, 2004). Néri (2005) points out that surveys have shown that one of the main problems faced by small builders is the shortage of clients. This is one of the reasons, he claims, why introducing supply policies such as microcredit, technical assistance and training leaves much to be desired, given that the market is too small to absorb the products and services on offer in this sector. Néri goes on to argue that the main requirement is therefore for policies targeted at increasing demand. The same author (in 2007), examining the profile of informality vis-à-vis the social protection area, proposes two types of measures for reducing informality: firstly, by making structural modifications to the personal contributions incentives system by modifying the relevant legislation; and, secondly, by introducing a series of operational initiatives (publicity, media exposure, mobile information/consultation units etc).

Finally, Kunh (2007), in his study of informal labour relations in the construction sector in the municipality of Cascavel, seeks to identify on the basis of his survey of developers, construction companies, property owners and workers, exactly who is responsible for reducing or combating informality in the sector. According to the interviewers, this responsibility falls primarily to the public federal, state and municipal authorities and secondly to the workers' trade unions or associations. Moreover, according to the interviewees, intermediate responsibility should be shouldered by the Ministry of Labour, developers, unions/labour associations, professionals and technical staff working in the construction sector and also by the workers themselves. In the final analysis, changes in the situation are seen to be (according to this sample) fundamentally the responsibility of society as a whole, with much depending on the approach and performance of individual firms.

Kunh’s survey revealed that according to the workers themselves the trade unions should draw more attention to the advantages and benefits of formal employment, as well as to the risk of work accidents. Meanwhile, the developers suggested that different government bodies should act to prevent informality by reducing taxes and other charges (leading to overall cost reductions), insisting on better professional qualifications and ensuring that all building companies, developers and related
practitioners should place a greater value on the formal registration of their workers. The construction firms suggested that the government should change the pertinent laws and reduce taxes, that construction professionals should take action to combat informality and that the workers’ trade unions should do more on their part. The commissioning owners believe that the workers’ trade unions should devote more effort to assisting, representing and defending the cause of employees, that the government should insist on compliance with the law and work towards reducing the tax burden, that the Ministry of Labour should inspect civil works more thoroughly and that the engineers and technical staff signing off projects and attendant documentation should also regularly visit and inspect works on site.

3. Conclusions

The construction industry in Brazil, particularly the home building segment, has experienced promising growth in recent years. Investment in the housing sector will, according to some forecasts, be boosted from the current US$ 97.2 billion to US$ 262.7 billion by 2030 (Ernst & Young, 2008).

Ensuring that growth in this sector occurs in a sustainable and wholesome manner, a number of issues need to be resolved or at least addressed regarding urban policies, the provision of appropriate infrastructure, improvements in the management capacities of public and private institutions, as well as questions related to the labour force at all different levels - from engineers to common labourers.

One of the concrete contributions made by the International Labour Organisation has been the Action Plan for the Construction Sector in Brazil based on a participatory process involving government, employers and workers alike (ILO, 2005).

Three main lines of action were suggested in this document with a view to improving the guidelines related to "decent working conditions": (a) health and safety at work; (b) formalisation of informal labour and generation of employment; and (c) professional training. One of the steps recommended for formalising informal labour was to institutionalise the Home Builder and Small Specialised Building Firms. Another was to provide support for institutions engaged in developing production activities in a cooperative framework, testing a method for generating employment and formalising informal labour on the basis of ‘community contracts’.

It is clear from the above that combating informality is a key step in the direction of promoting a "decent working conditions" agenda based on four strategic pillars: (a) to bolster employment opportunities for salaried and self-employed workers; (b) to ensure social protection for workers; (c) to respect the fundamental rights and principles of workers; and (d) to engage in social dialogue. This is an important agenda for a modern world where a billion people suffer from unemployment and underemployment and where the masses of poor people and the gap between rich and poor continue to grow.

Wells (2007) argues that labour force informality in the construction sector is only one of the informality-related aspects of the sector. Other problems to be tackled include the informality
practiced by and within the construction companies themselves, informality in the organisation of
construction processes and informality with regard to the end-products of this process. All these
aspects are obviously interrelated, but it is vital to explore each of them in order to be in a position to
take the best action possible to ensure that the construction sector can genuinely contribute towards
the country’s sustainable development.

The Brazilian government's present posture with regard to the construction sector is to provide
incentives for development by financing public sanitation and other infrastructure works and by
facilitating the supply of housing credit. Despite these efforts we believe that reducing and combating
informality in the construction sector as a whole, and especially with regards to the labour force, is
essential, while at the same time opportunities need to be generated aimed at improving the
professional qualifications and skills of the many workers involved in this important sector of the
economy.

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Construction Waste Management in Newly Industrialized Countries

Manowong, E.
Civil Engineering Department, Bremen University of Applied Sciences, Bremen, Germany
(email: emanowong@ext.hs-bremen.de)

Brockmann, C.
Civil Engineering Department, Bremen University of Applied Sciences, Bremen, Germany
(email: Christian.Brockmann@hs-bremen.de)

Abstract

Newly industrialized countries are in transition towards the stage of advanced industrialized countries. The dynamic of this process leads to a change of institutions. Institutions can be understood as social structures with a high degree of resilience and they rest on the three pillars of regulations, norms and culture (Scott, 2001). New Institutional Theory can provide a framework of analysis for the problem of construction waste. Millions of tons of waste from construction and demolition (C&D) activities are generated every year. Problems related to C&D waste are being faced in least developed, newly industrialized, and advanced industrialized countries but the problems are handled within different institutional frameworks. Literature and data on C&D waste management in advanced industrialized countries are abundant; however, this is not the case for newly industrialized countries such as Thailand. A field study on C&D waste management in Thailand based on site observations, questionnaire surveys, and interviews provides data for an institutional analysis while a review of the existing literature on other least developed and new industrialized countries allows broadening the analysis. While urbanization in newly industrialized countries accelerates with great speed, the institutions of C&D waste management are developing at a slower rate. They are lagging behind in comparison with the status in advanced industrialized countries. Findings and lessons learned are expected to contribute to raising awareness and willingness for a change of institutions among policy-makers, developers, and key construction stakeholders at the national level in Thailand and internationally among those of developing and newly industrialized countries.

Keywords: newly industrialized countries, new institutional theory, construction, waste management, Thailand
1. Introduction

Institutional theory has expanded from a formative stage in the works of Marx, Weber, and Veblen to what is called today New Institutional Theory (Selznick, 1948; Powell and Dimaggio, 1991; Scott, 2001). It can be used for the analysis of society as well as economics. As C&D waste management is both, a societal and an economic problem, New Institutional Theory provides a promising framework. Therefore, the three institutional pillars of regulations, norms, and culture (Scott 2001) are categories of our analysis.

According to the per capita gross national income, countries can be differentiated into least developed (LDC, or low income countries), newly industrialized (NIC, or middle income countries), and advanced industrialized countries (AIC, or high income countries). The transition from LDC to NIC is especially marked by a move from an agrarian to an industrializing economy; the one from NIC to AIC is typified by a further industrialization and a widening of the service sector (World Bank, 2003). The changes are accompanied by an institutional development as the old institutions are no longer adapted to the environment.

Thailand is a NIC with high economic growth in the past and a rapid urbanization. There is a host of environmental problems connected to C&D waste management. A lack of landfills leads for example to dumping in public areas, causing environmental problems to the local communities. Research on and implementation of C&D waste management are rather new issues in Thailand. Thus, data were gathered on the status quo within the construction industry in different regions of Thailand. Then, the available literature on C&D waste management practices in other NICs was also studied. A comparative analysis allowed us to identify obstacles, potentials and opportunities for future improvement and implementation of sustainable C&D waste management for Thailand as well as other newly developed countries.

2. C&D waste management problems and practices

2.1 Global economic and environmental problems

The construction industry is globally among the main consumers of energy and resources. Excessive use of natural resources and a large amount of C&D waste are a result of a lack of awareness of resource-efficient construction practices (UNEP, 2002). The methods of Reduce, Reuse, and Recycle (3Rs) are widely applied for municipal waste management but less practiced in the construction industry. One of the reasons is that recycling building materials is not cost-effective (Wong and Yip, 2004). There is a lack of market demand for some types of construction waste such as concrete and broken bricks (Duran et al., 2006). Previous research on C&D waste has mainly focused on the types of wastes, management processes, and technologies. The institutional development (e.g. willingness to change attitudes and behaviour pertaining to waste generation, collection, and disposal) has been less researched. There is a need to investigate the construction project stakeholders’ attitude and percep-
tion reflecting their actual needs, behaviour, and decision making regarding waste handling (Kulatunga et al., 2006).

### 2.2 Newly and advanced industrialized countries

Advanced institutions of C&D waste management have been implemented in AICs such as Australia, Denmark, Germany, the Netherlands, the UK, and the USA. In these countries, acceptance of recycled materials is driven by scarcity of landfill sites and natural resources (Addis, 2006). Issues of waste recycling are well covered by established policies, legislations, directives, and waste management strategies. Construction stakeholders have been widely involved in the process by government agencies such as the “Kreislaufwirtschaft” (Recycle) scheme in Germany, the Department for Business, Enterprise and Regulatory Reform (BERR) in the UK, and the US Green Building Council’s Leadership in Energy and Environmental Design (Weisleder and Nasseri, 2006). Such initiatives aim to help the construction industry in delivering more sustainable construction methods and products with improved resource efficiency, overall effectiveness, and social responsibility (BERR, 2008). In Asia, AICs such as Japan, Hong Kong, and Singapore are well equipped with advanced C&D waste management practices. In such countries, there exist not only specific regulations and norms for C&D waste management but also extensive research on C&D waste management is available.

Asian NICs such as China, India, Indonesia, Malaysia, Sri Lanka, and Thailand, as well as NICs in Africa and South America, are still in need of institutional development for C&D waste management. Generally in Asia, national and regional policies, laws, and regulations governing 3R principles for C&D waste are rare and the 3R program is rather spearheaded by relevant international organizations (Nitivattananon and Borongan, 2007). Examples are the Asian Development Bank (ADB), the Canadian International Development Agency (CIDA), and the German Gesellschaft für Technische Zusammenarbeit (GTZ, Technical Cooperation Agency) who work in cooperation with different Asian governments.

### 2.3 The example of Thailand

Thailand has been experiencing high economic growth which has lead to rapid urbanization and an increased demand of real estate and infrastructure development. In consequence, large amounts of waste have been generated from construction activities. Similarly to other NICs with transition economies, Thailand has just begun to broadly study and promote C&D waste management (PCD, 2007). As such, there does not exist a widely published body of academic research on C&D waste management in Thailand. Recently, Kofoworola and Gheewala (2009) attempted to estimate the C&D waste generation in Thailand and emphasized benefits of C&D waste recycling in terms of job creation and energy savings.
3. Objectives, methods of study and analysis

This study aims to examine current C&D waste management practices in Thailand in order to produce an output that is useful for the country’s regulatory and normative framework for C&D waste management in the future. As stakeholders’ inputs are crucial, norms, attitudes and perceptions of Thai construction stakeholders were studied, and so were regulatory initiatives from the private sector and the government. Furthermore, the study also builds upon experiences from different NICs in order to broaden knowledge of C&D waste management approaches.

The field study was carried out in 2008. Construction projects of various sizes (small, medium, and large) in various regions of Thailand were selected for the study attempting to generally reflect the C&D waste situation within the country. There were nine projects from the Bangkok metropolitan and peripheral provinces, ten projects from the north, three projects from the north-east, and twelve projects from the south of the country. Data were collected via site observations, questionnaire surveys and interviews. General statistics were applied for data analysis. Then, practices in other NICs were studied by means of a literature review and qualitative analysis. The status quo is evaluated based on the following aspects:

1. Construction waste quantification and classification.
2. Regulatory institutions for C&D waste management
3. Normative institutions for C&D waste management
4. Construction waste recyclability and resource recovery

4. Results and findings

4.1 C&D waste quantification and classification in Thailand

There were in total 384 respondents directly or indirectly involved with construction projects and/or affected by such projects. They are project participants (e.g. project owner, managers, designers, site engineers, foremen, workers; 43.7%), government officials (24.3%), people from the local community (living or working near construction sites; 31.0%), and waste recycling companies (1.0%). The survey results reveal that the largest amount of waste was generated during the construction stage (67.6%) compared to other stages such as material transportation and preparation (14.2%), and design (9.7%). Figure 1 shows the amount of waste of different construction materials produced on-site as well as the preferred waste handling method. Materials such as concrete and bricks were largely dumped to landfill sites because they were considered as difficult to recycle or reuse. Only metal, wood, paper, and plastic were more often recycled than sent to landfills.

Especially on small scale projects, C&D waste is not segregated so that broken bricks and tiles, cement, plastering, cement bags, packaging and other rubbish are mixed together and then sent for landfilling. Hence, improper handling on construction sites and material yards (cf. fig. 2) is considered as
one of the major causes that made large volumes of waste material not reusable or recyclable as they were mixed and as their quality was considerably reduced. The variation in composition of C&D waste in Thailand is high. As a result, such materials cannot be reused in construction. The construction firms segregate only immediately reusable and recyclable C&D debris such as steel and wooden frames. The rest of C&D waste such as concrete debris, bricks and cut-off piles are mixed with other types of waste and disposed as fill material.

Figure 1: Construction site waste profile and management in Thailand

Figure 2: Mixed and improper store of C&D waste
57% of the respondents knew of related C&D waste management regulations in their localities. Some of the construction contractors had already initiated their own waste management processes such as keeping C&D waste in separated storage areas and transporting C&D waste to landfills. However, a considerable percentage of the respondents (26.6%) were unaware of any regulations on C&D waste management, or they even indicated that there were no such regulations (16.4%). In fact, Thailand has no regulations specifically pertaining to the management of C&D waste. The available environmental protection laws are applied as fundamental guidelines for waste handling, transportation, and disposal. Besides, the unclear regulatory situation of C&D waste management has lead to uncertainty of local government officials with regard to their role. They are not sure who should be responsible for dealing with C&D waste.

4.3 C&D waste norms of Thai construction stakeholders

The respondents indicated that the best way to manage construction waste is to “Recycle” (44.2%), followed by “Landfill” (34%), “Reduce” (9.6%), “Reuse” (8.3%), and other options (3.9%) respectively (cf. fig. 3). As a norm, recycling construction waste is a highly acceptable option. It was emphasized that selection of the C&D waste management alternatives depends on types of construction waste generated from construction activities. There is no significant statistical difference (Chi-Square Test; Sig. = 0.836) between gender. However, it was found that more women clearly prefer recycling to landfilling while men’s opinions on these two options did not much differ. This implies that, in Thailand, women may be more responsive to recycling regulations.

Figure 3: Respondents’ preference on C&D waste management options
The construction stakeholders’ norms were further investigated regarding obstacles to and limitation of construction waste management in Thailand. While the norms show a preference for recycling, the 3Rs are hardly practiced because it is difficult to change the people’s behaviour and because the process is regarded as being costly. Project owners rank “profit” as the most important factor while rating “waste management” as the least important. Any additional investment leading to a reduction of profits is not favoured. In sum, implementing 3Rs is valued only as long as there is no financial trade-off involved. Recycled construction products are not popular for consumers in Thailand. However, other factors promote implementation of C&D waste management such as “health and safety”, “social and environmental impacts”, “quality of work”, “time management”, and “expenses” because they were overall ranked as important factors supporting more engagement in C&D waste management.

4.4 Construction waste recyclability and resource recovery

An additional study was carried out attempting to investigate potential energy savings in the studied projects through C&D waste management. This estimate is based on the approach proposed by Kofoworola and Gheewala (2009). By applying recent construction information provided by Thailand’s National Statistical Office (TNSO, 2009), it was found that the amount of Thailand’s construction waste generated in 2008, i.e. the period of this study, was estimated at 1.03 million tons. Assuming that construction waste previously sent for land filling would be recycled, total energy savings would have been about $57.4 \times 10^5$ GJ or 1,593 kWh per year. If all waste generated on-site would be recycled, the total amount of energy saving would increase to $127.9 \times 10^5$ GJ or 3,553 kWh per year. The total value of energy savings is approximately 5,300 millions Baht (106 millions Euros) per year.

4.5 Comparing C&D waste management practices in Thailand and other NICs countries

Results of C&D waste status and management practices in Thailand and other NICs from Asia are compiled and briefly compared (table 1) as well as from other countries (table 2). They are discussed in the next section.

5. Discussions and recommendations

In Thailand, some construction waste such as wood, plastic, paper and metal is used for recycling but a larger part such as concrete, cement, and bricks is sent to landfills because of lower cost and greater convenience. This is similarly found to be the case in other NICs. It is difficult to change such behaviour of construction operatives as long as it is not economically rewarded. This constitutes the most important obstacle for improving voluntary C&D waste management. As indicated by Kulatunga et al. (2006), attitudes and behaviour of construction operatives limits the extent of waste management. The additional cost of the process discourages recycling of C&D waste, as previously pointed out by Duran et al. (2006). All activities affecting economic interests face resistance. Hence, to encourage
recycling of C&D wastes, it is essential to promote economic incentives as a leading objective. Although salvaged materials are commonly reused, many consumers are little attracted to products made from recycled waste. Hence, the government agencies could take a lead in using more recycled products in the public construction projects.

Table 1: Comparison of C&D waste management status quo in NICs (Asia)

<table>
<thead>
<tr>
<th>Country</th>
<th>Classification</th>
<th>Quantification (tons/year)</th>
<th>Regulations</th>
<th>Norms</th>
<th>R&amp;D, Recyclability, Resource Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>No classification</td>
<td>18 millions in 2008 (Jones, 2007 and RIC, 2009)</td>
<td>No specific C&amp;D law, Environmental laws for construction projects (Chen et al., 2007), Strictly imposed on municipal projects (Jones, 2007)</td>
<td>Low awareness and willingness of contractors (Chen et al., 2007), Low public awareness (Chen et al., 2007)</td>
<td>Growing R&amp;D, extensive in Hong Kong, Many recycling facilities, Building houses from C&amp;D waste (Fan, 2009)</td>
</tr>
<tr>
<td>India</td>
<td>No classification</td>
<td>20 millions in 2003 (Joseph, 2007)</td>
<td>No specific C&amp;D law, Environmental laws for all large construction projects, Municipal rules require C&amp;D waste to be separately stored and disposed (Joseph, 2007)</td>
<td>Low awareness (Kumar, 2007), Growing trend of willingness for reuse &amp; recycle</td>
<td>Growing R&amp;D, Waste used as mixture of road construction material (Merchant, 2009), Solid waste &amp; energy recycling facility initiated (Joseph, 2007)</td>
</tr>
<tr>
<td>Malaysia</td>
<td>No classification</td>
<td>2 millions (Periathamby et al., 2009 and Begum et al, 2006)</td>
<td>No specific C&amp;D law, Reuse &amp; Recycle are promoted (Begum et al, 2006), Encouraged economic return policy (Begum et al, 2006)</td>
<td>Low awareness (Begum et al, 2006)</td>
<td>Growing R&amp;D supported by government, Currently focused on waste minimization through economic incentives (Begum et al, 2007)</td>
</tr>
<tr>
<td>Sri Lanka (Lower Middle Income)</td>
<td>No classification</td>
<td>No data</td>
<td>No specific C&amp;D law (COWAM, 2004), Environmental law and waste regulations available but devoid of penalty/incentive (COWAM, 2004)</td>
<td>Moderate to high awareness, Low willingness, less priority given (Kulatunga et al., 2006)</td>
<td>R&amp;D assisted by foreign supports (COWAM, 2004), Concrete waste not recycled (COWAM, 2004), Reuse/Recycle industry newly emerged, with high demand</td>
</tr>
<tr>
<td>Thailand</td>
<td>No classification</td>
<td>1 million (field study in 2008)</td>
<td>No specific C&amp;D law, Investigation on reuse &amp; recycle of disaster debris was initiated (Nativattananon and Borongan, 2007)</td>
<td>Moderate to high awareness, Low willingness</td>
<td>Beginning R&amp;D</td>
</tr>
<tr>
<td>Vietnam (Low Income)</td>
<td>No classification</td>
<td>1 million (VEM, 2004)</td>
<td>No specific C&amp;D law, Little environmental liability of waste producers (VEM, 2004)</td>
<td>Low awareness and willingness</td>
<td>R&amp;D focused only on hazardous waste</td>
</tr>
</tbody>
</table>

Table 2: Comparison of C&D waste management status quo in NICs (world)
One common problem of C&D waste management in NICs is a lack of official records of C&D waste. Regarding the institutional initiatives, there are no regulations specifically dealing with C&D waste management in Thailand. Most regulations are related to environmental protection laws, and the situation is similar for majority of other NICs. At the same time, research and development on waste management or recycled products as construction materials are also key factors to reflect a country’s intention to achieve the goal of sustainable construction. Some NICs are already more active on C&D waste research, supported by government and the construction industry. It is, however, not necessary to manage C&D waste with high technology and expensive recycling facilities. As practiced in India
(Merchant, 2009), it has been proved that use of recycled materials in basic infrastructure construction can be economical.

It is therefore recommended that NICs with limited financial resources should combine C&D waste management initiatives with the countries’ basic requirements for economic development, while improving environmental protection and social welfare. To achieve such goals, specific challenges have to be overcome: (1) Positive change of the norms of construction stakeholders with regard to C&D waste management. (2) Establishing of waste classification systems with quantification of waste. (3) Waste reduction. (4) Integration of recycling and national energy savings programs. (5) Extended research on C&D waste recyclability and its implementation, with support from public and private sectors to provide broader alternatives for handling C&D waste. (6) Establishment and enforcement of specific regulations. Although they are not motivating factors to improve C&D waste management practices, they are essential starters and drivers to achieve the goal of sustainable construction in NICs.

6. Conclusion

C&D waste in NICs usually is a result of their rapid economic growth and urbanization. Many governments of NICs are lacking institutions for C&D waste management. Although waste reuse and recycling are practiced, this applies only to some kinds of waste such as steel, paper, wood, and plastic. Inert waste such as concrete and bricks are not recycled in most NICs, including Thailand. On the other hand, possible energy savings in Thailand could range from $57.4 \times 10^5$ GJ or 1,593 kWh to $127.9 \times 10^5$ GJ or 3,553 kWh per year. As real estate and infrastructure development in NICs continues to expand, C&D waste generation is likely to increase further. Sustainable construction in NICs can be achieved through effective utilization of resources in construction, material recovery, an improved system for C&D waste management, and energy savings. In the case of Thailand and other NICs, low-cost management strategies and tactics are possible and should be primarily considered. However, the first objective to be achieved is a change of the stakeholders’ norms. To drive towards the goal of sustainable construction in NICs, strong regulatory initiatives such as specific laws and policies for C&D waste management are as important as the stakeholders’ awareness and willingness to participate.

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Analysis of System Development of China’s Construction Market in the Thirties Years of Reform and Opening-Up

Wang, Y.
Harbin Institute of Technology
(email: ywwanghit@vip.163.com)

Abstract

China’s construction industry has been through tremendous change since the past thirty years. The main process of reform and development of construction industry in China in the past thirty years was reviewed. The development process was divided into three stages. The development characteristics and achievements in each stage were summarized. The development situation was analyzed from six aspects: size of the construction market, construction team, market effects, market structure, market management system and market access system. Several suggestions were put forward for China’s construction industry to develop better and faster in the future.

Keywords: construction market, reform, market size, market structure, China
1. Introduction

China has been focused on the central task of economic construction since the thirties years of reform and opening-up. China’s national power has reached a new level and urban and rural appearance has been through tremendous change. The Gross Domestic Product (GDP) has increased from 362.4 billion in 1978 to 30.067 trillion in 2008. The urbanization rate has increased from 17.9% in 1978 to 45.68% in 2008 (National Bureau of Statistics, 2009). With the development of the construction industry, the system of the construction market is gradually established and improved.

2. Development history of China’s construction market

2.1 The first stage: from 1978 to 1984

In the process of China’s reform and opening-up, the construction industry is developed fast and its productivity has a significant improvement. However, the related issues, such as supporting systems, personnel training, technological innovation, and laws and regulations for protection, are still less developed, which impedes the further development of the construction industry.

From 1978 to 1982, the national economy gradually returned to normal. The construction industry began to establish industrial teams with multi-section and multi-ownership co-existence and development. In the meantime, the construction industry separated enterprises from the government. The establishment of China State Construction Company in 1982 indicated the new development period of the construction industry. The number of construction companies was 61684, increased by 10.89% of that in 1981. The number of the employees was 11.54 million, increased by 11.63% from 1981 (National Bureau of Statistics, 2008a). From plan to market, bringing in planned commodity economy indicated that this socialist country initially formed its market. The early 80 coincided with the beginning of the reform, while economy was developing fast and the demand of construction was strong. From 1983 to 1984, the construction industry was on the right track and the construction market was initially formed. The value of construction industry in 1984 was increased by 25.1% from 1983.

On September 18th in 1984, the Provisional Regulation about the Issues of Reforming the Construction Industry and the Management System of the Infrastructure, released by the state council, specified the reform emphasis on the construction industry, which includes three parts: the compensation for the use of construction funds, lump sum investment in construction projects and construction contract bidding system. It has significance for the sake of shortening the project cycle, improving the project quality and reducing the project cost.

2.2 The second stage: from 1978 to 1984

Since from 1984 to 1988, the construction industry became overheated, the government began to rectify the construction industry. Only in 1988, there were more than 14400 capital projects stopped
or postponed. Over 44.2 billion RMB was compressed in the subsequent years. The milestone time was September 26th in 1988 when the Third Plenary Session of the 11th CPC Central Committee proposed that the next two years’ key point of reform and construction was the improvement of the economic environment and the rectification of the economic order. Improving the economic environment mainly means compressing the general social demand and restraining inflation. China began to impose regulatory taxes on the investment in fixed assets as the primary measure to adjust the investment structure. The differential taxation was implemented according to state’s industrial policy and projects’ economic scale. This tax system has been used until 2000.

Meanwhile, due to the situations of compress of the infrastructure investment scale, surplus construction team and lack of construction assignments had a lot of pressure on the state-owned construction enterprises. In this stage, the primary object for the construction industry was adjustment. Under the leading of the Ministry of Construction, many industry standards has been established since 1989. These industrial standards strengthened the control on the construction industry by the relevant departments and established the status of social supervision system in the construction industry.

During this stage, because of the decrease of state investment, many public infrastructure and industrial bases were ceased. However, with the improvement of people’s life and the deepening of housing system reform that from the mid 80s in 20th century, the corresponding demand of material culture increased, particularly in demand of the residential buildings. In that period, the primary demand in the construction market was the housing system reform, as well as the construction of the residential buildings and supporting facilities.

2.3 The third stage: from 1996 to now

Since 1995 when Construction Law has been promulgated, China has successively issued the Contract Law, Tendering and Bidding Law, etc. In the meantime, the impact of WTO accession and further in-depth economic reform makes the market level of the construction industry further improved and strengthens its competitiveness. During this period, the reaction of the construction industry was very active. The industry has great transformation through the introductions of bill of quantity, qualification registration and construction enterprises further reform. Since 2002, total output value of China’s construction industry has maintained a growth by over 20%. Until 2008, national construction enterprises (identified as general contractors or professional construction companies with qualification level, exclusive to labor subcontractors) completed 6203.68 billion RMB of construction industry output (National Bureau of Statistics, 2008a).
3. Analysis of development situation for China’s construction market

3.1 Extended Petri net Gradual expansion of the construction market scale

According to the statistics, during 1953 to 1978 China's total investment in infrastructure was 651.3 billion yuan. The number in 1978 is the largest which is up to 50 billion yuan. The number in 1979 is 52.3 billion yuan and 55.9 billion yuan in 1980 (National Bureau of Statistics, 2008b).

The construction investment grew rapidly when it was in the 80 years of the 20th century. The construction field completed the total fixed asset investment up to 2.77 trillion yuan which was beyond the aggregation of the previous 32 years from 1981 to 1990. There were 1109 large and medium size projects, 879 renovation projects and more than 90 million small-scale construction projects (National Bureau of Statistics, 2008a). It not only increased the productive capacity of various industries, but also increased the country's economy and overall strength directly. It made an important contribution to the first step strategic goal to realize China's socialist modernization.

The total fixed asset investment grew more rapidly in the 90 years of the 20th century. The total fixed asset investment firstly went up to 2 trillion yuan in 1995, and more than 3 trillion yuan in 2000. It was 6.37 trillion yuan in 8th-five-plan and 13.9 trillion yuan in 9th-five-plan. It got a total number of 20.27 trillion yuan of ten years in the whole 90 years of the 20th century. The growth of the total fixed asset investment can be described as overfly when it came in to the 21st century. The total fixed asset investment was 3.72 trillion yuan in 2001 and 4.35 trillion yuan in 2002. It was an increase of 16.9%. The total fixed asset investment in the 10th-five-plan was more than 25 trillion yuan. In 2008 the total fixed asset investment was 17.2291 trillion yuan. There was a year-on-year growth of 25.5%. It was about 345 times of the total investment in 1978 (FFA and CCIA, 2009a).

3.2 Increase of the construction teams

Since the reform and opening-up, especially after the mid-80s of last century, construction employment system reformed and the labor-layer employed a large number of migrant workers. According to the statistics of the national economic census in 2004, construction employee reached a number of 32.524 million which is about 4.3% of the employed population. The migrant workers were about 25 million and it was 77% of the construction employee. In accordance with this ratio to estimate, the population of the construction employee was 33.1495 million and migrant workers was 25.5251 million in 2008(FFA and CCIA, 2009b). Construction and construction labor export has become important source of the county's economic in some areas and farmers’ income growth.
3.3 Remarkable achievements of the construction market

In the aspect of project, there were 11.762 thousand projects completed and put into use and 99 large or medium-scale projects in 1978. In 1980 there were 24.823 thousand projects completed in which there were 82 large-or medium-scale projects. There were 44.477 thousand projects completed 121 large or medium-scale projects in 1985. In 1990 there were 36.502 thousand projects completed in which there were 152 large-or medium-scale projects (National Bureau of Statistics, 2008a).

In the 8th-five-plan (1991-1995), there were 243.735 thousand projects completed and put into use and 954 large or medium-scale projects. In the 9th-five-plan (1996-2000), there were another 254.796 thousand projects completed and there were 974 large or medium-scale projects. In 90 years of the 20th century, the total number of the projects completed was 498.525 thousand for ten years and large or medium-scale projects were 1928 (National Bureau of Statistics, 2008b). In the 10th-five-plan, infrastructure investment in basic industries is the most and developed fast. A large number of major infrastructure projects and key enterprises in the technological transformation projects completed and put into use. In those five years, China's new highway length came up to 35 million km, of which 24,000 kilometers were expressway. The additional handling capacity of port of 10000-ton reached 452.32 million tons (National Bureau of Statistics, 2009). The new railway got the mileage of 7063 kilometers. The project which played a significant role in promotion to long-term economic and social development put into operation one after another and was effective. Pipeline project which transport the natural gas from the west to the east achieved commercial operation. Qinghai-Tibet Railway Line has been laid. The Three Gorges project has progressed smoothly. The power station project has put 14 generating units into operation. It generated 94 billion KWh accumulated. The North Channel, Middle Channel and South Channel of electricity transmission from the west to the east formed capacity of more than 32.5 million kilowatts. At the end of 2005, generating capacity was more than 500 million kilowatts and it increased 180 million kilowatts compared with the end of 2000. Advances in industrial technology accelerated. Equipment manufacturing industry technology improved rapidly. High-tech industry developed fast.

The completion of these projects not only greatly enhanced China's economic strength, but also helped to meet the needs of people's production and living. It is of profound meaning.

3.4 Change of the construction structure

As a normal competitive field, China’s construction industry has earlier taken the innovation of privatization of strategic reorganization. Construction enterprises, especially those township's state-owned construction enterprises and construction team, carried out a bold reform of the privatization through mechanism innovation. Structural adjustment achieved a remarkable result. The reform of enterprise property has begun. At the beginning of reform and opening-up, construction belongs to the state-owned and township enterprises. After 1992, private construction enterprises developed rapidly. In terms of quantity, the extent of privatization in the construction industry has now reached a relatively high level. Private and other non-state-owned construction enterprises accounted for more than 80% of the total number of the enterprises. The ratio of reform enterprises was up to 99% in
Zhejiang and Neimenggu province and over 85% in Shandong, Hebei, Tianjin, Fujian and Ningxia. Property reform of construction enterprises has basically completed in Jiangsu through five years of hard work. The private construction company accounted for more than 90% in Zhejiang, Shandong, Hubei, Hunan, Neimenggu and Yunnan. The ratio in Liaoning, Fujian, Shanxi and Qinghai was beyond 85% (FFA and CCIA, 2009a). The number of listed companies was increasing continuously.

Under the push of ‘Nation back and Private forward’, the state-owned enterprise of construction conducted a three-level, two levels of reorganization. They optimized the industrial structure, improved efficiency and competitiveness of enterprises and established a standard of corporate governance structure. Some of them have become listed companies with a diversified capital structure. State-owned enterprises gradually withdraw from the original monopoly and released people's economic vitality and entrepreneurial spirit.

By 2008, the number of listed construction companies has been 31. These companies have achieved 622.115 billion yuan in 2008 (FFA and CC1A, 2009b).

3.5 Improvement of the construction market management system

China's construction industry put regulation system of comprehensive and professional into practice. The regulation of the government to the construction industry includes three aspects: management to the qualification of market subject, the whole process management to the construction projects, and the standard management of economy technology to the construction projects.

Main regulators includes,

1. Department of Housing and Urban-Rural Construction, which is responsible for the comprehensive supervision of the construction industry.

2. Department of transportation, which is responsible for the projects of the whole country’s ports and highway.

3. Ministry of Railways, which is responsible for the railway construction projects of the whole country.

4. Ministry of Water Resources, which is responsible for the water construction project of the whole country.

5. Development and Reform Commission, which is responsible for investment and plan of the infrastructure construction projects.

6. Provincial and municipal governments, which have set up the building management and traffic management departments are responsible for plan, review and approval of construction projects.
With the further increase of gradual economic reform deepening and opening-up efforts, the management of the construction industry gradually develops to the direction of market-oriented. Administrative relations between construction and authorities are gradually diluted. Construction enterprises tend to be horizontally integrated. The introduction of modern enterprise system makes forms of ownership to be diverse. The construction industry is moving towards the direction which adapts to market economy requires.

3.6 Completion of the market access system

Construction engineering is a kind of special products, which is related to many aspects, including safety and personal hygiene of construction workers and users, urban and rural planning, road transportation, environmental protection, etc. To the construction field, China implements relatively strict market access mechanism and gradually sets up the Qualification Management System for Construction Enterprises, Project Contracting and Bidding System, Construction Supervision System, normative construction contract and letter of guarantee. Additionally, China carries out the whole-course supervision from bidding phase to maintenance phase in the construction projects.

At present, China’s architectural market access system is as follows,

1. Qualification Management System for Construction Enterprises

According to the demand of market and industry development, Qualification Management System for Construction Enterprises divides the construction enterprise qualifications into construction general contract, specialized contract and labor subcontract. Every type has different categories and ranks. Every construction enterprise, which wants to run businesses, must get relevant qualification certificate and could only have their businesses which are permitted by the qualification. Construction enterprises qualification implements dynamic management. Enterprises which take the business of general contract could do the construction on their own or subcontract the non-main works. Enterprises which have the qualification of specialized contract could take the specialized projects subcontracted by the general contractors or the specialized projects issued by the clients. Specialized contractors could do the construction on their own or subcontract their labor works to the enterprises which have the relevant qualification. Enterprises which have the qualification of labor subcontract could get down to the labor works subcontracted by general contractors or specialized contractors.

2. Project Contracting and Bidding System and Construction Supervision System

China gradually introduces the competition mechanism into the construction industry and promotes project contracting and bidding system and construction supervision system, which means that contractors and supervisors are determined in the way of bidding. Contractors could get projects at bidding price. And the project manager lifetime responsibility law has been implemented in the aspect of construction quality. Other parts involved, including investors, suppliers and intermediary agencies, are brought into construction market gradually and the government establishes a unified, open and orderly market system which conforms to the international practice.
The Ministry of Construction of China issued the *Regulations of Qualification Management for Construction Supervising Enterprises* (No. 158) and the related qualification standards in 2007. According to the new standards, project supervising enterprise qualifications are divided into 3 series: comprehensive qualifications, professional qualifications and business premises. Comprehensive qualifications only have class A. While professional qualifications have class A, B and C, and is divided into 14 professional project classifications in terms of engineering properties and technical characteristics. In spite of building construction, water conservancy and hydroelectric power, road and municipal administration, those professional project classifications don’t have class C. Meanwhile, the new standards have made some adjustments in minimum capital requirements. The original *Regulations of Qualification Management for Construction Supervising Enterprises* (No. 158) regulated that the enterprise capital of Class A should be no less than 1 million yuan while that of Class B no less than 500 thousand yuan and class C no less than 100 thousand yuan. When it comes to the new standards, the standard registered capital of comprehensive qualifications should be no less than 6 million yuan whereas that of class A in professional qualifications no less than 3 million yuan, class B no less than 1 million yuan and class C no less than 500 thousand yuan.

3. Qualification Management of Survey and Design Enterprises

According to the *Regulation of Qualification Management of Survey and Design Enterprises*, construction engineering survey and design enterprise qualification is divided into Engineering Survey Qualification (ESQ) and Engineering Design Qualification (EDQ). ESQ is divided into Engineering Survey Comprehensive Qualification, Engineering Survey Specialized Qualification and Engineering Survey Labor Qualification. There is only First rate in Engineering Survey Comprehensive Qualification. According to nature and technical character, there are different categories and ranks in Engineering Survey Specialized Qualification. Additionally, there are no distinct categories and ranks in Engineering Survey Labor Qualification. EDQ is divided into Engineering Design Comprehensive Qualification, Engineering Design Industry Qualification and Engineering Design Special-event Qualification. There is only First rate in Engineering Design Comprehensive Qualification. According to the nature and technical characteristics, there are different categories and ranks in Engineering Design Industry Qualification and Engineering Design Special-event Qualification.

4. Countermeasures for China’s construction market development

4.1 Gradual perfection of the laws and regulations of the construction market

During the past three decades, China’s construction industry has paved out a developing path which both take international practices for reference and in line with the inner basic laws of construction while suited to China’s situation. It embodied in a system of laws and regulations of construction and construction management, which is lead by *Construction Law* and includes many administrative
regulations, government regulations and normative documents, such as Regulation on the Quality Management of Construction Projects, Regulations of Safe Production Management for Construction Project, Regulations of Survey and Design Management for Construction Project and Regulations of Registered Architect.

Construction Law – brought the normal operation of the construction market and construction industry into the legal system for the first time.

Enforced from March 1st, 1998, as the first law of construction since 1949, Construction Law brought the normal operation of construction market and construction industry into the legal system for the first time and it is the basis and direct foundation of construction related laws and regulations. With a total of eight chapters and 85 clauses, Construction Law is divided into general principles, construction permits, construction bidding and contracting, construction supervision, construction safety production management, construction quality management, legal liability and supplementary articles. The law covers each field of the construction industry. For its emphasis on administration, the provisions of Construction Law are mainly on management and regulation, and a large number of the provisions are mandatory requirements, the issues related to the construction contract are ruled by the Contract Law, this is decided by the social characteristics of the construction industry. It is for sure that Construction Law played a key role in the promotion of the standardized development of China’s construction industry and well participation in international market. However, with the continuous development of Chinese macro-economy and the changing international market, Construction Law can not meet the requirements of economic development of the new era from some aspects, mainly in: 1) Inadequate in compulsory stipulation of project guarantee; 2) Exclusive of energy-saving issue; 3) Weak regulation on construction companies and so on. Now the amendment of Construction Law is under way and the contents not involved are regulated by relative laws, administrative regulations and departmental rules for the time being.

Contract Law – the direct legal norm on contract issues of the construction industry.

Contract Law belongs to the basic laws in Civil and Commercial Matters. The 16th chapter Construction Contract as well as the 15th chapter Undertaking Contract are the direct regulation of construction industry. From a legal perspective, construction contract is a special kind of undertaking contract. While in Clause 287, it is clearly stipulated that the contents not regulated in Chapter 16 are suited to Undertaking Contract. Contract Law took into effect on October 1, 1999 and in one of the most basic laws in the contract area in China. With the development of market economy, enterprises can get involved in the construction market only in a way of contract signing, which is written evidence for protecting their own rights. Because Contract Law are intended to titration, not too much mandatory provisions are required, and most of the freedom rights are given to the litigants in order to fully reflect the freedom will on contract of the parties. In the current Contract Law, the provisions on the construction projects are relatively framework, with most of the provisions general needing full consultation during signing of the contract and specific agreements should be made under the premise of mandatory provisions without violating the laws and administrative regulations.

Bidding Law - sunshine Law of Sunshine Project in the construction market.
Before reform and opening-up, projects are allocated to construction companies by plan, so do materials and equipments. In 1984, it is explicitly required by the State Council in *Interim Regulations on Issues of Reform of the Construction Industry and Infrastructure Management System* that bidding of construction should be strongly promoted. Afterwards, bidding mode is gradually introduced in survey, design, construction and procurement of equipments and materials. *Construction Law, Bidding Law* and their corresponding supporting regulations further regulate the bidding of survey, design and construction in construction projects. The law has changed the external environment for enterprises’ development and promoted the transformation of production and business model as well as internal organization. Construction is a typical bidding area, in *Bidding Law*, which was enforced on Jan. 1st, 2000, it is clearly required that construction projects including survey, design, construction and supervision, as well as the procurement of important equipment and materials related to construction projects within China must bid. The regulation of specific scope and standards were authorized to relevant government departments, thus the law introduced Chinese bidding into the legal track.

With *Bidding Law* as the foundation and the special provisions and refinements in *Management Regulations on Bidding and Design of Construction Projects, Bidding of Construction Projects and Approaches of Survey, Design and Bidding of Construction Projects Bidding* promulgated by building department, as well as special provisions on important issues in bidding area in *Standard of Scope And Scale of Bidding of Construction Projects* which is made by the State Development Planning Commission and approved by the State Council, the integrate system of laws and regulations in the field of Chinese construction bidding are basically built, which provides legal basis for bidding area in construction industry.

Particularly, it should be noted that in *Standard Requirements of Bidding Scope and Scale of Construction Project*, which is developed by State Development Planning Commission and approved by the State Council, the criteria of specific scope and scale of tender-must projects which are authorized and mandatory requirements of the law, otherwise will lead to original and certain invalid of bidding behavior and thus the contract signing. This law, with eight years’ implementation, has effectively promoted and regulated bidding activities in the field of construction. At the same time the State Council is making implementation regulations of the law in order to make it more workable and remedy its defects.

*Bidding Law* and the corresponding implement regulations should strengthen legal regulations and adjustments from several aspects, such as perfecting administrative supervision system, improving the management of the bidding evaluation experts, establishing honesty and self-restraint system, adjusting the scope of mandatory tendering, setting up the qualification management system of bidding employees, introducing e-bidding, containing false bidding, bid-rigging, or bid-lifting, fighting against illegal transactions to maintain the legitimate rights of the parties and increasing the transparency of the bidding of the whole process.
4.2 Introduction of credit rating system

The credit rating for the construction market can be taken separately by government administrators, government authorized agencies and private institutions, each of which has its own features and advantages. The credit rating institutions can evaluate the credit of the enterprises based on the enterprises’ request, or rate their dealing rivals in the market on for any subject of the market. In the long term, the latter one will play the key role and makes important impact on rectifying the market activities.

4.3 Promotion of the establishment of engineering guarantee system

Engineering guarantee system plays an important part in credit guarantee in the construction market. The realization of the credit relies on system regulation while engineering guarantee is an effective economic method instead of governmental means. The main function of this system is to prevent dishonest from happening as well as stimulate the entities in the market to develop their own quality and management rather than offset the dishonest after their happening. A typical project includes tendering and bidding, design and construction as well as quality warranty. Each stage has its corresponding guarantees, such as bid and performance guarantee, payment guarantee and warranty period. All these based on the contract compliance and cover the whole process can benefit the credit system and should be included in laws and regulations according to the theoretical foundation and practical needs.

To enforce the implementation of this system, rectify the order of the construction market and project subcontracting behavior, prevent and solve the project risks, prevent defaulting project payment and employee’s salary, and guarantee the quality and security of the projects, the Ministry of Construction issued *The Regulation about Further Promotion of Engineering Guarantee System in Construction Projects* in 2007. It clearly clarifies that each real estate project whose cost in the contract exceeds 10 million yuan (including new, refurbishing and expanding projects), the construction companies must provide contractor performance guarantee taking the owners as beneficiaries, while the owners must provide payment guarantee taking the construction companies as beneficiaries.

This regulation also advises that before June 2007, all provincial capitals and cities with independent planning should start demo projects. By the end of 2008, all the prefecture-level cities should have the same pilot projects. The regions whose conditions permit can expand the range of experiment in accordance with their situations. The purpose of the experiment is that by the time 2010, the engineering guarantee system should have relatively perfect legal and regulatory system, credit management system, risk control system and industry self-regulatory mechanism.

Meanwhile, all the administrative departments of provinces, autonomous regions and municipalities should determine their experimental cities or projects before the end of March 2007. On the basis of the problems happened during the experiments, such as imperfection of legislation, lack of market supervising, immature of professional guarantee agencies and non-standard behaviors of engineering guarantee, the provisions should be developed according to the law and regulations and the practical situations to promote the implementation of local engineering guarantee systems.
5. Conclusion

This paper reviews the development characteristics and achievements of construction market in the last 30 years of reform and opening up in China. The analysis results show that in the first stage, domestic construction market increased demand which resulted in the increases in the number of construction enterprises as well as of the practitioners. But there is lack of corresponding law and regulation to guarantee the normal operation of the market. A lot of problems and conflicts emerged while the construction market developed. In the second stage, in accordance with the situation of construction enterprise surplus and lack of construction tasks, the government took several measurements to regulate the market. Another characteristic in this stage is the increase of residential demand. The characteristic in the third stage is that the GDP in the construction industry maintained a growth rate of over 20%. A series of law and regulations were promulgated to ensure the sound progress.

The development situation of China’s construction market in the past thirty years was concluded from six aspects. The suggestions were proposed to promote the market development, including the improvement of law and regulation of the construction market, utility of credit rating system and construction of engineering guarantee system. There is still a lot of work to do that needs the government policy support and capital investment. However, with the development of the whole national economy, the prospect for the future development of the construction market in China is bright.

References


Infrastructure Construction in Developing Countries: Risk Analysis for General Contractors

Taylor, J.M.
Auburn University
(email: taylojt@auburn.edu)
Carn, W.
Auburn University
(email: wcarn@accentcm.com)

Abstract

Contractors building internationally are exposed to a variety of risks that their domestic counterparts are not exposed to. Construction risk in developing countries offers contractors a heightened degree of risk than can be expected from a developed nation. Consequently, many contractors chose not to participate in these markets. However, an enormous amount of opportunity exists in the developing world for those willing to accept the risks involved. The purpose of this study is to provide an analysis of what risk factors contractors consider when looking to build in the infrastructure sector of developing countries. The most important consideration that international contractors must be concerned with is how they manage their risks since political, institutional, economic, and social conditions can vary so much in developing countries. As a result of these varying factors, contractors evaluating risks in developing markets are often charged with having to be more creative with their risk outlook. A number of industry professionals working in this sector of construction will be interviewed and asked to rate different risk elements and their related opportunities. From this research, a utility theory analysis will be developed to provide a numerical ranking regarding this risk-reward opportunity.

Keywords: infrastructure construction, developing countries, risk, risk analysis
1. Introduction and methodology

Contractors who build internationally are exposed to a variety of risks that their domestic counterparts are not exposed to. Construction risk in developing countries offers contractors a heightened degree of risk than can be expected from a developed nation. Consequently, many contractors chose not to participate in these markets. However, an enormous amount of opportunity exists in the developing world for those willing to accept the risks involved. The purpose of this paper will be to provide an analysis of what risk factors contractors must consider, when looking to build in the infrastructure sector of developing countries.

U.S. Contractors involved in international construction were identified and sent surveys aimed at discovering their perception of various risk factors they considered when weighing opportunities for international work. Twenty-six responses were received from contractors involved in infrastructure construction in developing countries. Each was followed up with an interview. From these responses, a preliminary analysis was performed to rank the different risks identified.

An ordinal ranking system was utilized based upon a utility theory analysis. It should be noted that the researchers did not identify specific countries considered to be developing nor did the survey attempt to place a definition on the term “developing country”. As the contractors surveyed would have slightly different definitions of “developing country”, this research is aimed at providing general rankings of risk factors and not aimed any specific country or region.

1.1 Developing countries

Developing countries exhibit several distinguishable characteristics that developed countries do not. First, there is a large gap in the standard of living in terms of nutrition, housing, education, and other basic necessities for life. Second, developing countries generally have a stagnant agricultural economy which is usually dependent on the export of one commodity such as coffee, cocoa, or sugar. Third, these nations also have a shortage of centralized capital for economic and industrial development, and are ultimately highly dependent on international aid and private foreign investment. Finally, developing countries are categorized as having lower educational standards, administrative capabilities, and technical skills training.

Although the socioeconomic outlook for developing countries may appear bleak at first glance, there are some unique investment opportunities available in these markets. According to Ramamurti & Doh, U.S. investment in developing countries rose from $23.7 billion in 1990 to $204 billion in 2001 – an eight-fold increase in just eleven years. Furthermore, the stock value rose during the same period from $245 billion to $2,181 billion (Ramamurti & Doh, 204). Developing countries are often made attractive to contractors and foreign investors by the host government itself. The attitude of host governments towards multinational corporations has changed significantly since the 1990’s, from being adversarial and confrontational, to being non-adversarial and cooperative. Consequently, they are more willing to make it attractive for investors to do business with their countries as long as they see the benefits to their own national interests. Contractors have an exceptional opportunity when
working with a realistic host government. They realize that the risks of building in a developing nation may be viewed as too high by their competition, leaving the door open for a higher potential return on investment. These types of returns would be difficult to realize in a more developed nation.

1.2 Risk management

Risk management has been defined as the economic process of allocating a business firm’s financial resources in the optimum combination of loss control and loss financing methods to minimize the costs of pure risks. Contractors evaluating risks in developing markets are often charged with having to be more creative with their risk outlook. For example, if a contractor was looking to build in a politically hostile environment, the initial perception may be that the risk is too high despite the potential for higher profits. However, when the risk manager discovers that political risk insurance is available, and reasonably priced, through organizations such as the Overseas Private Investment Corporation (OPIC), or the Multilateral Investment Guarantee Agency (MIGA), then the risk may be worth taking (Ramamurti & Doh, 2004). According to many, the most important consideration that international contractors must be concerned with is how they manage their risks since political, institutional, economic, and social conditions can vary so much in developing countries.

2. Regulations and customs

A successful international contractor must be informed as to the diverse local regulations and customs of the country of interest. A common error that many contractors make, is the assumption that geographically neighboring countries function in a similar fashion. This is particularly the case when operating in Southeast Asian countries (Lyles & Steensma, 1996). It is of critical importance to foreign contractors that they understand the governmental entities that they will be working with. In many developing countries, several different agencies, state governments, and federal entities may all have controlling interests in projects for their country. Contractors must take every precaution to fully understand host governments and the political dynamics associated with each one. Contractors can develop this understanding by building relationships with host governments and local contractors. Relationship building is critical in developing trust in the Southeast Asian marketplace. These relationships are not developed overnight, but take considerable time to evolve. This evolution often requires a foreign firm to establish an office in the host country prior to actually doing any business dealings (Lyles & Steensma, 1996).

A competent risk manager must be sensitive to the attitudes of local employees and managers as well. This sensitivity correlates into the risk manager possessing a geocentric outlook. A geocentric risk manager recognizes the importance of the host country’s viewpoint, local customs, and the global objectives of his construction firm. This manager must walk a fine line between thinking globally, in respect to his business, and subsequently, be able to manage a local and often extremely volatile environment in the host country he is operating. Local regulations were determined to be the most important point for a contractor to understand to have the best chance of success on their project. This ranked two to three times more important than the least important aspects, as revealed in our survey.
3. Stability of government

Volatility in developing countries often starts with the host government, their attitude towards foreigners, and the role they play in their respective country. Host governments can absorb risks in various ways: for example, by building risk-transfer into contracts by passing input cost inflation or exchange rate depreciation into prices, or to third parties through counter guarantees (Doh & Ramamurti, 2003). However, host governments may also be a huge source of risk, primarily the risk of defaulting on specific contractual commitments. Many governments in developing countries possess a natural suspicion towards foreign contractors for two main reasons. First, there is a belief that these firms crowd out indigenous firms, suppressing their growth efforts. Second, funds are taken out of the host economy, and consequently, are not cycled through the host economic system (Rashid & Aziz, 1993). Skilled foreign contractors have the ability to recognize when an opportunity presents itself, and are willing to work with cooperative host governments.

Host governments in developing countries may not always adhere to the professional standards that multinational contractors are accustomed to. For example, some governments are notorious for altering legally binding contractual agreements, after they have been agreed upon. This practice is especially prevalent when political parties shift, or ruling governments change. Since infrastructure projects are so capital intensive, and take so much time to complete, it is critical that contractors be aware of the risks associated with entering developing markets (Ramamurti & Doh, 2004). Governments in developing countries must make an effort to use their power of control to change the irrationalities that often exist in the construction industry, in order to make conditions more favorable to contractors (Wells, 1986). If the host government is to be involved, then the idea would be to have the government or its institutions, participate as lenders, insurers, or underwriters of infrastructure project debt. These are generally the most supportive and least threatening of the governmental roles. For contractors who understand the aforementioned risks, the question then becomes: where does investment come from, and how can infrastructure projects in developing countries be financed? Government stability is rated as the third most important element discussed in this paper by those responding to the questionnaire.

4. Project financing

The financing options that this research will analyze include: foreign direct investment (FDI), equity and joint-venture partnerships, the International Monetary Fund (IMF), and the World Bank (Bank). The infrastructure sector has seen a tremendous amount of private investment throughout the developing world. The opening up of Eastern and Central European economies has fuelled privatization in developing countries (Doh & Ramamurti, 2003). Private investment in the infrastructure sector of developing countries totaled $750 billion between 1990 and 2001. Additionally, significantly higher levels of investment have taken place in East Asia and Latin America than other regions such as Africa. The increased level of growth to these regions can be directly attributed to their commitment to privatization and market reform. However, infrastructure projects inherently possess an increased level of risk due to their requirements of massive capital and lengthy completion times. In addition, the developed economies of the world will have to contribute
greatly to adequate amounts of technology and capital in order to make these projects successful (Chen, 2002). Contractors are once again implored to use creativity, in regards to how they obtain financing for construction projects in these developing markets.

Foreign Direct Investment (FDI) is one strategy that has increased steadily in developing countries over the past decades. According to Albuquerque, there is significant data to support the fact that FDI is the most effective form of investment in developing countries. For example, during the Mexican debt crisis of 1994, FDI inflows fell from $11 billion in 1994 to $8 billion dollars in 1996, a drop of 27%, but recovered fully by 1997. Alternatively, portfolio equity and debt flows fell by 89% and 45% respectively in just one year, from 1994 to 1995 (Albuquerque, 2003). Unique project financing concepts allow contractors and financiers to minimize their risk exposure, by exploiting financial leverage and limiting their exposure in a single project to the equity invested in it (Ramamurti & Doh, 2004). Debt is secured by the project’s own assets and contracts rather than the developing country’s assets or credit. Lenders are attracted to this method since the project’s debt is supplied by a group of banks or financial institutions, therefore limiting each lender’s exposure.

Not surprisingly, equity partnerships are an attractive form of investment for infrastructure projects. Equity partnerships are prevalent in infrastructure projects since companies may ultimately be able to sell their products for use in the actual construction processes. Risk may be further spread by contractors’ use of multiple foreign or local partners. By using this approach, contractors can effectively spread their financial risk. In addition, equity partnership can also have a greater influence over host governments (Ramamurti & Doh, 2004). Joint-venture partnerships have also become an attractive form of investment in developing countries such as Africa, Asia, and Latin America. Developing countries are attracted to joint-venture projects for various reasons including, their lack of capital and risk mitigation. Furthermore, countries believe that an ownership interest, and the responsibility associated with it, is a symbol of equality. Contractors are greatly benefitted by this notion because it helps to reduce the deeply ingrained suspicions of foreign investment.

Financing may also be obtained through the International Monetary Fund (IMF), or the World Bank. The role of the IMF has remained predominantly steady over the course of its 64 year history (World Bank & IMF, 2008). According to the IMF, recipient governments are encouraged to build their economies in order to promote free trade, but are not obligated to directly follow the obligations dictated by the Fund. The IMF describes itself as “neither a development bank, nor a world central bank, nor an agency that can or wishes to coerce its members to do much of anything”. However, opponents of the IMF say that the Fund often wields its enormous power over recipient governments, and greatly contributes to their debt problems. The original purpose of the Bank was to organize development projects for reconstructing Europe post World War II. But as Europe recovered, the Bank shifted its focus to other countries in need of development – mainly Latin America and Africa. The main work of the Bank comes from the International Bank for Reconstruction and Development (IBRD). The IBRD provides loans and grants to middle to lower income countries. The second arm of the Bank is the International Development Assistance (IDA), which focuses on lending to the poorest of countries. These are countries who cannot qualify for lending from the IBRD. However, over the past decades, the Bank has exploded into a development bank that supports funding for a host of
projects all over the world, with the ultimate objective of fighting poverty worldwide (World Bank & IMF, 2008).

Understanding the financing background, history and requirements for a potential project is ranked the second most important risk by those responding to the questionnaire. This is closely tied to other attributes that were analyzed; primarily project financing as it is affected by government stability or instability and also that related to the regulatory climate of the host country.

5. Mitigation of risk

Selecting the appropriate financing option will have a lot to do with the degree of risk that the parties involved will be exposed to. There are several different ways that contractors, financiers, and investors may mitigate their financing risks in developing markets. One example of this would be the issuing of project bonds that would include event-risk provisions (Chen, 2002). Managers and equity stakeholders would be less inclined to restructure project activities that might enhance the equity of the bondholders. As a result, a balance is developed so that agency problems between stock and bondholders may be reduced. The event-risk concept to project bond issuance is even more powerful. In this instance, the implementation of event-risk provisions in project bond contracts would be a deterrent to politicians who may want to alter policies in host countries.

In the case of the Bank and the IMF, contractors do have an added benefit in the sense that these organizations, whether they admit it or not, do have an effect on policy direction of recipient host governments (Evrensel & Kutan, 2005). For example, the IMF understands that there is a short-term political policy impact in many of the countries they loan to. In other words, the political leadership has something to boast about when they receive funding, and may use this to direct political policy. However, the IMF is fully aware that sooner or later these policies, usually in the form of balance of payments catastrophe, will hamper the actual economic growth of the country. Consequently, they will be more inclined to pay close attention to what the host governments are doing.

It is well understood that no financing package will guarantee that a contractor will get paid for the work performed or expenses incurred. The money may be there for the capital intensive upstart costs of the project, but what about available funds upon completion? The research has proven that the risk of working with host governments is still quite large, and there may be no concrete solution as to how contractors may effectively insulate themselves from this risk. However, in the case of the IMF, the countries they lend to do not appear to be in danger of widespread poverty. Even though the countries may appear to be more stable, research indicates that the ultimate success of the lending depends on the macroeconomic stability of the recipient countries. Furthermore, it appears that the most effective risk mitigation strategy for contractors is to make an effort to thoroughly know the environment that they will be operating in, specifically host government officials and policy makers (Evrensel & Kutan, 2005).

Additionally, contractors must carefully analyze how they want to proceed in regards to insurance. Contractors may obtain insurance through multinational insurance/reinsurance giants, such as Zurich -
Multinational Insurance Proposition (MIP), Munich Re, or Swiss Re (World Economic Forum, 2008). Contractors could mitigate their risks, particularly in regards to loss from natural disasters, if the host country of interest is the recipient of funding from the Bank. While the Bank does not directly finance hazard management projects, they integrate hazard management into disaster mitigation and post disaster reconstruction projects, as well as into the Bank’s main interests, urban development and infrastructure projects (World Bank, 2008). The Bank has contributed over $47 billion in financing to more than 500 projects with hazard management components since 1980. The decision that contractors make in regards to insurance will more than likely be project specific. However, research indicates contractors have many opportunities to insure their interests adequately and therefore risk mitigation is one of the least concerns of the contractors responding to the questionnaire.

6. Weather and climate

Aside from financing and insurance risks provisions, contractors must also be aware of the significant risks posed in developing markets by weather patterns, materials, labor, cultural issues, and corruption. Weather is a critical risk factor to consider in developing markets. Many parts of the developing world are susceptible to violent weather patterns that many U.S. contractors have never operated in. Weather delays are a critical cause for concern in both domestic and international projects, but nowhere on earth could they be more of a factor than in the equatorial rainforests of Sub-Saharan Africa. In an effort to improve the economy, the government of Zambia decided to spend a considerable amount of money on infrastructure (Kaliba, Muya & Mumba, 2008). For example, in 2005 $118 million was allocated towards road construction, and in 2006 the government spent another $227 million. The spending effort is part of the Zambian government’s Fifth National Development Plan which stresses the importance of adequate infrastructure for future development. However, the Zambian government believes that road construction efforts will not be fully realized until projects of desired quality are completed on time and within budget. According to the research of Kaliba, et al., contractors interviewed cited bad weather, due to heavy rains and flooding, to be the number one cause of cost escalation. However, this research concludes that weather is not a major concern to contractors in assessing their risk as this is somewhat predictable and thus can be incorporated into the contractors price or contract language.

7. Building materials, labor and equipment

Building materials, or the lack thereof, in developing countries can cause enormous complications for contractors. Many developing countries lack the capacity to provide for building materials. Local vendors are often only equipped to handle very small jobs, and their ability to handle complex projects is almost impossible. Contractors are forced to procure their materials from outside sources, only adding to the difficulties of the project. It is critically important that contractors be aware of the host governments policies in regards to materials, particularly, price inflation. For example, cost estimation practices in China are based on quotation books issued by the government, not by market conditions. Therefore, when preparing their cost estimates, contractors must change the quotations to reflect current market prices prior to submitting their bid (Zou, Zhang & Wang, 2007). Materials
shortages are also something that contractors must contend with as well. During the mid-1980s in Tanzania, materials shortages were so bad that that many contractors left projects unfinished. No imported materials were available at all, except through the black market at extremely high prices.

The vast majority of developing countries tend to be highly populated, and thus labor is generally abundant. In developing countries, there is great demand for both skilled and unskilled labor. Equipment use can help provide more efficiency, but only in more developed parts of a country. For example, in the more metropolitan cities of India, contractors may use more technical machinery to increase efficiency since these cities are much more likely to produce technically proficient workers. Conversely, the majority of rural India may offer an abundance of unskilled labor, but it is highly doubtful that any of them will possess technical skills (Koehn & Jagushte, 2005). Contractors are often faced with a dilemma in developing countries, concerning the use of labor intensive construction methods, or more efficient equipment intensive methods. The decision will often be project specific relative to the country they are operating in. The decision to use more equipment intensive methods can be risky, and because of the serious cost implications, should be analyzed carefully.

The majority of developing countries manufacture very little construction equipment. Consequently, contractors will more than likely have to import a great deal of their equipment. In addition, they will also have to import fuel and spare parts to maintain the equipment, as these items are not readily available in developing countries. While labor may be abundant, the concern that many contractors have is the productivity relative to the workforce. A large workforce that is willing to work for lower wages may not be the best answer. There must be sufficient supervision from trained personnel to maintain a productive workforce. In addition, safety is a big issue in developing countries that is often overlooked by host governments and supervisory personnel. Safety regulations in the developing world are far different from the standards which are prevalent in other markets. For example, many Indian construction workers polled believed that it is their personal fault if they were to be injured, despite the fact that safety measures are inadequate. Therefore, contractors should make every effort to train workers, especially supervisors, in proper safety techniques. Most contractors say that finding this type of trained supervision is extremely difficult in developing markets. Contractors must be aware of the workforce they will have to employ in the countries they choose to operate in. The collective knowledge of the indigenous workforce will also help contractors mitigate risk further, as they decide what method best suits their needs: a more labor intensive method or equipment intensive.

Contractors are very good at anticipating their productivity with a known quantity of resources. As the resource variability increases (i.e., will something be available or not) the confidence that the contractors place on their budgets decreases. As a result, problems associated with the availability of materials, labor or equipment rank as the fourth most important risk element to consider behind the aforementioned government regulation, financing scenarios and government stability risks.

8. Local culture

In developing countries, contractors must not only be aware of the potential workforce availability, but also the cultural concerns associated with it. There are several considerations that contractors must
look at regarding cultural issues including regional, tribal, and religious differences (Al-Husan & James, 2003). The potential for conflict exists not only on the jobsite, but also at the corporate level. Contractors must make an effort to strike a balance with host governments in order to ensure that the work will run smoothly. Contractors who participate in developing markets must make a concerted effort to develop an awareness of their surroundings. Maintaining relationships, building trust with host governments, and a physical presence will all help to ensure the future success of their projects. Relationship building will also help contractors to develop a situational awareness as to the prevalence of corruption in these markets.

Corruption in developing markets is rampant, and contractors should make every effort to be informed, as to what officials are responsible for in their countries of interest. According to Heineman & Heimann, “corruption distorts markets and competition, breeds cynicism among citizens, undermines the rule of law, damages government legitimacy, and corrodes the integrity of the private sector” (Heineman & Heimann, 2006). The Bank estimated in 2004, that public officials worldwide receive more than $1 trillion in bribes every year, and that figure does not include embezzlement. It is important for contractors to understand the variations in corruption. In developing countries, there are two different levels of corrupt officials. First, there are corrupt high-level government officials who direct national policy, and second, are the low level officials who control access to basic services such as education and electricity. The lower levels of corrupt officials can have a direct effect on the actual day to day operation of an infrastructure project, which could have a huge impact on the success of the project. Unfortunately, there are no clear solutions to avoiding corruption in developing countries. However, there are some steps that contractors can take to help mitigate their risks. For instance, international companies should participate in forums to discuss the problems associated with compliance of government officials and business leaders in developing countries, and especially with the leaders of those businesses wishing to become a presence in the marketplace (Heineman & Heimann, 2006). While knowledge of the local culture plays an important role in the success or failure of a project, this is not considered to be an essential risk element based upon the results of our questionnaire.

9. Conclusion

The research conducted proves that there is little doubt the risks associated with infrastructure construction in developing markets are high. Contractors should start the risk analysis process with an exhaustive look into the region that they are looking to operate in. They need to be familiar with the structure and stability of the host government, their attitude towards investment, local regulations and customs, and the legal framework of the country of interest. Building lasting relationships is critical to a contractor’s ultimate success in a developing country. Contractors may accomplish this by opening an office in the host country, making an effort to help host governments with financing or policy, and by reaching out to local contractors and their communities. Successful contractors make an investment on the front end to build those valuable relationships. They recognize that risk mitigation starts there, and is further realized as the host government and local communities become more receptive to foreign investment.
Contractors must also consider the risks associated with financing infrastructure projects. Since infrastructure projects are capital intensive, it is critically important to have adequate financing. Financing options include private, such as foreign direct investment, or from international lending institutions such as the Bank or the International Monetary Fund. Risk may be further transferred by the implementation of joint venture partnerships or equity ownership. As far as insuring infrastructure projects, contractors may insure privately through global insurers and reinsurers. Risk mitigation options are readily available to contractors who participate in developing countries.

Many parts of the developing world are susceptible to harsh climates. Contractors should be keenly aware of weather patterns in their country of interest. Building materials are often not readily available in developing countries. Consequently, contractors will often have to import large quantities of materials. The importation of these materials could be very costly to contractors, particularly if there are shortages or delays due to poor access. Labor is also a critical component to the construction process. The majority of developing countries offer a large workforce, often willing to work for lower wages, but a shortage of skilled supervisory personnel. The result is a higher probability of a decreased level of productivity. In addition, research indicates that safety regulations in developing countries are often inadequate. Contractors should make an effort to train both workers and supervisors in proper safety techniques. Ultimately, contractors must decide if a labor intensive method should be used, or if a method more dependent on the use of equipment is appropriate. Cultural issues should also be considered when analyzing a potential workforce. These issues should further be considered at the corporate governance level as well. Finally, contractors must be very careful to avoid being caught up in local corruption. Corruption is widespread in developing countries, and contractors are vulnerable if they do not know the market. However, their exposure can be mitigated if they know what to look for. They can ascertain this knowledge by developing a thorough understanding of the country of interest and the collective region.

The research in this paper indicates that the future of infrastructure construction in developing countries is promising. The vast majority of developing countries understand that the development of a solid infrastructure is paramount to their growth, and subsequently, their influence on the developed world. However, the work is not without challenges, and contractors considering participating in these markets should seriously examine the risks of such an endeavor. The research in this paper attempts to provide a framework from which contractors may analyze the risks in developing markets. In spite of the risks, these markets offer skilled contractors a unique opportunity to profit in a difficult environment. Opportunity may be further developed as contractors work to build relationships, not only in the countries they operate, but also throughout the region. Contractors, with the use of the information provided through this research, are in a better position to carefully analyze their risks, so that they may profit in infrastructure construction projects throughout the developing world.

References


Appendix

Questionnaire sent to a number of general contractors involved with international construction. Twenty six responses were received an analyzed. The number at the end of each question simply reflects the response closes to the mean response of all participants.

Please circle the corresponding number from 1-7, where one is the “least critical” (i.e., of “no concern”), and seven is “most critical” (i.e., of “great concern”).

1              2              3              4              5              6              7

NOTE: The value of this questionnaire is related to individual responses from those with experience in international construction. Please take 2-3 minutes to answer.

1) Delay or refusal from the host government in issuing project approval or permits. (7)
2) Circumstances out of your control: i.e. war, disease, fires, storms, embargo, etc. (3)
3) Fluctuation in currency exchange rate, or convertibility. (3)
4) Competition from other international developers, contractors, and/or investors. (1)
5) Inconsistency in local government’s application of laws and regulations. (2)
6) Effectiveness of Build-Own-Operate (BOO) projects when working with local gov’t. (6)
7) Local inflation and/or changes in interest rates due to local economy. (6)
8) Stringent environmental protection rules. (2)
9) Lack of legal judgment reinforcement. (2)
10) Quality control issues related to, local contractor. (2)
11) Cost overruns outside your control. (4)
12) Effectiveness of Bilateral Investment Treaties (BIT’s). (3)
13) Public image concerns due to local living standards, values, culture, etc. (2)
14) Influence of local government on court proceedings regarding project disputes. (7)
15) Theft of property, and/or inadequate site security. (2)
16) Differences in culture, education, values, language, etc between parties. (1)
17) Corruption among local officials. (2)
18) Where financing is obtained from: i.e. World Bank, IMF, private investors. (3)
19) Effectiveness of Public-Private Partnerships when working with local government. (4)
20) Obsolete technology and practices by local contractors. (2)
21) Access to information concerning a local contractor’s financial soundness. (5)
22) Takeover of local project facility due to political, social, or economic pressures. (6)
23) Inefficient project management team. (2)
24) Difficulties in hiring and keeping suitable and valuable employees. (5)
25) Intentional/unintentional negligence from auditors, bankers, and/or creditors. (2)
26) Inadequate forecast of market demand. (2)
27) Gov’t. policies on foreign firms: i.e. mandatory joint venture, differential taxation, etc. (3)
28) Design changes in design/drawings due to difference in local design custom and practices. (5)
29) Failure to promote safe building practices by local contractors. (3)
30) Effectiveness of Build-Operate-Transfer (BOT) projects when working with local gov’t. (5)
Assessment of Building Sustainability in Micro and Small Construction Firms on Southern Brazil

Patzlaff, J. O.
PPGEC/UNISINOS, Sao Leopoldo, Brazil
(email: jpatzlaff@brturbo.com.br)

González, M.A.S.
PPGEC/UNISINOS, Sao Leopoldo, Brazil
(email: mgonzalez@unisinos.br)

Kern, A.P.
PPGEC/UNISINOS, Sao Leopoldo, Brazil
(email: apkern@unisinos.br)

Abstract

This paper describes a tool to assess building sustainability on micro and small construction companies in a southern Brazilian context. In recent years great transformations have occurred in design and production phases of buildings. More recently, as well as in other industrial segments, sustainability concept became very important in civil construction sector, due to the significant impact of this sector in the environment. The application of sustainable innovations mainly occurs in mid or large construction companies, generally in larger cities, however, Brazilian construction sector is composed mainly (more than 90%) of micro and small companies, especially in lesser cities. Therefore, the development of ways to help small construction firms to apply sustainable concepts in their projects is very welcome. In this context and based on literature, this study proposes criteria to be used by small construction firms to search the application of sustainable concepts in construction projects. Those parameters were tested through a case studying, involving a sample of typical buildings produced by a small construction firm of a small city in the South o Brazil. It was evaluated that the projects reached low average in the efficiency on materials and resources, water efficiency and environmental loads, concluding that all these dimensions represent opportunities to improve construction sector and create or develop sustainable policies.

Keywords: sustainable building, assessment, micro and small companies, Brazil
1. Introduction

Construction industry is a great consumer of natural resources. The transformation of raw materials in buildings components and the need of the transportation of construction materials over long distances require an additional amount of energy resources, provoking significant environmental impacts. Resources for operation, maintenance, demobilization and demolition also are consumed throughout the life cycle of construction and, as a consequence of these characteristics, construction industry is also responsible for water consumption, and the large amount pollutants generation.

Looking for sustainability in the constructed environment involves a wide range of actions, among which, we highlight the following: training builders and designers, improving the quality of materials, training of manpower, environmental certification, recycling, improving the communication and information exchange, and the search for innovative materials and technologies. These initiatives are expected to increase the competitiveness, to improve the quality of products and services, to reduce costs, to optimize resource use, and especially to reduce waste and environmental impact of construction.

Studies related to sustainable building are gaining importance, but the application of innovation often occurs only in mid and large companies, which work in larger cities. However, Micro and Small Construction Companies (MSCC) are the majority on Brazilian construction sector. Therefore they are responsible for constructing large part of the buildings and also for employment generation.

Concerning this context, the objective of this paper is to propose several parameters that can help small construction firms to consider sustainability concepts in design and production of new projects.

2. Indicators of building sustainability

The assessment of sustainability degree in construction sector is a complex issue. There are several approaches, mostly based on two lines: Life Cycle Assessment (LCA) and a set of criteria and indicators.

LCA is used to evaluate the environmental impact through the quantification of materials and energy involved in a product. It is aligned with issues that were discussed at the Rio-92 and Rio+10 conferences, in terms of what actions should be planned for the development of production and consumption policies in order to improve products and services, reducing environmental impacts (UN 1992, 2002). Silva et al. (2002) states that methods and results of LCA used in other countries may not be appropriate for Brazil, and appropriate techniques must be developed concerning national conditions and peculiarities. In fact, the evaluation of the life cycle presents some practical difficulties such as the lack of information from local manufacturers of materials and components, complexity of analysis and dependence on factors such as transport distances.

In terms of sustainability criteria and indicators, Silva et al. (2002) argue that, although there is no formal classification, environmental assessment schemes available can be clearly separated into two
categories. On the one hand, methods designed to be easily absorbed by designers or to receive and disseminate market recognition about the efforts provided to improve the environmental quality of projects, implementation and operational management (such as BREEAM - Building Research Establishment Environmental Assessment Method, and LEED - Leadership in Energy and Environmental Design). On the other hand, there are evaluation-oriented tools, such as BEPAC (Building Environmental Performance Analysis Club) and its successor, the GBC (Green Building Council) that emphasizes the development of a comprehensive methodology with scientific reasoning, which can guide the development of new systems.

Techniques based on criteria such as LEED and BREEAM are flexible and allow the use of qualitative assessments and try to cover environmental, economic and social sustainability of the built environment. These indicators capture trends to inform decision makers, in order to guide the development and monitoring of policies and strategies, among other roles. They are useful for designers, owners, users, managers, policy makers and other public officials involved in the construction industry.

Lately, aiming to meet market requirements and follow the trend of sustainability, construction companies have chosen environmental certifications methods. However, adjustments to current standards of environmental preservation require organizations major investment, and represents an extra cost that usually does not return in profits in short term. This bad relation of benefit and cost in short-medium term is more difficult to smaller construction companies.

In Brazil, the most known and popular building environmental certification method is LEED. This evaluation method was created in the United States in 1999. It is currently the method with greatest potential for expansion, according to the massive investment that is being made for its dissemination and improvement. LEED was inspired on BREEAM and it is based on criteria and indicators. The system is updated regularly (every 3 - 5 years) and versions for different types of projects have been developed gradually (USGBC, 2005). The LEED criteria evaluate the following types of project: new construction and major reforms, existing buildings (phases of operation and maintenance), interiors, core and "envelope", and schools in the pilot phase, neighbourhoods, retail and residences. The criteria are distributed in six dimensions or categories of requirements, resulting in a total of 69 points (USGBC, 2001):

- Sustainable sites (01 prerequisite and 14 credits)
- Water efficiency (05 credits)
- Energy and atmosphere (03 prerequisites and 17 credits)
- Materials and resources (01 prerequisite and 13 credits)
- Indoor environmental quality (02 prerequisites and 15 credits)
- Innovation and design process (05 credits)
After Silva (2007), in Brazil there are considerable efforts to develop sustainability indicators at different scales of the built environment, however, those indicators vary widely, and they are defined according to criteria and methodologies which are not replicable in some cases. In addition, there are some items that do not apply to national or regional phenomenon. Some studies have been developed for the generation of evaluation mechanisms in Brazil. For example, Kuhn (2006) and Sedrez (2004) proposed mechanisms for assess the sustainability of social housing projects, and Oliveira (2005) proposed a method of environmental assessment of roofing on social housing.

### 3. A method for sustainability assessment

A building sustainability assessment method needs to take into account different aspects such: regional particularities, buildings types characteristics (considering materials, manpower and techniques used), and the size and structure of the construction company responsible for the implementation among other issues.

This study is focused in vertical residential or commercial (office) building, constructed through traditional Brazilian technique by small construction firms. To propose sustainable parameters, different sustainability assessment methods were considered to define the dimensions of sustainability (themes) and criteria to be used in the concerned context. The proposal of the 45 criteria is presented in Table 1. The first 42 are easily evaluated, while the last 3 must to involve people questioning.

The assessment considers the adequacy of the criteria for each building, using a scale form 0 to 3. Except for the last question, 0 (zero) means “no”, when the criteria examined is not seen in the context of the building; 1 (one) means “in part”, when the factors are applied only in a small part; 2 (two) means “most part”, when the factors are applied in a great part; and 3 (three) means “full”, when the indicator was completely attained. There is a small difference on the last issue, which took into account the energy consumption for transportation to the job site, taking 3 points for access by foot or bike, 2 using public transport, 1 when people use car, and 0 when people goes to site on truck.

All indicators have the same weight, so the maximum score is 135 points. Because there are different amounts of indicators in each dimension, the results were converted into percentages, so all dimensions have equal weight in the final index what contribute to an easily understanding and comparison.
<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Sustainable sites</td>
<td>1 Urban integration</td>
</tr>
<tr>
<td></td>
<td>2 General location and solar orientation</td>
</tr>
<tr>
<td></td>
<td>3 Access ways</td>
</tr>
<tr>
<td></td>
<td>4 Parking space</td>
</tr>
<tr>
<td></td>
<td>5 Alternative transportation</td>
</tr>
<tr>
<td></td>
<td>6 Storm water management</td>
</tr>
<tr>
<td>(B) Water efficiency</td>
<td>7 Reduce water use</td>
</tr>
<tr>
<td></td>
<td>8 Reduce sewage and gray water</td>
</tr>
<tr>
<td></td>
<td>9 New technologies for reduce water use</td>
</tr>
<tr>
<td></td>
<td>10 Storm water reuse</td>
</tr>
<tr>
<td></td>
<td>11 Wastewater reuse</td>
</tr>
<tr>
<td>(C) Energy and atmosphere</td>
<td>12 Energy efficiency</td>
</tr>
<tr>
<td></td>
<td>13 Renewable energy and green energy use</td>
</tr>
<tr>
<td></td>
<td>14 Thermal insulation</td>
</tr>
<tr>
<td>(D) Materials and resources</td>
<td>15 Building reuse (retrofit or other strategies)</td>
</tr>
<tr>
<td></td>
<td>16 Reuse or recycling materials and components</td>
</tr>
<tr>
<td></td>
<td>17 Construction waste management</td>
</tr>
<tr>
<td></td>
<td>18 Local or regional materials</td>
</tr>
<tr>
<td></td>
<td>19 Renewable materials</td>
</tr>
<tr>
<td></td>
<td>20 Certified wood</td>
</tr>
<tr>
<td></td>
<td>21 Easy maintenance</td>
</tr>
<tr>
<td></td>
<td>22 Environmental quality of materials</td>
</tr>
<tr>
<td></td>
<td>23 Life cycle assessment</td>
</tr>
<tr>
<td></td>
<td>24 Layout and use flexibility</td>
</tr>
<tr>
<td>(E) Indoor environmental quality</td>
<td>25 Natural ventilation</td>
</tr>
<tr>
<td></td>
<td>26 Thermal comfort</td>
</tr>
<tr>
<td></td>
<td>27 Daylight and views</td>
</tr>
<tr>
<td></td>
<td>28 Noise control</td>
</tr>
<tr>
<td></td>
<td>29 Finishing and furnishing adequate to users</td>
</tr>
<tr>
<td>(F) Environmental loads</td>
<td>30 Waste management</td>
</tr>
<tr>
<td></td>
<td>31 Environmental responsible management</td>
</tr>
<tr>
<td></td>
<td>32 Water infiltration into the soil</td>
</tr>
<tr>
<td>(G) Design and building</td>
<td>33 Design innovation</td>
</tr>
</tbody>
</table>
4. Application of the proposed methodology

The proposed method was tested on three residential projects (two single-family housing and a multifamily residential building), involving analysis of the construction sites and contact with agents, such as architects, civil engineers, builders, workers, material suppliers and users. The projects are located in the region of the Caí River Valley and they are administered and produced by MPEC. The region has around 160,000 inhabitants (on 2007), composed by 20 cities, covering 1,854 km², and it has a GDP around US$ 6,500 (on 2006).

The projects were chosen to the study because they are very typical in the region, and the researchers had easily access to the information from building companies, designers and construction sites. The basic features of each of the projects are presented as follows:

1) Project 1: vertical residential building, multi-family use, it has 3,200 m² area, composed by twenty-four apartments and thirty-six parking spaces; it was studied during the design phase;

2) Project 2: horizontal residential building, single-family use with the area of 117.95 m²; it was studied during the production phase;

3) Project 3: horizontal residential building, single-family use with the area of 204.53 m²; it was studied during the production phase;

Mostly based on information from constructors and from site constructions observation, each indicator were evaluated. For the last three indicators 25 people involved were interviewed, including engineers, architects, realtors, municipal officials, suppliers, and workers, all engaged in professional activities or residing in the Caí River Valley. The obtained results are presented in Table 2.

Table 2: Evaluation of the analyzed projects
In the overall evaluation, the 3 projects studied have reached about 2/3 of the maximum level of the proposed method, with a balance between them. The highest level was reached in dimension (E) and the smaller are on dimensions (B), (D) and (F). It may be concluded that the quality of the internal environment is quite good, while the efficiency on materials and resources (D), water efficiency (B) and environmental loads (F) do not reach high levels. All these dimensions generate construction waste and represent opportunities to improve construction sector and create or develop sustainable policies.

The chart below (Figure 1) helps to examine the results qualitatively. It can be seen major differences in the dimensions (A) and (C) and a balance among (E) and (G), among the 3 projects. From Figure 1 it is possible to conclude that there is potential for progress, represented by the blank area on the chart.

![Figure 1 - Evaluation according to dimensions of sustainability and buildings](image-url)
5. Comments

This paper proposes a method for assessing the sustainability conditions of construction projects produced by micro and small construction firms that are usually established in smaller cities. Some indicators were organized according to a thematic structure. The proposed method was suitable to the context, and is also flexible, allowing easy inclusion, exclusion, union or subdivision of indicators.

The next steps on the research are the dissemination to people involved, and to create a mechanism to be used in project licensing on small cities, initially as a guide. In the future it may work as part of a property tax law, perhaps indicating incentives in the form of discounts on taxes in proportion to the level of sustainability achieved by the project.

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Waste Management in Brazilian Construction Sites: Quantitative Assessment

Lordsleem, A.
Department of Civil Engineering, Polytechnic School, University of Pernambuco
(email: acasado@upe.poli.br)

Fucale, S.
Department of Civil Engineering, Polytechnic School, University of Pernambuco
(email: sfucale@yahoo.com.br)

Abstract

This paper presents a quantitative assessment of waste management from six construction sites in the city of São Paulo, from which it was possible to verify the degree of compliance with the requirements of National Council of the Environment – CONAMA Resolution No 307. The methodology consisted of the development and implementation of a questionnaire, including the adoption of grades for the following assessment requirements: cleaning, segregation at source, final conditioning, and appropriate destination. The results demonstrated the effective application of the guidelines laid down in legislation, but also pointed to the need for action on improvements associated with each condition evaluated, as well as measures that seek to increase the involvement of subcontractors in the execution of the job, address the shortage of licensed areas for the disposal of some types of waste, implement mechanisms for control and monitoring, and encouraging the recycling of waste.

Keywords: evaluation, solid waste; civil construction; construction management
1. Impacts of construction waste on the urban environment

The circumstances of economic transformation and the need to streamline construction have required greater concern over the entire production environment with respect to reducing costs, improving product quality and increasing efficiency of the production processes.

However, many deficiencies can be found in all stages of the building construction process. Included in these deficiencies is the management of waste generated by the construction sites, which causes serious urban problems of public sanitation and environmental contamination arising from the scarcity of disposal areas.

According to Pinto (1999), the waste generated by construction represents about 61% of the total waste produced in urban areas, accounting for various negative environmental, economic and social impacts.

According to Agopyan et al. (1998), Dorsthorst and Hendriks (2000), John (2000) and Schneider (2003), the organizational and productive methods of construction require changes to promote the rationing of resources, reducing the waste of time and materials and their impacts on cost as well as the need for waste disposal land located within urban areas.

In this context, Resolution 307 of the National Council of the Environment – CONAMA (2002), in force since 2003, establishes guidelines, criteria, and procedures for construction waste management, creating responsibilities for waste generators, transporters and receivers, as well as city governments, pressuring construction companies and public officials to develop actions in order to meet legal requirements and ensure environmental sustainability.

According to Lordsleem Jr. et al. (2007), a transformation in the reality of Brazilian urban centers is beginning to be seen from initiatives on the part of construction companies to implement waste management, with the requirements of CONAMA Resolution 307 as a reference.

The Worksite Environmental Waste Management Program of the Civil Construction Industry Syndicate of the State of São Paulo – SINDUSCON-SP has been the principal reference for waste management at Brazilian construction companies (Pinto, 2005).

This program consists of the implementation of actions to meet the requirements of worksite waste management, which includes the following stages: planning, implementation, evaluation, and taking corrective action.

The evaluation stage is the subject of this article, through which the worksite is verified with regard to cleaning, segregation at source, final conditioning, and appropriate destination of waste.
2. The city of São Paulo and construction waste

Currently, 84.2% of the population of Brazil lives in urban areas, with the city of São Paulo being the largest metropolitan agglomeration in Brazil and the fifth largest in the world, with 18.8 million inhabitants, behind only Tokyo (35.7 million), New York, Mexico City, and Mumbai, each with 19 million (Revista, 2009).

São Paulo is the principal financial, corporate, and trade center of Latin America, taking over the role of the business and service center of the country.

The construction waste management policy adopted by the São Paulo City Hall is implemented by the Municipal Plan for Sustainable Management of Waste. The plan meets the guidelines established by CONAMA Resolution 307 and seeks to increase the supply of areas for the regular deposit of construction and demolition waste from small to large generators, as well as facilitate and encourage the recycling of these materials.

According to the Brazilian Association of Public Sanitation and Waste Collection Companies – ABRELPE (2005), civil construction produces 17.24 thousand tons of waste per day in the city of São Paulo, which is about 55% of the total.

The average composition of construction waste generated in São Paulo is, according to Brito Filho (1999), made up of 33% concrete and mortar, 32% soil, 30% ceramics and 5% other materials.

3. Objective

This article aims to describe the evaluation of environmental waste management at six construction sites in the city of São Paulo, from which it will be possible to verify the principal problems associated with each evaluated condition.

4. Methodology

The research methodology was divided into two stages: 1) development of a questionnaire to define the requirements for evaluation and the criteria for allocation of grades; 2) on-site evaluation of actions implemented in worksite waste management.

Figure 1 presents the questionnaire developed and applied in the evaluation.

The following requirements for evaluation were:

- cleaning: refers to the implementation of collecting and sorting and the sweeping of environments;
• segregation at source: refers to the occurrence of activity as close as possible to the place where waste is being generated, making it available in a compatible size and preserving the organization of space in the various sectors of the worksite;

• final conditioning: refers to the size, quantity, location, and type of device used for the final conditioning of waste;

• appropriate destination: refers to the formalization of the waste destination through the identification and registration of transporters and recipients, the issue of a Waste Transportation Control – CTR for registration of the destination, and the payment to the transporter.

The application of the check list evaluation at each worksite lasted 8 hours and was performed on a monthly frequency throughout the execution of the work.

The following evaluation criteria were considered:

• grades from 1 to 10: the values were assigned by evaluating the fulfillment of the requirements in each environment. A grade of 1 is the worst evaluation (without any implementation of waste management) and a grade of 10 is the Best (no problems, full compliance with the waste management program);

• weighting factors: are associated with the volume of each collector used: bags, boxes, and bins.
The areas delimited for the evaluation of cleaning and segregation at source were formed by the division of environments represented in the planning of the waste management program implementation at each site.
5. Presentation and analysis of results

5.1 Characterization of the worksites and of the waste management program

The worksites are identified here by the letters A, B, C, D, E and F in order to preserve their identities and are characterized in Tables 1 and 2.

Table 1: Characterization of worksites

<table>
<thead>
<tr>
<th>Site</th>
<th>Type</th>
<th>Area</th>
<th>Description</th>
<th>Phase of construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Commercial high-rise building</td>
<td>29,701 m²</td>
<td>18 floors, doctors’ offices and clinics.</td>
<td>Structure, masonry, façade, and waterproofing.</td>
</tr>
<tr>
<td>B</td>
<td>Residential high-rise building</td>
<td>17,302 m²</td>
<td>27 floors, 1 triplex, 2 apartments per floor.</td>
<td>Plaster, installations, waterproofing, external façade.</td>
</tr>
<tr>
<td>C</td>
<td>University high-rise building</td>
<td>20,377 m²</td>
<td>6 floors, 27 rooms, library and auditorium.</td>
<td>Structure, external masonry, internal plaster and façade.</td>
</tr>
<tr>
<td>D</td>
<td>University high-rise building</td>
<td>12,214 m²</td>
<td>9 floors, classrooms, library.</td>
<td>Structure and masonry.</td>
</tr>
<tr>
<td>E</td>
<td>Shopping center.</td>
<td>76,175 m²</td>
<td>Fashion center.</td>
<td>Finishing and installations.</td>
</tr>
<tr>
<td>F</td>
<td>Shopping center – expansion.</td>
<td>9,000 m²</td>
<td>Cinema and mall.</td>
<td>Plaster and installations.</td>
</tr>
</tbody>
</table>

A and B had a greater height than the rest of the buildings; the buildings at sites C and D were for educational use, with D being executed inside a functioning campus; enterprises E and F were shopping centers, with E being an expansion of an existing structure, executed while the shopping center was open and functioning.

The following steps were completed in the implementation of the waste management program: diagnosis and planning of site management, proposal of mechanisms and physical arrangement, purchase of equipment, training of staff, orientation of the application of CTR, periodic inspections with check-list of monitoring and corrective actions.
Table 2: Characterization of worksites

<table>
<thead>
<tr>
<th>Site</th>
<th>Materials storage</th>
<th>Equipment for waste transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>The areas for the storage of materials were arranged on the ground floor.</td>
<td>1 crane and 1 lift rack, installed on opposite side of the building.</td>
</tr>
<tr>
<td>B</td>
<td>The areas for the storage of materials were arranged on the ground floor and in the basement.</td>
<td>1 lift rack.</td>
</tr>
<tr>
<td>C</td>
<td>The areas for the storage of materials were arranged on the ground floor.</td>
<td>1 crane and 1 lift rack.</td>
</tr>
<tr>
<td>D</td>
<td>The areas for the storage of materials were arranged beyond the projection of the building.</td>
<td>1 crane and 1 lift rack.</td>
</tr>
<tr>
<td>E</td>
<td>The areas for the storage of materials were arranged on the ground floor and in the basement levels.</td>
<td>1 crane.</td>
</tr>
<tr>
<td>F</td>
<td>The areas for the storage of materials were arranged on land outside of the construction area.</td>
<td>1 crane.</td>
</tr>
</tbody>
</table>

It was the responsibility of the quality department along with the management team and engineering team at each site to implement the above mentioned steps.

5.2 Evaluation of waste management at worksites

5.2.1 Requirements and criteria for evaluation

Table 3 presents the results obtained from the evaluation of waste management at the worksites.

It can be seen from the results presented in Table 3 that the worksites evaluated better with regard to waste management were (in decreasing order): B, C, D, A, F and E. The lowest grades refer to the commercial building sites.

The quantitative evaluation attributed to each of the requirements reflects as well a qualitative (subjective) evaluation performed by simple observation of the worksites during the visits made while performing the research.
Table 3: Results of the evaluation of worksite waste management

<table>
<thead>
<tr>
<th>Evaluation requirements</th>
<th>Sites</th>
<th>Requirements average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Cleaning</td>
<td>8.3</td>
<td>9.1</td>
</tr>
<tr>
<td>Segregation at source</td>
<td>8.1</td>
<td>9.7</td>
</tr>
<tr>
<td>Final conditioning</td>
<td>9.4</td>
<td>8.0</td>
</tr>
<tr>
<td>Appropriate destination</td>
<td>7.5</td>
<td>10.0</td>
</tr>
<tr>
<td>Average</td>
<td>8.3</td>
<td>9.2</td>
</tr>
</tbody>
</table>

It also can be seen that the requirement which received the best evaluation was that of appropriate destination followed by, in descending order: cleaning, segregation at source and final conditioning. This requirement receiving the best evaluation is in the interests of worksites in addressing compliance with the requirements of CONAMA Resolution 307 through the control of documentary evidence of the appropriate destination.

It is important to emphasize that the responsibility to comply with the other requirements of the evaluation involves comparatively more agents, thereby increasing the difficulty of meeting the requirements.

5.2.2 Principal problems identified

The principal problems identified in waste management are described in Table 4.

Some of the problems verified were found to be common among the various sites, for example those related to segregation at source. It was also observed that the problems identified reflected the level of knowledge of those responsible for waste management at the worksites, because they waited for the intervention of the quality department to correct any deviations.

Figures 2, 3 and 4 show some of the main problems identified in the evaluation of waste management at the worksites participating in the study.
### Table 4: Principal problems observed in the evaluation of worksite waste management

<table>
<thead>
<tr>
<th>Sites</th>
<th>Principal problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>The destinations of the following types of waste were not completely defined: wood (incinerated off-site) and plastic (bags accumulated at the site, awaiting collector).</td>
</tr>
<tr>
<td></td>
<td>The method of cleaning at the source had not been assimilated, because waste remained mixed on the floor and only separated during final conditioning.</td>
</tr>
<tr>
<td>B</td>
<td>There was much evidence of a poor understanding of segregation at source. Bags of garbage were seen with mixed waste (masonry, metal, plastic).</td>
</tr>
<tr>
<td></td>
<td>There was an unidentified metal barrel on the 23rd floor. A few materials (plastic and paper) were mixed in a bin of concrete/block/mortar.</td>
</tr>
<tr>
<td>C</td>
<td>Bags were not provided at the worksite, in conformance with planning and orientation.</td>
</tr>
<tr>
<td></td>
<td>There was much evidence of a poor understanding of segregation at source. Batteries were found mixed with waste (concrete, metal, and plastic).</td>
</tr>
<tr>
<td></td>
<td>A legible certificate for the landfill which was the destination for concrete and masonry was not presented.</td>
</tr>
<tr>
<td>D</td>
<td>There was much evidence of a poor understanding of segregation at source. Cleaning carts were seen with mixed waste (concrete, paper, plastic).</td>
</tr>
<tr>
<td></td>
<td>There was no place at the site for the final conditioning of concrete waste. There was only one bin of wood.</td>
</tr>
<tr>
<td></td>
<td>There was no cleaning and isolation of the elevator pit.</td>
</tr>
<tr>
<td>E</td>
<td>With regard to segregation at source, a barrel was found being used for common trash. Several barrels were not found (without explanation or control).</td>
</tr>
<tr>
<td></td>
<td>The plastic bag was not being used for final conditioning. The subcontracted stalls were not being used correctly (stall for plaster with plastic and metal mixed in).</td>
</tr>
<tr>
<td></td>
<td>The waste management system was not widespread at the site. The company contracted for cleaning did not understand segregation.</td>
</tr>
<tr>
<td>F</td>
<td>There was much evidence of a poor understanding of segregation at source. Bags were seen with mixed waste (paper, plastic, wood, plaster).</td>
</tr>
<tr>
<td></td>
<td>The bags were prepared without a protective cover (rain).</td>
</tr>
<tr>
<td></td>
<td>The concrete/masonry bin was found with mixed plastic and paper waste.</td>
</tr>
</tbody>
</table>
Figure 2: Problems of waste management: a) site A – plastic bags awaiting definition of collector, b) site B – residue mixed in bag

Figure 3: Problems of waste management: a) site C – mixture of waste at the source, b) site D – single bin at the site for the conditioning of wood

Figure 4: Problems of waste management: a) site E – stall with mixture of plaster, paper, and plastic; b) site F – bags without cover
It can be seen in Figures 2, 3 and 4 and according to Table 4 that there is a need for greater interaction between the various actors participating at the worksite, in light of the various wastes observed at each site.

Furthermore, another relevant aspect identified was related to the improved planning of the necessary devices, making them compatible with the existing space as well as with the frequency of collection for transport to the final destination.

6. Conclusion

The management of waste at worksites is a relatively recent Brazilian concern, having been stimulated by the institution of CONAMA Resolution 307 (2002). The requirements of legislation, the environmental call of society and the concern regarding the indiscriminate use and continuous depletion of non-renewable resources have served as a stimulus for the adoption of actions focused on waste management at construction companies.

In analyzing the research results presented in this article, it can be seen that the actions implemented by the construction companies have contributed to the promotion of environmentally committed waste management.

The evaluation of waste management attributed an overall average grade of 8.3 and identified 15 problems, these being (average and number of problems, respectively): site A (8.3 and 2), site B (9.2 and 2), site C (8.9 and 2), site D (8.4 and 3), site E (6.9 and 3), and site F (7.0 and 3).

It is important to note, however, that a number of the problems can be found at more than one worksite. As positive aspects observed in the evaluation, knowledge about the regulatory requirements and the actions relevant to their effective enforcement was noted, as can be verified by the higher grades for the appropriate destination of waste at the majority of sites.

The principal negative aspect identified in the evaluation was related to the need that those responsible for the site must have with regard to changes, alterations and difficulties in taking more effective measures. The disappearance and/or distinct use of the waste collection bins was another critical and negative aspect observed at the worksites, especially those of greater horizontal extension.

In general, it was also possible to conclude that in order to improve the management of waste, it is necessary to have a greater awareness and effective control of both maintenance and distribution of devices, as well as the segregation of waste at source, which is required for the implementation of new training courses for the teams responsible for cleaning.
References


Implementing Built Environment Research Findings in Developing Countries – the Case of Africa

Rwelamila, P.M.D.
University of South Africa, South Africa
(email: rwelapmd@unisa.ac.za)

Abstract

Following the two phases of the preliminary research: the first and second phase on implementing research findings in the African built environment focused on the Southern African Development Community (SADC) and Eastern and Southern Africa (ESA) countries respectively, a major (final) research was conducted. The major research reported in this paper is aimed at two main objectives: first to reflect on piles and piles of research findings on the African built environment (ABE) challenges which are gathering dust at various academic and research institutions; and secondly to clearly identify the primary reasons contributing to the gap between research findings and implementation. The paper shows that most of the challenges solutions are already found in various documents, while most of the same challenges which necessitated these research projects are negatively affecting the ABE. The primary objective of the paper is to initiate debate on the need to re-examine current research findings and convert them to applied form ready for use by practitioners and policy makers. The approach in gathering information is through a variety of methods and techniques, but primarily reviewing work across the world on implementing research findings; reviewing previous published research results on challenges facing the ABE; and semi-structured interviews to senior researchers and policy implementers in randomly selected African countries. Findings strongly suggest that researchers within these countries continue to present their findings at various forums, but very little translates to implementation and a number of causes of the situation are identified and recommendations are given towards addressing the challenges.

Keywords: Africa, built environment, implementation of research results
1. Introduction

According to the New Partnership for Africa’s Development (NEPAD), the poverty and backwardness of the African continent stand in stark contrast to the prosperity of the industrialised countries (UNCTAD, 2001). The continued marginalisation of Africa from the globalisation process and the social exclusion of the vast majority of its peoples constitute a serious threat to global stability. At the heart of the Africa dilemma, argues Todaro (2000), is an inexorable economic decline, a drop in per capita incomes, rapid increases in population, the loss of export revenues, the curtailment of foreign investment, the destruction of fragile ecosystems, and the inability of many countries even to feed their people and meet other basic human needs. The International Institute for Environment and Development (IIED) and the World Resources Institute (WRI) (1987) expressed the situation within Sub-Saharan Africa as the greatest challenge to world development:

“Sub-Saharan Africa poses the greatest challenge to world development efforts to the end of the century and beyond. ...Africa is the only major region where per capita income, food production, and industrial production have declined over an extended period: the only developing region where development appears in reverse...Conventional development efforts by donors and governments have largely failed to halt the spiral, indeed in some cases have aggravated it.”

The New Partnership for Africa’s Development (NEPAD) preliminary document calls for the reversal of this abnormal situation by changing the relationship that underpins it (UNCTAD, 2001). The document advances an argument that Africans are appealing neither for the further entrenchment of dependency through aid, nor for marginal concessions. The NEPAD objectives are relevant to all African industries, including construction industries.

The reversal of this abnormal situation needs a number of initiatives across all industries in Africa. One of the reversal initiatives is to address various challenges which are affecting African industries negatively. There is enough evidence to suggest that various experts and researchers across the continent across all industries have proposed a number of solutions to these challenges, but their proposals seem to be gathering dust in their offices without any significant initiative to implement them. This paper focuses on all African countries built environment (ACBE) and specifically on one of these industries: the broader construction industry and critically looks at ‘research results implementation’ issues.

This paper is a follow-up to previous papers by Rwelamila (2009a&b), which focused on the on the Southern Africa Development Community (SADC) countries and Eastern and Southern Africa (ESA) countries built environments. It reflects on piles and piles of research findings on the East and Southern Africa countries built environment challenges which are gathering dust at various academic and research institutions, while most of the same challenges which necessitated these research projects are tearing apart the greater ACBE construction industry. The paper takes a closer look at the various research themes on challenges facing the ACBE and solutions proposed towards a good practice ACBE. Furthermore, the paper reports on the results of semi-structured interviews from senior built environment researchers and policy implementers in Algeria, Egypt, Ethiopia, Ghana, Sierra Leone,
Nigeria, Rwanda, Burundi, Kenya, Uganda, South Africa, Botswana, Zambia and Tanzania, on what has been implemented from published research results.

Finally the paper makes recommendations on ‘the research results implementation challenge’ which researchers, practitioners and policy implementers, need to address in order to modernise the African Construction Industries (ACIs) and provide a base for the NEPAD infrastructure initiatives, and consequently contribute to the greater development of the African continent.

2. Implementing research results – theory and practice

The gap between research findings and practice within the ACBE has been, and continues to be, a concern for those knowledgeable about the region and those who believe that construction development should be the deliberate and managed process to optimize the contribution of the construction industry in meeting ACIs construction demand. Construction demand is tied closely with regional social economic development objectives, industry wide performance and competitiveness, and improved value to clients and society.

Taking a close look around the world and across industries and sectors, the situation is not pleasing when you look for good practice approaches on ‘research results implementation’ to benchmark on. There are very few trappings of success stories in almost every industry, but the health industry across the world, seem to have realized the negative effect of the gap between research findings and practice with a different attitude. A significant number of research projects and workshops have been taking place and there are positive signs of formulating appropriate initiatives towards closing the gap (see for example Haines and Donald 1998; Haynes and Haines 1998; and Garner, Meremikwu, Volmink, Xu and Smith 2004). Literature from the health industry is used extensively in this document to address the underlying issues of theory and practice.

Reflecting on various developments from the health industry research (for example: Lipman and Jones 1999; Pless 1982; and Garner, Kale, Dickson, Dans and Salinas 1998; and Bero, Grilli, Grimshaw, Harvey, Oxman and Thomson 1998) provides appropriate lenses to reflect on developments in the greater Africa Construction Industry (ACI). There are strong indications to suggest that getting the results of research into the right hands so that it can be used to improve the construction industry is not an easy task. Like in the two preliminary studies which focused the SADC and ESA countries (Rwelamila 2009a&b), language, seem to be one of the stumbling block across industries and more so in any construction industry. The technical language of various research specialists is in most situations not the same as the general public. Furthermore, academics love to share findings, but they are not trained to deal with the public. Plus, there’s little incentive in the tenure system for academics to share their findings (Lipman and Jones 1999; Pless 1982). Motivation is on producing research results and not in disseminating it?
2.1 Implementing research findings: who is responsible?

Reflecting on the health industry, Pless (1982) argues that for many practitioners research has an air of mystery, generated, often unnecessarily, by strange terminology and an overdose of statistical symbols and notations. This observation is true for the construction industry and without doubt across most of the other industries. This is why many practitioners within construction companies and other construction experts for example, find it difficult to interpret the conclusions and to decide whether, when and how the findings should be applied. Much the same uncertainty and confusion surrounds studies of construction industry development policies: the conclusions are not always easily understood, and the practical implications are frequently unclear. Therefore, many potentially useful findings are never applied for the benefit of stakeholders or the general public.

It is assumed that interested practitioners take the trouble to seek out, read and digest, as best they can, the findings reported in journals and conference proceedings. Most investigators, argues Pless (1982), however realize that they should not rely upon reader’s eagerness to learn or the passive diffusion of knowledge to ensure that their results are acted upon rapidly or appropriately. He further contends that: ‘...not all results should be put into practice quickly, since, in many instances, the passage of time helps sort the wheat from the chaff.’ However, Pless (1982) strongly suggest that researchers still must learn how to increase the efficiency with which their results are implemented – results that have usually been produced with considerable expense, time and energy. Clearly, not all researchers have equal cause for concern. Many conduct their research (Lipman and Jones 1999; Pless 1982) at a very basic level of enquiry, and their results are usually of interest only to other researchers. They can safely assume that any published findings of genuine merit will become part of the general store of knowledge. However, much of the research, contends Pless (1982), is in most situations intended to modify current practices. Whenever the results of such research are sufficiently conclusive there should be some measurable response after their publication. There are strong indications to suggest that the processes of dissemination and adoption of new findings are slow and generally inefficient.

3. Implementing research results – the evidence

3.1 Interview logistics

Fifty six (56) semi-structured interviews were conducted among randomly selected senior built environment researchers and policy implementers in countries listed in Table 1.
Table 1: Categories and number interviewed

<table>
<thead>
<tr>
<th>Countries surveyed</th>
<th>Category &amp; number interviewed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenya</td>
<td>Academics &amp; Researchers (2); Researchers (1); Policy implementers (1)</td>
</tr>
<tr>
<td>Uganda</td>
<td>Academics &amp; Researchers (1); Researchers (1); Policy implementers (2)</td>
</tr>
<tr>
<td>Botswana</td>
<td>Academics &amp; Researchers (2); Researchers (1); Policy implementers (1)</td>
</tr>
<tr>
<td>South Africa</td>
<td>Academics &amp; Researchers (1); Researchers (1); Policy implementers (2)</td>
</tr>
<tr>
<td>Tanzania</td>
<td>Academics &amp; Researchers (2); Researchers (1); Policy implementers (1)</td>
</tr>
<tr>
<td>Zambia</td>
<td>Academics &amp; Researchers (2); Researchers (1); Policy implementers (1)</td>
</tr>
<tr>
<td>Algeria</td>
<td>Academics &amp; Researchers (1); Researchers (1); Policy implementers (2)</td>
</tr>
<tr>
<td>Egypt</td>
<td>Academics &amp; Researchers (2); Researchers (1); Policy implementers (1)</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>Academics &amp; Researchers (1); Researchers (1); Policy implementers (2)</td>
</tr>
<tr>
<td>Ghana</td>
<td>Academics &amp; Researchers (2); Researchers (1); Policy implementers (1)</td>
</tr>
<tr>
<td>Sierra Leone</td>
<td>Academics &amp; Researchers (1); Researchers (1); Policy implementers (2)</td>
</tr>
<tr>
<td>Nigeria</td>
<td>Academics &amp; Researchers (2); Researchers (1); Policy implementers (1)</td>
</tr>
<tr>
<td>Burundi</td>
<td>Academics &amp; Researchers (1); Researchers (1); Policy implementers (2)</td>
</tr>
<tr>
<td>Rwanda</td>
<td>Academics &amp; Researchers (2); Researchers (1); Policy implementers (1)</td>
</tr>
</tbody>
</table>

The distribution for all interviewees is as indicated in Table 1.

Research findings covered in the interviews were taken from randomly selected papers and reports written by expert researchers from fourteen randomly selected African countries. The recommendation themes summary of these documents was formulated as indicated in Table 2.

After identification of recommendation themes (A and A1; B&B1; C&C1; D&D1; and E,E1 &E2) through content analysis technique (Leedy and Ormrod 2005), an informal verification process was carried out by communicating with the interviewees (Table 1) in order to establish if the recommendation themes were relevant to the respective country - these are identified with a letter ‘R’. Furthermore, the interviewees were requested to indicate if they were familiar with the research report/paper on respective recommendation themes - these are identified with a letter ‘K’. The themes which were not relevant and those in which they were not familiar with letters ‘Ro’ and ‘Ko’ were used respectively.

Table 2: Research recommendation themes per country

<table>
<thead>
<tr>
<th>Countries surveyed</th>
<th>Research recommendations themes and authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenya</td>
<td>Msita (1998); &amp; DPW (1999); Rwelamila &amp; Lobelo (2000); Lema (2000)</td>
</tr>
<tr>
<td>Uganda</td>
<td>Lema &amp; Price (1998); Mlinga &amp; Lema (2000); Talukhaba (1988);</td>
</tr>
<tr>
<td>Botswana</td>
<td>Rwelamila, Talukhaba and Ngowi (1999); Kamala &amp; Hindle</td>
</tr>
<tr>
<td>South Africa</td>
<td>Rwelamila (1996)</td>
</tr>
<tr>
<td>Tanzania</td>
<td>Walls &amp; Wells (2000); Carradine &amp; Logie (2000); Ssegawa (2000)</td>
</tr>
</tbody>
</table>
3.2 Interview results – synthesis and analysis

In order to establish the levels of implementing research findings, recommendation themes identified in Table 2 were put before the respondents (see Table 1) to indicate if implementation had taken place and the extent of implementation. The following measurements were used to measure ‘implementation of research results recommendations’; a percentage from 0P (points) = no implementation and no plan evidence towards implementation to 100P (points) = full implementation has taken place. Each research result recommendation was treated independent of the other and marked on 100 points basis. With a total of 10 research results recommendations, a total 1,000 points is the maximum each country can get if full implementation of recommendations has taken place. The interview results with total measurement on implementation research results recommendation are shown in Table 3.

<table>
<thead>
<tr>
<th>Countries surveyed</th>
<th>Recommendation themes &amp; implementation scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenya</td>
<td>$A &amp; A_1$ $T=200P$  $B &amp; B_1$ $T=200P$  $C&amp;C_1$ $T=200P$  $D$ $T=100P$  $E$, $E_1$ &amp; $E_2$ $T=300P$  Total %</td>
</tr>
<tr>
<td>Uganda</td>
<td>$25P$ &amp; $05P$  $40P$ &amp; $05P$  $20P$ &amp; $05P$  $35P$  $40P$, $40P$ &amp;</td>
</tr>
</tbody>
</table>

Table 3 Interview results – implementation scores
The interview results confirm issues discussed under Section 2 above, that there is a significant gap between knowledge production and consumption. The percentage score on implementation of research results for all fourteen countries falls below 30%. The overall average is 28%, which suggest that approximately 72% of research results produced remain unimplemented in the fourteen countries surveyed. In order to get a clear picture of the situation and appreciate the underlying issues behind these dismal scores, the results are discussed by categorizing countries into three strata: Strata I: very worse and worse; Strata II: just improving and improving; and Strata III: positive improvement.

**Strata I:**
This category has two countries – Sierra Leone (13%) and Burundi (17%)

The Sierra Leonean research recommendations scores are the lowest of all countries surveyed (13%). Taking a closer look at theme A (score of 20P), you will find that construction experts are poorly coordinated because the traditional construction professions: architects and engineers are poorly regulated and there are lessons to be learnt from Tanzania (60P), South Africa (60P) and Zambia (60P). Insolvencies among construction firms seem to be a common occurrence. Like in other thirteen countries surveyed, there is no formal development programme in Sierra Leone for informal contractors. The post war environment has frustrated the whole situation to an extent that local contractors are left to fight for their survival. Project procurement approaches in Sierra Leone, like in most African countries are still dictated by the traditional procurement approach. This has led to a situation where alternative procurement systems are embraced with traditional procurement tools (hence theme C, with a score of 10P). The procurement system environment has directly affected the

<table>
<thead>
<tr>
<th>Country</th>
<th>30P &amp; 05P</th>
<th>50P &amp; 05P</th>
<th>20P &amp; 05P</th>
<th>40P</th>
<th>50P, 50P &amp; 20P</th>
<th>28%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Botswana</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Africa</td>
<td>60P &amp; 20P</td>
<td>60P &amp; 30P</td>
<td>50P &amp; 40P</td>
<td>50P</td>
<td>70P, 50P &amp; 20P</td>
<td>45%</td>
</tr>
<tr>
<td>Tanzania</td>
<td>60P &amp; 10P</td>
<td>40P &amp; 05P</td>
<td>50P &amp; 05P</td>
<td>35P</td>
<td>45P, 45P &amp; 10P</td>
<td>31%</td>
</tr>
<tr>
<td>Zambia</td>
<td>60P &amp; 10P</td>
<td>40P &amp; 05P</td>
<td>30P &amp; 05P</td>
<td>35P</td>
<td>45P, 40P &amp; 10P</td>
<td>28%</td>
</tr>
<tr>
<td>Algeria</td>
<td>50P &amp; 15P</td>
<td>50P &amp; 25P</td>
<td>45P &amp; 30P</td>
<td>40P</td>
<td>60P, 40P &amp; 15P</td>
<td>38%</td>
</tr>
<tr>
<td>Egypt</td>
<td>55P &amp; 20P</td>
<td>55P &amp; 25P</td>
<td>45P &amp; 40P</td>
<td>45P</td>
<td>60P, 45P &amp; 14P</td>
<td>41%</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>25P &amp; 05P</td>
<td>40P &amp; 05P</td>
<td>15P &amp; 05P</td>
<td>35P</td>
<td>40P, 40P &amp; 15P</td>
<td>23%</td>
</tr>
<tr>
<td>Ghana</td>
<td>65P &amp; 05P</td>
<td>40P &amp; 05P</td>
<td>45P &amp; 05P</td>
<td>30P</td>
<td>45P, 50P &amp; 15P</td>
<td>31%</td>
</tr>
<tr>
<td>S. Leone</td>
<td>20P &amp; 05P</td>
<td>25P &amp; 05P</td>
<td>10P &amp; 05P</td>
<td>20P</td>
<td>30P, 25P &amp; 05P</td>
<td>13%</td>
</tr>
<tr>
<td>Nigeria</td>
<td>60P &amp; 05P</td>
<td>35P &amp; 05P</td>
<td>40P &amp; 05P</td>
<td>35P</td>
<td>40P, 45P &amp; 20P</td>
<td>29%</td>
</tr>
<tr>
<td>Burundi</td>
<td>20P &amp; 05P</td>
<td>25P &amp; 05P</td>
<td>15P &amp; 05P</td>
<td>25P</td>
<td>35P, 25P &amp; 05P</td>
<td>17%</td>
</tr>
<tr>
<td>Rwanda</td>
<td>30P &amp; 05P</td>
<td>40P &amp; 05P</td>
<td>25P &amp; 05P</td>
<td>30P</td>
<td>35P, 35P &amp; 15P</td>
<td>23%</td>
</tr>
</tbody>
</table>
slow emergence of construction project management (CPM) as a distinct profession in Sierra Leone. This is also true in most countries surveyed with the exception of South Africa.

Like in most African countries surveyed, the majority of CPMs are still accidental project managers – again enthusiastic civil engineers and architects with very little CPM knowledge base seem to assume the role of a CPM (theme C1, with a dismal score of 05P). As in most African countries, the fact the majority of CPMs are accidental as confirmed under theme C1 score, processes of managing projects are consequently very poor (theme D, with a score of 30P). The quality and efficiency of construction materials logistics in Sierra Leone is still archaic and need a well organised strategy (theme E, with a score of 30P). The need to reconstruct war torn areas has indirectly put pressure on the development of local contractors and this has brought a slight change on the plight of citizen contractors, but still a lots need to be done (theme E1, with a score of 25P). Financial management ethos of SMMEs, are almost at infancy (theme E2, with a score of 05P).

The Sierra Leone built environment, and specifically the construction industry still faces an enormous challenge of bridging the gap from a 13% positive research implementation position to a deficit which is standing at 87%. There are strong indications to suggest that Sierra Leone seems to have the worst research implementation environment. Beside her disorganised built environment the past war environment seems to have made the situation worse. A well conceptualized project seems to be the only option in order to move out of this sorry state.

The Burundi situation is closely related to Sierra Leone and similar interventions are recommended.

**Strata II:**
The majority of countries surveyed fall under this category. These include Kenya (27%); Uganda (23%); Botswana (28%); Tanzania (31%); Zambia (28%); Ethiopia (23%); Ghana (31%); Nigeria (29%); and Rwanda (23%). Each of these countries seems to be working towards establishing communication between researchers and practitioners and policy makers. While Ethiopia, Uganda, Kenya and Rwanda have started to create an environment conducive for researchers/practitioners/policy makers to communicate, Tanzania, Botswana, Zambia, Ghana and Nigeria have notable progress ahead of the former. The establishment of the National Construction Council in Tanzania and similar organisations in Zambia, Ghana and Nigeria has brought awareness on the need to bridge the gap between research and implementation. Beside Tanzania and Ghana which seem to have a research deficit below 70%, the rest of the countries have a deficit above 70%.

Taking a closer look, at theme A, you will find that construction experts are now well coordinated across these countries because the traditional construction professions: architects, engineers; and quantity surveyors are statutorily regulated. The only professions which are currently not regulated by law are construction project management and construction management. Again, this is where South Africa has got an edge over these countries.

The majority of CPMs within these countries are still accidental project managers – again enthusiastic civil engineers, architects, construction managers and quantity surveyors filling the gap with very
little CPM knowledge base. The fact that the majority of CPMs are accidental as confirmed under theme C1 scores, processes of managing projects are consequently very poor (see theme D scores).

**Strata III:**

Only three countries fall under this category – these are South Africa (45%) and Egypt (41%).

The South African research findings implementation scores are the highest of the fourteen countries surveyed. Probably this was expected when you compare economic development levels between the countries. A closer look at theme A (coordination of construction professionals, score of 60P). This is a very high score and a reflection on the status of organisation of construction experts. All construction professionals in South Africa have a statutory requirement to register, and this has brought a formal framework of regulating professionals for good practice. Egypt scores less than South Africa (55P) because not all construction professionals are registrable (CPMs and CMs).

The principal aim of regulating the professions is to protect the public. It is important to state that South Africa is the only country within Africa with a statutory registration requirement for construction project managers (CPM) and construction managers (CM) as distinct professionals. Although insolvencies among construction firms (theme A1, score of 20P for both countries) are to some extent very common but South Africa and Egypt situations are slightly better than other twelve countries surveyed. Strict financial systems and corporate governance systems advances have contributed significantly to the situation. When compared with other countries surveyed, the general quality of constructed work could be described as good. This promising situation is clearly confirmed by theme B scores of 60P. There is no formal development programme in South Africa on informal contractors, but like Botswana, the informal contractors seem to enjoy the trappings of some initiatives which are primarily intended for formal emerging contractors (theme B1 scores). But, it should be said that the state of informal contractors support is still below the required levels. Project procurement approaches in South Africa and Egypt are still dictated by the traditional procurement approach and this is the same for Strata I and Strata II countries.

It is important to note that although Egypt is categorized together with South Africa, the South African situation looks better than the rest of the countries surveyed, though still a long way to reach required levels. Although the majority of CPMs practicing in South Africa are predominantly accidental like in most other countries, the emergence of the statutory registration body: the South African Council for Project and Construction Management Professions (SACPCMP) has brought in an element of standards and a future possibility of enhancing CPM knowledge as one of the requirements (thus theme C1, with a score of 40P).

The gap between research findings and implementation is still very huge. A deficit of approximately 55% for South Africa and 59% for Egypt is alarming for both countries which boast a good number of world class construction companies and a well established construction expert base.
**Interview results summary**

The interview results from randomly selected senior built environment researchers and policy implementers in the fourteen countries, have confirmed once again the author’s belief from the first and second phases of this study (Rwelamila 2009a&b), that there is a gap between research findings and practice in the African built environment. Research implementation gaps shown in Table 3 should be a concern to all ABE stakeholders – especially public policy implementers, constructors and other construction experts.

The Sierra Leonean implementation score, which are the lowest of all countries surveyed (13%), leaves a lot to be desired. The 87% gap need combined efforts from all Sierra Leonean construction industry stakeholders - academics, researchers, and policy makers and implementers to work as a team and reflect on the Sierra Leonean construction industry challenges solutions which are gathering dust in various research documents.

The Burundi implementation score (17%), which very close to Sierra Leone should be a cause for concern and a challenge to all Burundi built environment stakeholders. The 83% gap is a clarion call to all policy makers, researchers and practitioners to find ways of addressing the gap.

Countries falling under Strata II, have an average implementation score of 27% and thus an average deficit of 73%. Although better than Burundi and Sierra Leone, this is a significant deficit which need an appropriate solution. Current developments of prioritizing construction development within these countries, especially in Tanzania (31%), Ghana (31%) and Rwanda (23%) are encouraging and should be supported by both public and private sector.

Although South Africa and Egypt seem to have better research implementation scores of 45% and 41% respectively, when compared with the other twelve countries, these scores are not proportional to their economic development levels and resources ability to address challenges facing both construction industries. The corresponding gaps of 55% and 59% respectively, need to stimulate debate among the academics, researchers and policy makers and implementers within these countries.

If these results could be interpolated, for the whole African built environment, the message to all stakeholders is that despite the considerable resources which are spent on research, relatively little attention is being paid to ensuring that research findings are implemented in practice. There is a need to find appropriate interventions that can be used to promote behavioural change among construction industry practitioners and the implementation of research findings. The W107 could become a convener for these interventions.

4. Conclusions and recommendations

The results of this third and final study and theory and practice issues reported above strongly suggest that a large gap exist between built environment knowledge generated through research and its application in individual, industry stakeholders, expert organisational, and policy innovation.
An average deficit of approximately 72% for the fourteen countries surveyed is alarming—*it is a huge challenge.* Hence the question which should be asked by ABE stakeholders is: *How can the built environment community solve this challenge?* First, the research community must acknowledge that the problem exists. Various studies in the medical industry have identified a number of barriers which are relevant to the construction industry, these include: *inadequate interaction between researchers and practitioners, lack of knowledge of advances in various spheres of project management and construction management, and resistance to change.* One can’t fault these perceptions. At the heart of the problem are deficiencies in the construction researchers’ knowledge of how to inform and to alter behaviour of both practitioners and clients.

All the best efforts of basic researchers and those in construction management and construction project management research are of little use to the clients, users of built environment products and other construction experts if the results are not conveyed to those who can use them in an efficient manner. Busy construction industry practitioners can hardly be expected to peruse through journals, conference proceedings and other research reports or to interpret the results correctly when the reports are laced with statistics. It is the responsibility of the researcher to convey the information in a more palatable form and the follow up any construction industry development findings to determine if they have reached their targets and whether the intended changes in behaviour have occurred. If they have not, the researcher must find the reasons for the failure and begin looking for some means of rectifying it.

This is a challenging new task for most academics, researchers policy practitioners (like CIDB, NCI, etc) and may require combined talents from several construction expert areas. None the less, it is an essential undertaking and one that must be approached with dedication and imagination if research resources are not to be wasted in the lean years ahead. Probably the initiative should start with W107.

**References**


Abstract

Time, cost and most critical aspects for any construction project with both client and contractor. Studies were conducted to model the time–cost trade-off ranging from heuristic methods and mathematical approaches to genetic algorithms. Emergence of new contract procedures and construction techniques place an increasing pressure on maximizing the quality of projects while minimizing its time and cost, require the development of innovative models considering risk in addition to time and cost. In this study, a meta-heuristic multi-colony ant algorithm is developed for optimization of three objectives time-cost-risk as a trade-off problem. An attempt is devised to develop a Multi Objective Optimisation Model (MOOM) capable of minimizing time and cost of projects (inclusive of risk) as multi-objective optimization of time-cost-risk tradeoff. The model thus developed is then compared with analogous model and the efficiency of this model is ascertained. An example is analyzed to demonstrate the present method in generating optimal/near optimal solutions. The result obtained from the algorithm developed is weighed against solutions of the problem obtained from Modified Adaptive Weight Approach (MAWA) adopted and Multi Objective Ant Colony Optimization (MOACO) adopted and it is found that the model developed gives efficient results when compared to MAWA and comparable results when compared to MOACO.

Keywords: time-cost-risk trade-off, multi-objective optimization, multi-colony, ant colony optimization.
1. Introduction

The prime objective of construction project management is to execute the project within the stipulated time schedule meeting the quality specifications with minimal cost. Scheduling the project based on time and resource is highly needed to achieve project targets. Various methods like network based and non network based have been applied for scheduling in construction industry. Activities can be scheduled to comply with constrained resource usage, after critical path has been identified. This involves determining the start time of non critical activities within total float. Another aim is to make the resource consumption profile as smooth as possible thus minimizing the mobilization and demobilization cost. Sometimes different time estimates are available for activities. However lower activity duration leads to higher direct costs and lower indirect cost. In such a case it is important to study the tradeoff between completion time, risk involved in each resource option and cost of the project. Crashing of activities results in increase in resource utilization which eventually leads to increase in cost of the project and vice versa. Trade-off between these conflicting aspects of project leads to challenging job and as such planners are faced with numerous possible combinations for project delivery. This leads to time and cost of activities, each resource utilization option will yield a specific risk. If durations of the activities are reduced, the cost will increase due more resources allocated to their rapid accomplishment. On other hand, using fewer resources will result in increased duration of activities. In addition to time and cost of activities, every resource utilization option will yield specific performance quality that eventually leads to deviation from planned cost and duration. Construction projects are becoming increasingly complex and dynamic in their nature, and the introduction of new procurement methods mean that the every resource utilization option will have to be chosen according to the risk involved with each resource option. The construction industry has been plagued by risk and this has not been dealt with adequately, often resulting in poor performance which increases cost and results in time delays. Trade-off between these conflicting aspects of project is a challenging job and as such planners are faced with numerous possible combinations for project delivery. As an example, the number of possible combinations in a project with 18 activities and 4 possible resource utilization options for each activity will be more than 6 billion. A novel searching tool would then be worthwhile for comprehensive yet efficient time-cost-risk trade-off problem (El-Rayes. 2005).

These problems, when formulated mathematically as optimization problems, are Nondeterministic Polynomial (NP-complete). Since no solution techniques which can guarantee the optimal solution in polynomial time are available, nontraditional approximation algorithms like Genetic Algorithms, Ant Colony Optimization (ACO) will have to be used to achieve optimal solution. In recent years, evolutionary and meta-heuristic algorithms have been extensively used as search and optimization tools in various problem domains, including science, commerce, and engineering. Ease of use, broad applicability, and global perspective may be considered as the primary reason for their success. Ant colony optimization algorithms are inspired by the fact that ants are able to find the shortest route between their nest and a food source, even though they are almost blind (Dorigo. 1992). Researchers have reported the robustness of ACO and their capacity to efficiently search for and locate an optimum/near optimum especially in discrete optimization problems. The Ant Colony Optimization has been and continues to be a fruitful paradigm for designing effective combinatorial optimization
solution algorithms. After more than ten years of studies, both its application effectiveness and its theoretical groundings have been demonstrated, making ACO one of the most successful paradigms in the metaheuristic area. The constrained resource allocation problems can be solved using the ACO technique, where the objective will be to minimize the total time and risk of the project with resource availability and precedence relationships as constraints.

1.1 Ant Colony Optimization algorithm

The ant colony optimization algorithm (ACO) is a probabilistic technique for solving computational problems which can be reduced to finding good paths through graphs. Ant colony optimization algorithms are inspired by the fact that ants are able to find the shortest route between their nest and a food source, even though they are almost blind (Dorigo. 1992). The ACO algorithm has already proved to be very useful in giving nearly optimal solutions to many complex and discrete optimization problems.

In the real world the ants wander randomly in search of food and upon finding the food they return to their nest leaving behind a pheromone trail. Other ants in span of time find such paths and starts following the trail, thereby reinforcing the pheromone trail, if they are successful in finding food. However the pheromone is a highly volatile substance and over a time period it evaporates, thus reducing its strength. Hence a longer paths leads to more pheromone being evaporated when compared to a shorter path, thus in comparison always a shorter path is chosen because of relatively higher density of pheromones. The advantage of the pheromone evaporation is that it avoids the convergence to a locally optimal solution. Considering the case if there was no evaporation at all, then there would be no way for the ant to distinct between the shorter and longer path and hence an optimum pathway won’t be achieved, instead we will only get a general pathway. Thus, in actual when one ant finds a good (i.e., short) path from the colony to a food source, other ants are more likely to follow that path, and positive feedback eventually leads all the ants following a single path.

The idea of the ant colony algorithm is to mimic this behavior with "simulated ants" walking around the graph representing the problem to solve. These finite sizes of simulated ants collectively search for a good solution for the problem under consideration. Each ant builds a solution for the problem but ultimately the most efficient solution is chosen by all the ants and the optimized solution of the problem is obtained. While building its own solution, each ant collects information on its own performance and uses this information to modify the representation of the problem, as seen by other ants (Dorigo. 1992).

The Artificial ants release the pheromones while they are developing the solution. The amounts of pheromones deposited are further dependent on the efficiency of the solution. The more efficient the solution is the more pheromone is deposited. A coefficient ($\rho$) is defined in the algorithm which enables a more thorough analysis of the problem and prevents the local convergence of suboptimal solutions.

Let $\tau_{i,j}$ is the amount of pheromone on path $i,j$ and $\eta_{i,j}$ is the desirability of path $i,j$.
Transition probability from node $i$ to node $j$ may be defined as (Dorigo . 2004):

$$\rho_{i,j} = \frac{(\tau_{i,j})(\eta_{i,j})}{(\tau^{p}_{i,j})(\eta^{p}_{i,j})}$$

Where $\alpha$ is a parameter to control the influence of $\tau_{i,j}$ and $\beta$ is a parameter to control the influence of $\eta_{i,j}$. Also after every iteration the Pheromone Update will take place according to the following equation.

$$\tau_{i,j} = (1 - \rho)\tau_{i,j} + \Delta\tau_{i,j}$$

where $\tau_{i,j}$ is the amount of pheromone on a given edge $i,j$ before and after the respective iterations. $\rho$ is the rate of pheromone evaporation and $\Delta\tau_{i,j}$ is the amount of pheromone deposited, typically given by

$$\Delta\tau_{i,j}^k = \begin{cases} 
1/L_k & \text{if ant } k \text{ travels on edge } i,j \\
0 & \text{otherwise}
\end{cases}$$

where $L_k$ is the cost of the $k$th ant's tour (typically length).

2. Description of the problem and formulation

The present problem is modelled with options for resource utilization of varying cost, time and risk factors. The goal is to find the optimal or near optimal solution. In order to apply ACO algorithm to a specific problem, the problem should be represented as graph or similar structure easily covered by ants, in which a project with $N$ activities and $K$ resource utilization options is characterized. The path of arrows represents a typical solution which may be selected by ants. For more illustration and future reference a vector is defined for each possible solution that demonstrates the options of resource utilization for all of the activities respectively (Afshar. 2006). The problem mainly concentrates on selecting appropriate options for every activity to obtain the objective of time, cost and risk of a project.

Quantifying the risk involved in performing different activity as a function of different resource utilizations is a challenging work because of difficulty in measuring the impact of these strategies of performing activities on the quality. Moreover, it is a complicated work to evaluate the proportion of the individual activities’ risk on performance of the project. Some indicators have been investigated and identified in recent studies that were aimed at developing quality-based contractor prequalification systems (Sundarajulu. 2007). The identified quality indicators dependent on risk were derived from performance based models that correlate the long-term performance of the end product of each activity to its risk. The objective of risk may be evaluated with following function:

$$\text{Mean Risk} = \frac{\sum (r \times w)}{\sum w}$$

Where $r$ is the risk of the optimized resource option for each activity $w$ is the activity weight for each activity.
3. Multi objective optimisation model (moom) for time-cost-risk trade-off

In the proposed algorithm, for each objective a colony of agents is assigned. All the colonies have the same number of ants. All the ants in one colony try to find a solution at the same time according to the assigned objective. Solutions found for one objective in one cycle are not evaluated in the corresponding colony. The produced solutions are transferred to the next colony to be evaluated according to the assigned objective and the global trail of that colony is updated. The new solutions found based on the new pheromone trail in the second colony are transferred to third colony. This process (finding set of solutions in each colony and having the following colony to use these produced solutions for updating) continues up to a predefined iteration called cycle iteration.

3.1 Optimization parameters

We assume the initial $\tau_{ij} = 1/(\text{number of resource options})$. Where $\tau_{ij}$ is the amount of pheromone on edge i,j. So initially on all the nodes some pheromone is to be allotted in order to attract the ant. Considering initial pheromone to be distributed to be 1 and then divided equally among all the nodes it will initially making all the nodes equally attractive for the ants and hence ensuring more of less random movement of ants from one node to the other. $\rho$ is already defined as the rate of pheromone evaporation. Its value is significant because it leads to subsequent evaporation of the other trails on the paths which are longer than the optimized path, it value can range anywhere between 0.5 to 0.99 and the lower value only leads to faster disappearance of the residual paths. A value of 0.97 is chosen considering network to be dynamic and considering gradual disappearance of the redundant alternate path of the network. The value of $\eta_{ij} = (1/d_{ij})$, where $d_{ij} =$ cost of the kth ant's tour so in our case it will be the cost of using a particular resource option in between two activities.

Parameters $\alpha$ and $\beta$ values controls the influence of the $\tau_{ij}$ & $\eta_{ij}$ function respectively. This value can be changed to increase the influence of one with respect to other in influencing the probability of the path. Consider first the influence of the parameter $\alpha$. For $\alpha>0$, the larger the value of $\alpha$, the stronger chances are that activity with lesser cost will be selected, for $\alpha=0$ the pheromone trails are not taken into account at all and the selection probabilities are proportional to $\eta_{ij}$ only thus time and risk would have no bearing on the selection of activities. In such cases the activity with lowest cost will definitely be selected, and for $\alpha<0$ the most probable choices done by the ants are those that are less desirable from the point of view of pheromone trails. Hence, varying $\alpha$ could be used to shift from exploration to exploitation and vice versa. The parameter $\beta$ determines the influence of the heuristic information in a similar way. If $\beta = 0$, only pheromone amplification is at work and the selection probabilities are proportional to $\tau_{ij}$ only, the activity with lesser time and risk will have more probability of being selected. Finally, an important, though somewhat neglected, role in the balance of exploration and exploitation is that of the parameters $\alpha$ and $\beta$, which determine the relative influence of pheromone trail and heuristic information. (Dorigo.1992).
Parameters of the algorithm were tuned by trial and error. Final common parameters are set as $\alpha = 1$ and $\beta = 0.01$.

$\Delta \tau_{ij}$ is the amount of pheromones deposited in a particular iteration.

$$\Delta \tau_{ij} = \frac{1}{L_k}$$

$L_k$ is taken as the cost which is again taken as function of time. Regression analysis for parameters viz. time and cost of different construction activities was carried out taking into account the risk. Separate relations were obtained for different values of risks under different zones as laid down in the section zoning of risks. The curve obtained by the regression analysis between cost and time for typical construction activity is presented in Figure 1. The best fit for this activity is found to be power function with coefficient of regression value of 0.686. This function is then utilized for deriving $L_k$ value.

Figure 1: Cost vs. Time

$$L_k = \left( \frac{\text{duration}}{10} \right)^{\text{risk}} \cdot \frac{1}{0.25}$$
3.2 Zoning of risks

Risk assessment is a complex subject shrouded in vagueness and uncertainties. According to Carr V. 2001 vague terms are often unavoidable when defining risk since individuals often finds it easier to describe risk in quantitative linguistic terms. Risk management in a project encompasses identifying influencing factors that could potentially negatively impact a project’s cost schedule or quality baselines; quantifying the associated potential impact of the identified risk; and implementing measures to manage and mitigate the potential impact.

The risk associated with construction project is classified based on Figure 2 proposed by Kit. 2003. The risk factors thus identified are then groped based on the product of probability and impact as proposed in Graves 2000 into five zones. The zoning of risk is based on the severity of risk obtained as the product of probability and impact.

Risk occurrence in construction project for this study is categorized into

- project costs variation (increase or decrease),
- schedule (schedule delay & overrun), and
- Quality.

The risks are qualitatively those that have both the highest impact on the project and are most likely to occur. Here the impact, probability, and severity (criticality) of each risk were quantified into zones in the probability-impact matrix Graves 2000.

The risks associated with the construction industry were extensively analyzed using factor analysis with multiple regression models, ANOVA and T-tests sundarajulu 2007. The values used for probability and impact are indices that and represent combined effect of the risks. The quantitative assessment is based on the mean values which was proposed by sundarajulu 2007 This study incorporates nonnumeric probability scale (a three-level scale), where 1=Low Probability, 2=Intermediate Probability, 3=High Probability, and impact is measured as deviation in project schedule which is also represented on a nonnumeric scale of 1-3 where 1=Low Impact, 2=Intermediate Impact, 3=High Impact which is presented in Table 1. The impact on the project schedule was measured for the schedule project delay on a scale of 1-3 Graves 2000.

In this study presented the assessed probability and impact for each risk were used to determine the Severity based on

\[ \text{Severity (risk)} = \text{Probability} \times \text{Impact} \]

This is then zoned into the Probability-Impact (P-I) matrix as presented in Table 2. The matrix is then based on studies of divided into 6 zones Graves 2000 and presented in Figure 2. The scope of the study is restricted to five zones as the zone with low probability low impact is ignored in risk management practice.
Table 1: Rating Risk Impact on Schedule on a Three-Level Scale

<table>
<thead>
<tr>
<th>Scale</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Impact</td>
<td>Low</td>
<td>Intermediate</td>
<td>Very high</td>
</tr>
<tr>
<td>Risk on schedule of project</td>
<td>Overall project delay &lt; 5%</td>
<td>Overall project delay 5-25%</td>
<td>Overall project delay &gt; 25%</td>
</tr>
</tbody>
</table>

Table 2: Probability-Impact (P-I) Matrix

<table>
<thead>
<tr>
<th>Probability</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>LI=1</td>
<td>II=2</td>
</tr>
<tr>
<td>HP=3</td>
<td>3</td>
</tr>
<tr>
<td>IP=2</td>
<td>2</td>
</tr>
<tr>
<td>LP=1</td>
<td>1</td>
</tr>
</tbody>
</table>

The risk factors have been been classified into 6 zones based on the P-I matrix and the risk classified in the zone having lowest impact and probability is ignored in this study. The exclusion is based on the practice in industry. From the P-I matrix it is the zone with value 1. All other groups are divided according to the corresponding results. Based upon factor analysis, the corresponding probabilities were obtained and were subsequently classified into risk zones based on their likelihood which essentially is based on the mean values obtained Sundarajulu 2007.

Figure 2: Zoning for risks according to probability vs. impact curve

4. Case study

The concept and performance of the proposed algorithm is tested based on the test project with detailed information presented in Table 2 is used as a case study which was originally introduced by Feng .1992 and then the same used by Zheng .2005 for stochastic construction time-cost-risk trade-off analysis. Table 2 includes the related data on different resource utilizations and their
corresponding time, cost and risk is based on from Feng . 2005. The project has an indirect cost equal to $500/day.

The proposed Multi-Colony Ant Algorithm was fed with the project data as shown in Table 2. Other parameters of algorithm are set to $\rho = 0.97$, $\alpha = 1$, $\beta = 0.01$ and $Q=0.25$

### 4.1 Interconvertability of quality parameter to risk factor

The quality parameter mentioned in Afshar. 2006 is being converted to risk as shown in Table 3. This conversion is based on the comparative study and opinion analysis from experts’ viz. project managers, building construction contractors and construction management consultants. The values thus obtained are used to modify the data in Table 4 where column of quality parameters is replaced by risk factor values.

Construction risk is generally perceived as events that influence project objectives of cost, time and quality. Risk analysis and management in construction depend mainly on intuition, judgement and experience. Quality being one of the most important factors while assessing risk needs to be quantified and incorporated because of the importance at all stages of the project. One of aim of the industry is to deliver a good quality project after the trade off. Hence, maximum values of the risk zones classified above were used to demonstrate the model’s efficiency thus delivering least risk which corresponds to maximum quality. However any intermediate values can be obtained by interpolation depending upon the utility values and the $R^2$ values of the used utility lines.

Measuring quality parameter for engineering and economic analysis is a difficult task. However the relative importance of various risks affecting a construction project was quantified and the weights of relative importance level of each component quality criterion were determined. In this way, the value of the entire quality of construction projects was consequently measured Cau B T (1998) and hence was used to quantify into different zones of risks.

The comparison between both the models yields optimized cost considering different parameters. Although amongst the two solutions one cannot be said to be better than the other even as one model yields lesser cost while the other yields lesser risk. In the proposed model an attempt has been made to achieve a balance between cost, time and risk giving each parameter due importance hence yielding an optimized solution for the given trade off.

The optimal solution for time and cost obtained using multi objective ant colony optimization is compared with the standard MOACO (Multi Objective Ant Colony Optimization) technique proposed by Afshar .2006. The result thus obtained is presented in Table 5.

The most optimal solution is obtained from a set of solutions that are tradeoff between time cost and risk, taking into account the various resource utilization options. Results of the proposed approach for time-cost trade-off problem using MOACO as compared to those reported by Zheng . (2005) MAWA (modified adaptive weight approach) are compared in Table 6.
### Table 3: Risk-Quality inter convertibility table

<table>
<thead>
<tr>
<th>Quality Parameter</th>
<th>Risk Factor Zone</th>
<th>Risk Factor Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>96-100</td>
<td>ZONE 1</td>
<td>0.10</td>
</tr>
<tr>
<td>90-95</td>
<td>ZONE 2</td>
<td>0.20</td>
</tr>
<tr>
<td>80-90</td>
<td>ZONE 3</td>
<td>0.35</td>
</tr>
<tr>
<td>70-79</td>
<td>ZONE 4</td>
<td>0.45</td>
</tr>
<tr>
<td>&lt;60</td>
<td>ZONE 5</td>
<td>0.60</td>
</tr>
</tbody>
</table>

### Table 4: Detailed data of the example (Source: Afshar et al., 2006)

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>PRECEDING ACTIVITY</th>
<th>RESOURCE OPTIONS</th>
<th>RISK</th>
<th>DURATION</th>
<th>COST($)</th>
<th>WEIGHT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>1</td>
<td>0.10</td>
<td>14</td>
<td>23000</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>2</td>
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<td></td>
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<td>3</td>
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<td>12000</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0.10</td>
<td>15</td>
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<tr>
<td></td>
<td></td>
<td>2</td>
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<td>18</td>
<td>2400</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.35</td>
<td>20</td>
<td>1800</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>0.45</td>
<td>30</td>
<td>1200</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>0.60</td>
<td>60</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0.10</td>
<td>15</td>
<td>4500</td>
<td></td>
</tr>
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<td></td>
<td></td>
<td>2</td>
<td>0.35</td>
<td>22</td>
<td>4000</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.60</td>
<td>33</td>
<td>3200</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1</td>
<td>0.20</td>
<td>12</td>
<td>45000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
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<td>16</td>
<td>35000</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.60</td>
<td>20</td>
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</tr>
<tr>
<td>5</td>
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<td>1</td>
<td>0.10</td>
<td>22</td>
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<tr>
<td></td>
<td></td>
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<td>17500</td>
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<td>3</td>
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<td>28</td>
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<td></td>
<td></td>
<td>4</td>
<td>0.60</td>
<td>30</td>
<td>10000</td>
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<tr>
<td>6</td>
<td>4</td>
<td>1</td>
<td>0.10</td>
<td>14</td>
<td>40000</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>2</td>
<td>0.45</td>
<td>18</td>
<td>32000</td>
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<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.60</td>
<td>24</td>
<td>18000</td>
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<td>7</td>
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<td>2</td>
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<td>15</td>
<td>24000</td>
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<tr>
<td></td>
<td></td>
<td>3</td>
<td>0.60</td>
<td>18</td>
<td>22000</td>
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</tbody>
</table>
Table 5: Comparison between our solution and that obtained from MOACO

<table>
<thead>
<tr>
<th>SOLUTION</th>
<th>TIME(days)</th>
<th>COST($)</th>
<th>RISK</th>
<th>RESOURCE OPTION</th>
<th>MODEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>165500</td>
<td>0.136</td>
<td>1</td>
<td>1</td>
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<td></td>
<td>1</td>
<td>MOSO</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>155500</td>
<td>0.1835</td>
<td>1</td>
<td>1</td>
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<td></td>
<td></td>
<td></td>
<td>1</td>
<td>MOACO</td>
</tr>
</tbody>
</table>

Table 6: Comparison of the results generated by MAWA model (Zheng, 2005) with the proposed MOACO model

<table>
<thead>
<tr>
<th>S.No.</th>
<th>TIME</th>
<th>COST</th>
<th>MODEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>61</td>
<td>173000</td>
<td>50-MAWA</td>
</tr>
<tr>
<td>2</td>
<td>61</td>
<td>173000</td>
<td>100-MAWA</td>
</tr>
<tr>
<td>3</td>
<td>61</td>
<td>173000</td>
<td>30-MOACO</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>165500</td>
<td>MOSO</td>
</tr>
</tbody>
</table>

5. Conclusions

A Multi-Objective Ant Colony Optimization is developed to optimize the advanced time cost-risk trade-off problem. The model is capable of minimizing time, cost and risk of building construction projects. However with thorough analysis, this model can be extended to other sectors of construction and industrial project management.

The efficiency of the proposed algorithm is verified and validated based on the standard example which confirms the capability of model in considering risk and generating optimal solution. Moreover, the model was used to optimize time-cost-risk trade-off and compared to the results with MAWA approach (Zheng, 2005) and MOACO approach (Afshar, 2006). However the study needs to be carried out elaborately into the interaction of various risks and influence of interacting risk factors on building construction project. This model with its limitation is able to predict cost and time of the project more accurately than conventional techniques. The novelty concept of risk with time-cost trade off using ant colony optimization is introduced into construction management research. The inter convertibility of risk and quality is highly debatable by many researchers. The study is conducted be inter-converting risk and quality which is based on the observation for overruns in site and spotting that factors influencing quality is also influencing the risk factors. The present algorithm provides an attractive alternative for the solution of the construction multi-objective optimization problems.

References


Sundararajulu. V and Devadas Manoharan P (2007)."Important Factors for Successful Construction of Project Involving Concrete”, Journal of Indian Concrete Institute, Vol 8 47-54


The role of construction in socio-economic development has been addressed by various writers and international bodies, many of whom have focused on developing countries (Turin, 1973; World Bank, 1984; Wells, 1986; Ofori, 1990; Palalani, 2000). Developing countries and specially Sudan face major problems related to extended urbanization, which are result of war, conflicts, socio-economic factors and environmental depletion. This growth is creating exceptional demands for space and services to be provided by the construction industry which provides facilities necessary for the economic development and well-being of people. Therefore, Construction is an important sector contributing to survival and the economical output of nations, its role is inevitable. This study will review the status of construction and building industries and their importance in Sudan as a developing country with special emphasis on building materials and components industry. Peace and the following stage of the economical development and the future of construction industry in Sudan require a higher level of sustainable production of building materials and adoption of appropriate technologies in terms of economical, technological, and environmental efficiency. Therefore, this paper concentrates on the building materials with a special focus on Southern Sudan and Darfur since that these two regions, because of the war and conflicts, are experiencing severe supply problems. The availability, supply, quality, and distribution of building materials are of the most serious problems facing the construction industry and housing Sector and hence peace in these regions and in Sudan as a whole. This situation motivated the authors to attempt to throw light on it. This paper is prepared as an introductory to a wide research on the construction and building materials industries in Sudan. It identifies the common challenges that face developing countries generally and Sudan specifically in the construction and building materials industries. Surveys and available literature were the main source of data beside the statistics provided by governmental authorities in Sudan and international organizations; United Nations, World Bank, etc. The paper identifies a set a challenges, which face the construction and building materials industries in Sudan, to be investigated. As a consequence of war and conflicts, the regions of Southern Sudan and Darfur need more developmental programs and further attention.

**Keywords:** construction industry, building materials, economy, Sudan, southern Sudan, Darfur
1. Construction & building materials industries and development

1.1 Introduction

The Construction Industry has been identified as one of the main engines of growth in any economy. It provides the infrastructure required for other sectors of the economy to flourish, provides housing as the basic human need. The role of construction in socio-economic development has been addressed by various writers and international bodies, many of whom have focused on developing countries (Turin, 1973; World Bank, 1984; Wells, 1986; Ofori, 1990; Palalani, 2000). The provision and maintenance of shelter, other permanent structures and infrastructure networks are fundamental to the national economy. In almost every sector of the economy - agriculture, health, industry and communications - there is some construction component (UNCHS, 1986). Construction activity is an integral part of a country’s infrastructure and industrial development. It includes hospitals, schools, townships, offices, houses and other buildings; urban infrastructure (including water supply, sewerage, drainage); highways, roads, ports, railways, airports; power systems; irrigation and agriculture systems; telecommunications etc. Covering as it does such a wide spectrum, construction becomes the basic input for socio-economic development (Planning Commission (India), 2002). The construction sector has major linkages with the building materials industry since construction materials accounts for a sizeable share of the construction costs (Shaddad, 1979).

Sudan, as a developing country, has experienced great developments during the previous decades. These developments took place in many fields, of which the construction industry is an important one. A wide range of various construction materials is used in the construction of different types of buildings. The prefabricated units and high tech facades become common features in the today buildings in urban centers. Today, the construction companies draw a great attention to the management of the production resources and the environmental impact of its consumption. However, this development is concentrated in the capital and some of the big cities besides the areas of oil production. Areas of conflict- Southern Sudan and Darfur- suffer severely from the underdevelopment of the construction sector and experience challenges in the building materials industry on different levels (production, supply, use, waste treatment, … etc). Despite the resolution of the war in Southern Sudan and the increase in the level of construction works, the building materials form a major obstacle in the development process in the region. The regions of Southern Sudan and Darfur lack capacity to produce building materials in order to satisfy their local demand. No doubt, the whole country lack capacity in production, however, the situation in Southern Sudan and Darfur is more acute.
1.2 The relation between construction & building materials and components industries

A wide range of materials is used in building industry for new buildings, maintenance and civil engineering. Some materials like cement and bricks are produced exclusively for construction purposes. Other materials, although construction may be the largest user of the industry’s products, are nevertheless produced for a wide range of uses, e.g. iron, steel, and wood-based products (Elkhalifa & Shaddad, 2008). As many materials are actually made on site, especially at the early stages of economic development, a considerable overlap exists between the building materials and the construction industry. Production of such materials (e.g. concrete blocks) would count as part of the construction process. Many materials inputs (e.g. aggregate) are supplied in semi-produced or simply shaped state. Production of such materials is not always recognized as a manufacturing industry. Development plans and national statistics, when available in developing countries, cover only the key materials (i.e. cement steel, wood products). However, planning for inputs for construction must take account of the whole range of materials required; critical shortage of even small component would cause a serious delay to construction output (Shaddad, 1979).

Building materials constitute the single largest input to construction, accounting for 50 to 80 per cent of its total value (UNCHS, 1986). Generally speaking, the cost of building materials represents the highest share in comparison to other construction cost components for all categories of construction industry. Table (1) shows a breakdown of construction cost components for the main categories of construction industry, which is developed by Construction Industry Development Council Survey in India.

Table 1: Share of Construction cost components (%) into different construction categories (Source: Planning Commission (Government of India) Tenth Five year Plan 2002)

<table>
<thead>
<tr>
<th>Category</th>
<th>Materials %</th>
<th>Equipments %</th>
<th>Labor %</th>
<th>Finance %</th>
<th>Enabling %</th>
<th>Admin. %</th>
<th>Surplus %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building</td>
<td>58-60</td>
<td>4.5</td>
<td>11-13</td>
<td>7-8</td>
<td>5.5-6.5</td>
<td>3.5-4.5</td>
<td>5-6</td>
</tr>
<tr>
<td>Roads</td>
<td>42-45</td>
<td>21-23</td>
<td>10-12</td>
<td>7-8</td>
<td>5.5-6.5</td>
<td>3.5-4.5</td>
<td>5-6</td>
</tr>
<tr>
<td>Bridges</td>
<td>46-48</td>
<td>16-18</td>
<td>11-13</td>
<td>7-8</td>
<td>5.5-6.5</td>
<td>3.5-4.5</td>
<td>5-6</td>
</tr>
<tr>
<td>Dams, etc</td>
<td>42-46</td>
<td>21-23</td>
<td>10-12</td>
<td>7-8</td>
<td>5.5-6.5</td>
<td>3.5-4.5</td>
<td>5-6</td>
</tr>
<tr>
<td>Power</td>
<td>41-43</td>
<td>21-24</td>
<td>10-12</td>
<td>7-8</td>
<td>5.5-6.5</td>
<td>3.5-4.5</td>
<td>5-6</td>
</tr>
<tr>
<td>Railway</td>
<td>51-53</td>
<td>6-8</td>
<td>16-18</td>
<td>7-8</td>
<td>5.5-6.5</td>
<td>3.5-4.5</td>
<td>5-6</td>
</tr>
<tr>
<td>Mineral Plant</td>
<td>41-44</td>
<td>20-22</td>
<td>12-14</td>
<td>7-8</td>
<td>5.5-6.5</td>
<td>3.5-4.5</td>
<td>5-6</td>
</tr>
<tr>
<td>Medium Industry</td>
<td>50-52</td>
<td>7-9</td>
<td>16-18</td>
<td>7-8</td>
<td>5.5-6.5</td>
<td>3.5-4.5</td>
<td>5-6</td>
</tr>
</tbody>
</table>

Turin (1973) has devised a matrix for construction industry in developing countries based on the different levels of technology used. He categorized the construction industry into four different sectors; the international modern, the national modern, the national conventionally, and the
The four sectors of the construction industry make different demands on the building materials industry ranging from modern and sophisticated materials to local and simple materials. Similarly, the materials requirements differ between various building types and between building and civil engineering. Thus the composition of demand for materials is affected by the composition of construction output and by the construction technology employed. As Turin writes, “The different categories respond differently to changes in technological levels of demand. Resources released by one category cannot be used by another….” However, as with other manufacturing industries, it is impossible for building materials producers to have some influence on the demand. This may arise through changes in construction technology due to availability of certain materials instead of others, or through an increase in total construction activity due, for example, to a significant drop in the price of cement. All these changes are subject to time lag before their effect is observed.

1.3 The socio-economical signature of construction and building materials and components industries

The role of construction in socio-economic development has been addressed by various writers and international bodies, many of whom have focused on developing countries (Turin, 1973; World Bank, 1984; Wells, 1986; Ofori, 1990; Palalani, 2000). Turin and Wells, using cross-country comparisons, both found an association between construction investment and economic growth. (Lopes et al, 2000). The Construction Industry has been identified as one of the main engines of growth in any economy. It provides the infrastructure required for other sectors of the economy to flourish, provides housing as the basic human need, and is instrumental in providing national communications network (Palalani, 2000).

Many studies highlighted the positive relationship between per-capita income and the ratio of total construction investments to gross domestic product, indicating the economic significance of the construction industry to economic growth and development (Turin, 1969, 1973). Besides the direct impact of the construction industry on the economy through infrastructure provisions, further significant contributions are made directly/indirectly in terms of employment and income generation (Moavenzadeh, 1978; Ofori, 1988; Wells, 1985). The level of performance in the construction industry and economical output are cyclically co-related in a loop (Ebohon, 2000). This implies that increases in economic growth necessarily invites increased construction investments, resulting in high elastic demand for construction products and manifesting in rapid build-up of physical overhead, which affords significant employment and income generating opportunities. However, studies have shown that construction output grows particularly fast, often exceeding the rate of growth of the economy as a whole, as countries put their basic infrastructure in place during the early stages of development (ILO, 2001: 8).

The socio-economic signature of the construction industry can be gauged from a number of global indicators. Turin (1973) carried out the most comprehensive study on the role of construction in development through studying the economics of several countries. For the purpose of international comparisons, the most significant of these and those which are more readily available are;
• The Contribution of construction to GDP; About 2-3% in developing countries, 5-7% in industrialized countries

• Value added by construction; 3-5% in developing countries, 5-9% in industrialized countries

• Capital formation in construction; Represents 6-9% of GDP in developing countries, 10-15% for industrial countries, with an international average of about 55% of all capital formation

• The Contribution of new construction assets to GDFCF; 45-60% in all countries

• Intermediate inputs from other sectors in the economy;

• 50-60% of construction’s inputs comes from other sectors in the economy

• Level of imports of intermediate inputs for construction accounts for 5-8% of all imports of intermediate inputs in developing countries, about 5% of all imports.

• Employment share of construction sector; 6-10% of total employment in a majority of industrialized countries, and 2-3% in the less developed countries. When employment in the delivery of materials inputs is included, the share of construction employment can account for as much as 15% and 10% in industrialized and the less developed ones respectively (Hassan, 2006).

The significance of the construction industry in development, in terms of growth, is much higher in developing countries than developed countries. For instance, the percentage shares of the value added (VA) by construction for most developed countries in Western Europe appear to be relatively consistent over the 20-year period considered. Meanwhile, Eastern/Central European countries were also notable as their increasing needs for infrastructural developments generated more construction spending (Pheng et al., 2008).

Expenditure on building materials can be calculated at some 4-6% of the GDP (Shaddad, 1979). In Africa, Asia, and Latin America the value of imported building materials ranged from 5-8% of the total value of imports (UNCHS, 1986). Since expenditure on building materials is 3-5% of the gross domestic product (GDP) in developing countries, it is clear that building materials, as compared with inputs for other industries, use up a disproportionate share of foreign exchange. In less developed countries, and Sudan is one of them, however of building materials and components may contribute 20-30% of the output value (Shaddad, 1979). The role of building materials industry in socio-economical development in Sudan needs to be investigated and researched thoroughly.
2. Construction and building materials industries in Sudan

2.1 Sudanese economy overviews

Sudan is the largest country in Africa and the tenth country in the world, with a territory covering about 2,505,813 square kilometers of northeast and central Africa. The country’s primary resources are agricultural, but oil production and exports are taking on greater importance since October 2000. The country’s transportation facilities consist of 4,800 km single-track railroad with a feeder line, supplemented by limited river steamers, Sudan airways, and about 1,900 km of paved and gravel road—primarily in greater Khartoum, Port Sudan, and the north. Some north-south roads that serve the oil fields of central/south Sudan have been built. Extensive petroleum exploration began in the mid-1970s and might produce all of Sudan’s needs. Significant finds were made in the Upper Nile region and commercial quantities of oil began to be exported in October 2000, reducing Sudan’s outflow of foreign exchange for imported petroleum products. There are indications of significant potential reserves of oil and natural gas in southern Sudan, the Kordofan region and the Red Sea province.

Instability is the main characteristic that dominates the performance of the Sudanese Economy. Since independence and till now, a number of plans were put under application, most of these plans weren’t carried out properly and hadn’t follow the time schedule set for the plans. The political instability was the main reason behind the failure in the application of different economical plans. The economical instability resulted clearly on higher inflation rates, instable and fluctuations in exchange rates, and low level of investments. Similar to many developing countries, corruption has been a major characteristic of the Sudanese economic scene.

2.2 Sudan civil wars

Sudan has been in near constant conflict since it became independent in 1956. The two most extensive conflicts have been those between the North and South, with the first civil war lasting from 1956 to 1972, and the second civil war from 1983 to 2005. The war in Southern Sudan was the most critical to the Sudanese society socially, economically and politically.

Sudan’s Comprehensive Peace Agreement (CPA) was signed on 9 January 2005, finally bringing peace between the North, represented by the government, and Southern Sudan, represented by the SPLM/A\textsuperscript{1}, for the first time in 20 years. A final resolution of Sudan's civil war could greatly help the country's economy, lead to the lifting of various sanctions against the country, and encourage investment by foreign companies including oil companies.

\footnote{Sudanese People Liberation Movement/ Army}
Reopening the wounds of war, a conflict broke out in Darfur in 2003 and continues to date. Coming at a particularly inopportune time, during the peace negotiations between the government and SPLM/A, two rebel groups in Darfur, the SLM/A\(^2\) and the JEM\(^3\), began organizing themselves in the course of 2001 and 2002 in opposition to the Khartoum Government. While only loosely connected, the two rebel groups cited similar reasons for the rebellion, including socio-economic and political marginalization of Darfur and its people. The rebel movements began their first military activities in late 2002 and in the beginning of 2003 (UN, 2005). The conflict in Darfur has complicated attempts at ending the country's larger civil war. The International community is looking forward to resuming the conflict in Western Sudan sooner. Great efforts have been carried out by the Sudanese government and neighbor countries to end the new civil war in Sudan to avoid any of the results of the war in Southern Sudan. Optimistic points of view consider the situation as less critical than the previous war.

### 2.3 War impacts

Sudan in general and the southern region in specific have been negatively affected by war for all but 10 years of the independence period, resulting in serious neglect, lack of infrastructure development, and major destruction and displacement. More than 2 million people have died, and more than 4.5 million are internally displaced or become refugees as a result of the civil war and war-related impacts (UN, 2005).

War and economy are interdependent (Gueli, 2007), most of the nation’s resources were devoted to the war rather than development projects. The war in the South affected construction activities since developmental projects were suspended every now and then and some projects have started a long time ago without been finished yet. Construction projects suffer from the war as many other developmental projects (i.e. Jonglei canal)\(^4\). Moreover, a great portion of the economy output was devoted towards the military work and the war shifted most of the funds assigned for developmental and constructional projects to the war. The shifting of funds towards war has its observable impacts on all markets in Sudan. Construction and housing as growing markets suffered from the war severely. The equilibrium between demand and supply was not subject to market forces; instead it was at the mercy of the war and the resources available after covering the war costs. The market was reluctant to respond to the gap between demand and supply.

The migration was inevitable due to the war; migration wasn’t organized by the government. As a normal result for unorganized migration, demand and supply were unpredictable making it difficult to create a well organized and planned market for real estate and its submarkets. As a result, investing in

\(^2\) Sudan Liberation Movement/Army  
\(^3\) Justice and Equality Movement  
\(^4\) It is estimated that water worth over $1 million to agricultural production is lost annually, through spreading, evaporation, and seepage, in Africa's Sudd swamp. In 1974, Egypt and the Sudan agreed upon the construction of a canal - the Jonglei Canal - that would partially drain the Sudd, minimize the water losses, and provide Egypt with water needed during the arid season. This project will study the impact the Jonglei Canal might have on the inhabitants of the region. The work in this project has stopped since 1983.
construction and real estate was characterized as risky investment. Therefore, the role of the private sector in the construction and real estate markets was unrealizable.

In Darfur, which became the latest chapter in Sudan’s civil wars, 10,000-30,000 people have been killed and nearly a million have been displaced (UN, 2005). No doubt, if this war continues, it will cost the Sudanese economy as similar as the war in the South did. Sudan is in need of any resources including human resources in order to recover its economy.

### 2.4 Economy performance and implications on construction and building industries

During the last 15 years the Sudanese economy experienced a relatively high level of stability; 7.9% as an average rate of growth in GDP. The inflation rates dropped to economical acceptable levels; from 121.9% in 1991 to 8.1% in 2008 (CBOS). The value of the Sudanese Pound against the American Dollar increased on regular bases by year 2005. Low inflation rates, stability of exchange rates and oil production attracts foreign capital to invest in Sudan. The growth in the invested capital result in a higher demand for space which is reflected on higher construction activities. The share of the construction industry increased during the five years following oil production. The relative stability in the Sudanese economy performance and oil production attracts foreign capital to participate in business.

In many developing countries nowadays, as it is the case in Sudan, development efforts often focus on the modern construction sector so as to deal with growing investment programs and to meet pressing needs for urban shelter. Most of the construction work activities take place in the City of Khartoum and some other big cities. Figure (1) shows how big the difference is in the level of construction activities and needs of space in Khartoum, the South, and North Darfur.

![A hut in the South](image1) ![A house in N. Darfur](image2) ![Alfatih Tower in Khartoum](image3)

Figure 1: Differences in construction work in Khartoum, South, and Darfur

The real growth that the construction sector experienced in Sudan was negative till the mid 1990s, it became positive in 1997. The shift from negative to positive growth was a result of the national development projects those were going on that time such as national roads, bridges housing projects
and redeveloping of some projects and infrastructure. Moreover government start to built oil infrastructure in 1998, when it was finished the construction share decreased from 10% in 1998 to 2.4% in 1999 because of finishing the oil infrastructure. After 2000 the amount spent on construction continues to increase because of the entry of foreign companies and investors. The share of the construction and building sector to GDP is shown in (fig 2). The future of this demand is expected to increase for many reasons;

• The resolution of the Civil war in Southern Sudan.

• Devoting the war budget for developmental projects

• Developmental projects and infrastructure are expected to take place in the South.

• Expected entry of foreign capital

The construction industry is considered a tool for enhancing peace in the immediate aftermath of major conflict and even avoiding conflicts in the first place (Gueli, 2007). Motivated by the cease of the civil war in the south, construction activities increased significantly including infrastructure projects, governmental facilities, health care facilities, educational buildings, social facilities, … etc. Following the activation of the CPA, many national and international organizations participated in the development programs. The movement of development on the political and economical levels results on higher demand for space and infrastructure. The boom in construction industry led to a higher demand for construction products and materials production. Most of building materials are imported from the foreign market. The government of Southern Sudan is the major client beside the international organizations that are concerned with the development of southern Sudan. The case of Darfur is not yet settled, thus, no development programs are taking place.

The equilibrium between demand and supply of space and infrastructure is subject to the rate of response of the construction sector to the demand and political policies and decisions. As a matter of fact, suppliers of building materials depend on the international market as a source of building materials.
materials. Cement, sand, gravel, and simple building materials are brought from the local market. However, not a single cement factory is located in Southern, Western (Kordofan & Darfur), or Eastern Sudan. All finishing materials, decorative items, high quality materials, mechanical & electrical items are imported from abroad. Fluctuations in prices are normal result of the instability and unsteadiness of materials supply. Encouraging the local investors to produce building materials and products locally might have a great effect on the price of construction and the balance in the market.

In the case of Darfur, the status of construction activities is quiet different since the area is still lacking the secure environment required for developmental projects. Most of the undergoing projects, if any, provide the basic services required for the refugee campuses. These projects are far beyond the region’s needs and are developed to temporarily satisfy the needs of the region inhabitants and the IDPs. No doubt, the end of the conflict in Darfur will call for huge developmental construction activities. Generally, the following stage of the economical developments requires a higher level of production for the whole country and marginalized regions on specific.

3. Challenges facing construction and building materials industries in Sudan

3.1 The common scene

The construction industry everywhere, given its special problems and requirements, faces problems and challenges. However, in the developing countries, these difficulties and challenges are present alongside a general situation of socio-economic stress, chronic resource shortages, institutional weaknesses and a general inability to deal with the key issues. There is also evidence that the problems have become greater in extent and severity in recent years (Ofori, 2000). The situation in Sudan is similar to the general situation in developing countries. The difficulties that face construction industries in developing countries and the proposed solutions have been extensively investigated by the international organizations such the United Nations (1981, 1984), International Labour Office (1987), the World Bank (1984), also by Turin (1973), Wells (1986), Ofori (1990) and (Sultan & Kajewski, 2003 & 2004). The problems and challenges that face the construction and building materials industries in developing countries are common (Sultan & Kajewski, 2003), Sudan isn’t an exception. These challenges include;

- Lack of capacity of the construction sector (Du Plessis, 2002);
- Inefficiency and/or absence of regulatory instruments and professional institutions (UNCHS, 1996);
- Absence or inefficiency of quality assurance system, national standards and quality specifications; meaning that the quality of products and services (i.e building materials and
labor force) in the construction industry are questionable (Palalani, 2000), and (Okema, 2000);

- Poor organization of the construction industry with a large number of very small and inefficient firms (Wells, 1986);

- An unfavorable operating environment for construction enterprises, which is further aggravated by complex procedures and regulation, delays in payments, and unsuitable contract documents;

- Contractors capabilities; lack of technical and managerial expertise, lack of adequate finance, difficulty in obtaining essential resources materials, equipment and skilled personnel, and inadequate supervisory capabilities(UNCHS, 1996);

- Lack of planning at all the levels of the construction process(Wells,1986);

- Low and fluctuating overall levels of construction activity;

- Lack of capacity and “economic rationality” in design, construction, and the production of building materials (Wells,1986);

- Lack of Finance (UNCHS,1996);

- Information scarcity and lack of accurate data (Du Plessis, 2002; Palalani, 2000);

- Under development of the national systems of innovation (Milford, 2000);

- Inadequate and integrated research and development (R&D) facilities and programs beside the poor linkage between research and practice (Du Plessis, 2002; Ofori, 1994);

- High rates of risks and uncertainty (Du Plessis, 2002; Okema, 2000) including; Macro-economic risks and uncertainties, insurance industry risks and uncertainties, site production risks and uncertainties, natural calamities risks and uncertainties, bureaucracy and corruption risks and uncertainties, contract and contractual performance risks and uncertainties, project risk and uncertainty due to public demand, political and insecurity risks and uncertainties, and donor associated uncertainties;

- Corruption: it costs construction industry in the world a huge amount of money5 (TI, 2005). Construction industries are particularly susceptible to corruption in licensing, taxation and obtaining government contracts, including bribery, fraud, embezzlement, and kickbacks

5 The American Society of Civil Engineers claim that corruption accounts for an estimated $340 billion of worldwide construction costs each year.
(Sohail & Cailli, 2008). Beside the characteristics of the construction sector, the fragility of economies and ineffectiveness of the legal systems make developing countries prone to corruption (Fewings & Henjewele, 2008);

- Shortage of skilled labor due to absence of the training programs or failure to provide adequate rewards (Wells, 1986; Ofori, 1994); and

- Problems specific to the building materials industry:
  - Inadequate capacity and inefficiency in the building materials industry, (Wells, 1986);
  - Building Materials; expensive, high transportation costs, high production costs and energy costs (UNCHS, 1996);
  - Availability and price of building materials, (Wells, 1986);
  - Problems in availability of locally produced materials, (Wells, 1986);
  - Unhealthy reliance on imported materials in face of foreign exchange problems, (Wells, 1986); and
  - Frequent shortage of construction materials resulting from the preference of users for conventional materials, most of which are imports.

Imports of building materials are considerable; in many developing countries, a large proportion of building materials are imported. For instance, it is estimated that building materials alone annually account for 5 to 8 per cent of the total value of imports in Africa (UNCHS, 1986). The potential for developing the domestic building materials industry, therefore, would seem large. However, in many developing countries, these potential developments are difficult to realize because of the relatively small size and large fluctuation of present demand, not only at the local level, but also in the national context. Scale economies apply to the production of building materials since large-scale manufacturing results in production feasibility (Elkhalifa & Shaddad, 2008). Not only large demands are therefore required, but these demands should also be concentrated, considering the often low value/weight ratio, which prohibits transport to very long distances, certainly in an African setting, where transport in general is poor. Next to the small size of local demand, scarcity of finance and lack of know-how and skills prevent a rapid development of the building materials industry in most developing countries. These problems often result in high price levels of locally produced building materials. It is not, therefore, surprising that imports of building materials are considerable with a value of as much as 5-8% of the total value of imports.

Beside the underlying problems facing the construction industry in the developing countries and SSA countries on specific, apparently, the development of the construction sectors seems to be a challenge itself. It has been indicated that unless urgent steps are taken to develop appropriate institutions necessary to facilitate the development of modern and sophisticated construction industry, sub-Saharan Africa will remain a net importer of construction materials and services (Ebohon, 2000).
3.2 Problems of building materials industry specific to southern Sudan and Darfur

The regions of Southern Sudan and Darfur, beside the vulnerability of the socio-economical environment, face acute situation in their built environment. War, conflicts, and security situations have had devastating effects and contribute significantly to the current situation in both regions. Many of the internally displaced people (IDPs) who were forced to flee their homes have ended up living in make-shift camps around the major cities. Upon their return back to their original villages, returnees are going to face numerous difficulties, the most significant of which will be the mass destruction of local infrastructure and homes. Lack of infrastructure and basic services, lack of adequate and appropriate affordable housing alternatives, shelter poverty and high prices of building materials become common characteristics of the two regions. There is a shortage of building materials due to drought and the huge need for shelter. The most common rural house design is the Gutiyah made out of straw or millet stalks covering a wooden skeleton (fig 3). The environment has been exhausted and deteriorated with wood also being used in vast quantities for cooking.

The common problems of the building materials industry in southern Sudan and Darfur, which need to be addressed and researched thoroughly include;

**Lack of Security**
Due to war and ethnical conflicts, the general environment is classified to be unsecure. Obviously, in such a situation, local production of needed building materials is impossible. Skilled labors abandon their villages and flee to other regions in the country in search for security, work, and better living conditions. Security situation restricts the flow and transportation of building materials from other parts of the country. Even in the South, where the war is over, clashes and conflicts continue to exist.
Lack of capacity
The two regions face critical shortage in capacity for the production of building materials, including; lack of required infrastructure, lack of finance, lack of production facilities, lack of skilled labor, lack of education and training program. Besides, no investors or producers show interest in the making business in the two regions.

Lack of Finance& Management Capabilities
The establishment of building materials factories and production facilities calls for efficient management and technical experience beside the required finance. The lack of these capabilities affects the performance of the building materials industry and hinders its development.

Lack of skilled labors
The immigration, due to conflicts and socio-economical situation, leaves the two regions without the capable human resources for the production of building materials on local level. The work forces that carry the day-to-day work in construction either not trained or haven’t developed their capabilities.

Lack of materials and High prices
The two regions face severe shortage in the supply of building materials and raw materials for production. In the south, for instance, cement, brick, sand and gravel have to be imported from different parts of the country. The lack of key materials on the local level, results in high price due to high transportation cost and fees of intermediate providers. For example, the price of one cubic meter of gravel in the city of Malakal is 18 fold its price in Khartoum.

Inefficiency of transportation Systems
Limited means of transportation systems impose more constraints to the development of the building materials industry in the two regions. Paved roads are limited to the intra-city level, for the inter-city level gravel roads and natural routes are more common. During the rainy seasons, most of the inter-city routes become out of service. The river-streams in the south are inactive as a result of war and lack of maintenance and upgrading. No railway routes exist in the south and the region of Darfur except for some big cities. If proper and efficient transportation systems are available, prices of building materials will fall respectively. The inefficacy of the transportation system results in higher construction costs, project delays, and overheads. For example, in some places in the south, gravel, sand, and brick are packed in bags to be transported through unpaved roads.

Taxes and Governmental Fees
The country in general suffers from the high level of taxes and fees on the production, transportation, and sales of building materials. Taxation, custom duties, zakaat, fringes, highway taxes, and provincial fees beside other types of fees contribute to the high prices of building materials.

The General Environment
The country in general is characterized by the unfavorable environment with corruption, favoritism, bias, and high risks and uncertainties due to the political instability.
4. Conclusions

Construction activity is an integral part of a country’s infrastructure and industrial development. Covering as it does such a wide spectrum, construction becomes the basic input for socio-economic development. Besides, the construction industry generates substantial employment and provides a growth impetus to other sectors through backward and forward linkages. The construction sector has major linkages with the building material industry since construction material accounts for sizeable share of the construction costs. The cost of building materials represents the highest share in comparison to other construction cost components for all categories of construction industry.

Sudan as a developing country experienced great economical development during the previous decades as a result of oil production and the end of war in the south. This development took place in many fields, of which the construction industry is an important one.

Overcoming the challenges that face the Sudanese construction and building materials industries to meet the requirements of peace and development is progressively demanding. The industry is already under severe pressure which casts a shadow of doubts as to whether its capacity, efficiency, strength, and resources to cope with the existing and expected situation. The authors identified a set of challenges that face the construction and building materials industries in the country. The status of the building materials is more acute in the regions of Southern Sudan and Darfur as a result of wars and conflicts. Further attentions should be be drawn to these regions in order to sustain peace.

A general international, national, and multidisciplinary study to assess raw materials for the building materials industries (i.e., cement, brick, and timber, aggregate, sand, and steel) is urgently needed. The survey should cover the evaluation of the properties, quantities and means of economic exploitation of such raw materials. There is also a need for human power survey to assess the needs of the prospective building materials industries. International specialized organizations such as the United Nations Industrial Development Organization (UNIDO) and the International Labour Office (ILO) might be approached to carry out the proposed survey in cooperation with Sudanese professionals and staff.

References


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Appropriate Technology: Innovative Building Envelope Technological Design

Omondi, O.S.
Politecnico di Milano, Building Environment Science and Technology Department (BEST), Milano, Italy, 20133, Via Ponzio 31, Phone: +39 02 2399 6053
(email: samuel.obudho@mail.polimi.it)

Abstract

High cost of building construction in developing countries like Kenya partly attributed to the cost of materials is a catalyst to informal settlements upsurge within urban areas. Many buildings in the slum areas are constructed using new or recycled Galvanized Corrugated Iron (GCI) sheets since they are robust, cover large area and are durable when compared to other locally available materials. Though many dwellings are constructed exclusively using GCI sheets, they do not offer the desired thermal comfort for the inhabitants especially in tropical climates where solar radiation is high all year round. Through appropriate technologies, particle boards made from agricultural wastes like rice husks, wheat straws and coconut husks can be used as part of the building envelope to improve on the slum building thermal comfort. An insulation of 50mm air layer between the GCI sheets and the particleboards is used in energy plus to simulate thermal comfort expected in Nairobi, Mombasa and Kisumu using a model single detached building. Simulation results show that new non-oxidised GCI sheets offer better thermal comfort than old oxidised GCI sheets. Rice husks particle boards mitigate well on temperature fluctuations in comparison to wheat straw boards and coconut coir fibre boards.

Keywords: appropriate technology, particleboards, simulation, slums
1. Introduction

Slum settlement refers to the condition of an informal settlement while informal settlement refers to the legal condition of the settlement. The UN meeting in Nairobi in October, 2002 officially adopted the operational definition of slum as characterised by overcrowding, poor or informal housing, inadequate access to safe water and sanitation (Davis 2006).

In Kenya informal settlements are characterised by poor planning and are constructed using building materials that are of questionable properties and poor qualities. Most of the buildings within these settlements are not designed as standard dwelling units and the number of people it accommodates at a particular time is undefined. This compromises the thermal comfort of the inhabitants and results to poor health conditions. The problems are compounded further by lack of proper physical infrastructure.

From independence the government has instituted a pragmatic housing provision policy that have immensely contributed to the flourishing of informal settlements as witnessed today. There is still lack of clear policy that can facilitate and guide urban development, since many upgrading projects are made on ad hoc basis (HABITAT 2003: 195-228). Many efforts have been made with intangible outcomes, due to top-down approach and less regard to residents views (Pelikka et al, 2004) while land use management systems and laws are overlapping and mixed in urban areas. This makes land use planning difficult to enforce because of intense land divisions, legal regulations of transactions and powerful elites interests (Leach 2000). Non-implementation of the building code and rural urban migration has contributed to unabated growth of urban slum dwellings in the recent past.

Kenya’ economy largely depends on the agricultural sector, which accounted for 24% of the GDP in 2003. About 75% of Kenyans owe their livelihood to agriculture. Other than agro-production, the sector boasts a comparatively wide range of manufacturing industries, with food processing being the largest single activity. About 66% of the manufacturing sector is agro based, owing to the country’s agricultural economy foundation. Agricultural waste can be processed through technology to produce building products such as particleboards used in the building envelope to enhance thermal comfort.

1.1 Climate

Kenya’s different topographical regions experience distinct climates. Generally, the hottest time is in February and March and the coldest in July and August. The coastal region where Mombasa is located is largely hot and humid while the low plateau area is the driest part of the country. Higher elevation areas within the highlands where Nairobi is part of receive much larger amounts of rainfall. The Lake Victoria basin in western Kenya is generally the wettest region in the country, particularly the highland regions to the north and south of Kisumu. Table 1 below gives a summary of the major climatic conditions for the three cities in Kenya and their respective geographic locations.
Table 1: Climatic data for cities in Kenya

<table>
<thead>
<tr>
<th>City</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Elevation (m)</th>
<th>Dry-Bulb Temp (° C)</th>
<th>Relative Humidity (%)</th>
<th>Av. annual Precipitation (mm)</th>
<th>Sunshine (Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nairobi</td>
<td>1° 17’</td>
<td>36° 49’</td>
<td>1661</td>
<td>23</td>
<td>10</td>
<td>76</td>
<td>51</td>
</tr>
<tr>
<td>Kisumu</td>
<td>0° 10’</td>
<td>34° 74’</td>
<td>1145.7</td>
<td>35</td>
<td>14</td>
<td>68</td>
<td>47</td>
</tr>
<tr>
<td>Mombasa</td>
<td>4° 3’</td>
<td>39° 69’</td>
<td>54.8</td>
<td>34</td>
<td>20</td>
<td>79</td>
<td>69</td>
</tr>
</tbody>
</table>

1.2 Rice husks

Rice husk is the outer cover of rice that accounts for about 20% by weight of the rice (Natarajan 1998). Among its many uses include production of cement because of its high silica content (Ali 1986) and as a fertilizer and in particleboard production.

In Kenya Rice is the third most important staple food in Kenya after maize and wheat. It forms part of the larger diet for urban population. About 95% of the rice in Kenya is grown under irrigation in paddy schemes managed by the National Irrigation Board (NIB). Rice production increased from 45,099 Metric Tons to 47,748 Metric Tons in 2002 and 2003 respectively (EPZ 2005), the resultant husks is used in animal feeds production and fertilizers.

![Figure 1: Rice Husk Particle board. Source http://www.ipirti.gov.in/product%20development_8.html](http://www.ipirti.gov.in/product%20development_8.html)

In the production of the particleboards, Rice husk is screened and made dust free, mixed with glue and formed into a mat. The mat is hot pressed under definite temperature and pressure. Boards are then stabilized before trimming is done.

1.3 Wheat straw

Wheat is the second most important cereal grain in Kenya, after maize. The crop is grown largely for commercial purposes on a large scale. Kenya is self-sufficient in the hard variety of wheat. Wheat straw consists of stems and leaves, chaff that is a protective cover over the grain, and the underground root system. After the grain is harvested the straw is burned, removed, left on the field or ploughed back into
the soil. The choices made by the landowner depend on a variety of factors including the quantity of material, the next crop to be planted, the weather conditions, the soil erosion and nutrient needs, the slope of the land, and any markets that may be available for the straw (James and John 2001). Wheat production in Kenya increased from 106 metric tons to 113 metric tons in 2006 and 2007 respectively (RoK 2009).

![Wheat straw particleboard](http://www.ecplaza.net/tradeleads/seller/5840014/)

**Figure 2: Wheat Straw Particleboard. Source** http://www.ecplaza.net/tradeleads/seller/5840014/

### 1.4 Coconut husks

The husk is 35% of the mass of the coconut melon. It is comprised of about 67% pith, a lignin which behaves like a phenol resin, and 33% fiber, also made from lignin but with a fibrous morphology. Recent studies in the Netherlands support the idea that the husk can be hot pressed into particle board directly without adding any additional binder (Jan et al 2004). The pith can apparently chemically react and consolidate much like a phenol resin, with the fibers serving as reinforcement. Coconut trees in Kenya thrive in the coastal region where the weather condition favours their growth.

### 2. Model building

The model building consists of a naturally ventilated single detached unit with a net surface area of 59.50 m² and a net volume of 204.80 m³, and its floor plan and geometrical representations are shown in figure 4. The set up of the building surroundings is considered as a detached unit inside a neighbourhood of a 3x3 matrix of similar buildings. The building envelope consists of the following elements: 89.35 m² of opaque walls, 5.40 m² single glazed windows, 2.00 m² doors and 62.75 m² roof. Local shading for the windows is provided by the 0.50m gable roof overhangs (eaves). The internal partitions were simulated as 114.20 m² of internal thermal mass characterised by the same construction as walls. Wall profile consists of 50mm air layer between the particleboards and the GCI sheets (ISO 6946 2007).

The simulation scenario is with the building at the centre of a dense neighbourhood the streets width is 5m. The surroundings buildings are set with similar shape as the model house and with a general surface reflection factor of 0.2, the default value used by the simulation software.
2.1 Input data

Internal heat loads for the building were inferred from two sources and applied on a daily schedule with regards to a typical house in informal settlements as shown in table 2.

Table 2: Internal heat loads schedules for a residential building

<table>
<thead>
<tr>
<th>Heat source</th>
<th>Reference value</th>
<th>Daily schedules</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>00:00</td>
</tr>
<tr>
<td>Occupancy</td>
<td>Density (a): 0.085 ppl/m²</td>
<td>100%</td>
</tr>
<tr>
<td></td>
<td>Activity (b): 90 W/ppl</td>
<td>0%</td>
</tr>
<tr>
<td>Kitchen supplies</td>
<td>8.000 W/m² (b)</td>
<td>0%</td>
</tr>
<tr>
<td>Lighting</td>
<td>11.000 W/m² (a)</td>
<td>0%</td>
</tr>
</tbody>
</table>

Reference values (a) are calculated, while (b) are obtained from ASHRAE (2001)

Figure 3: Building model: floor plan (a) and geometrical representations (b).
The materials data used for the model building have been derived from SKAT (1993) and are listed in Table 3.

**Table 3: Material properties used in the simulations**

<table>
<thead>
<tr>
<th>Material</th>
<th>Conductivity [W/mK]</th>
<th>Density [kg/m³]</th>
<th>Specific Heat [J/kgK]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth/Mud</td>
<td>2,1000</td>
<td>1800</td>
<td>1250</td>
</tr>
<tr>
<td>GCI Sheet (Zinc new)</td>
<td>112,0000</td>
<td>7200</td>
<td>390</td>
</tr>
<tr>
<td>GCI Sheet (Zinc oxidised)</td>
<td>0,078</td>
<td>590</td>
<td>1300</td>
</tr>
<tr>
<td>Wheat Straw Boards</td>
<td>0,052</td>
<td>800</td>
<td>1250</td>
</tr>
<tr>
<td>Rice Husks Boards</td>
<td>0,090</td>
<td>1200</td>
<td>1500</td>
</tr>
<tr>
<td>Coconut Husk Boards</td>
<td>0,090</td>
<td>1200</td>
<td>1500</td>
</tr>
</tbody>
</table>

Since buildings in informal settlements are not properly planned and sealed, general infiltration of constant 1 air charge rate (ach) is assumed for air tightness, while 3 additional ach is set in case of indoor temperature exceeds 26°C and outdoor temperature is lower than indoor one, to allow free cooling through ventilation. The floor slab is set as directly built on the ground, while ground temperatures are calculated monthly using the “slab” tool in Energy-Plus.

### 2.2 Simulation cases and results

Hourly calculations were performed using Energy-Plus software for the model house building envelope materials, orientation, neighbourhood and location. Geographic location and construction materials have more influence on the simulation than neighbourhood type and orientation (Valentina and Obudho 2009). The U – values for the particleboards used were: Rice Husks 0.76 W/ m2K; Coconut Husks particleboards 1.10 W/ m2K and Wheat Straw particleboards 1.01 W/ m2K

### 2.3 Materials comparison

15mm thick particleboards from wheat straw, rice husks and coconut husks was used in the simulation to determine the indoor surface temperatures of the model building. The figure below show the wall surface temperatures for different orientations for a sunny hot dry day (Jan 15th) of the model building in Kisumu, Mombasa and Nairobi.
Figure 4: Surface temperature comparison for different orientations in a) Kisumu, b) Mombasa and c) Nairobi

Observations made from the above graphs indicates that Non-oxidized GCI sheets offer the best surface temperatures with highs of 37°C while the oxidized offers highs of 58°C. Though there is no much difference in surface temperatures for the particleboards, rice husks particleboards better in comparison with the others.

Roof surface temperatures were also compared and the figure below details the temperature ranges for the various materials simulated in north and South Orientation for Kisumu, Mombasa and Nairobi.
The figure above indicates that oxidised GCI sheets offer highs of 88°C while the non-oxidised GCI sheets have highs of 45°C.

### 2.4 Complete house comparison

Slum buildings are naturally ventilated meaning they do not use HVAC systems. Based on this, adaptive thermal comfort model was used to assess the general indoor thermal conditions in extreme conditions (De Dear et al 1997). Adaptive thermal comfort model is based on the principal that thermal sensation of the occupants is strongly affected by their expectations on long term or short term thermal experience.

The indoor operative temperature derived from the simulation results has been compared with adaptive comfort temperature limits. Equation to calculate adaptive temperature limits, for this work is the one developed by De Dear et al (1997) for ASHRAE (2004), which defines equations both for the warm and the cool seasons. The boundary conditions chosen, regarding the acceptability range is used as stated by Van der Linden et al (2006) for the ATL (Adaptive Thermal Limit) index used in the Netherlands. The consequent adaptive temperature limits used are summarized in table 4.
Table 4: Adaptive temperature limits

<table>
<thead>
<tr>
<th>Acceptability range</th>
<th>Lower limit</th>
<th>Upper limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>90%</td>
<td>$T_{op}&gt;17.80 + 0.11T_{e,ref}$</td>
<td>$T_{op}&lt;20.30 + 0.31T_{e,ref}$ if $T_{e,ref}&gt;12°C$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$T_{op}=22.7 + 0.11T_{e,ref}$</td>
</tr>
<tr>
<td>80%</td>
<td>$T_{op}&gt;17.05 + 0.11T_{e,ref}$</td>
<td>$T_{op}&lt;21.30 + 0.31T_{e,ref}$ if $T_{e,ref}&gt;12°C$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$T_{op}=23.45 + 0.11T_{e,ref}$</td>
</tr>
<tr>
<td>65%</td>
<td>$T_{op}&gt;16.55 + 0.11T_{e,ref}$</td>
<td>$T_{op}&lt;22.00 + 0.31T_{e,ref}$ if $T_{e,ref}&gt;12°C$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$T_{op}=23.95 + 0.11T_{e,ref}$</td>
</tr>
</tbody>
</table>

The reference outdoor temperature ($T_{e,ref}$) is the external running mean temperature, which is an exponentially weighted mean of the daily air temperatures of the preceding days. It is used to represent the short-term thermal experience of the occupants as a history series of the external temperature. It can be calculated from the following equation (EN 15251, 2007).

$$\theta_{rm,n} = \frac{0.8 \cdot \theta_{dm,n-1} + 0.6 \cdot \theta_{dm,n-2} + 0.5 \cdot \theta_{dm,n-3} + 0.4 \cdot \theta_{dm,n-4} + 0.3 \cdot \theta_{dm,n-5} + 0.2 \cdot \theta_{dm,n-6} + \theta_{dm,n-7}}{3.8}$$

Where:

- $\theta_{rm,n}$ is the running mean temperature in the $n^{th}$ day [°C];
- $\theta_{dm,n-1}$ is the daily mean temperature in the $(n-1)^{th}$ day [°C].

The acceptability range is then translated, as shown in table 5, to the qualitative definition of the 7-point ASHRAE thermal sensation scale, that defines the occupants’ mean vote (predicted or surveyed) on the thermal environment (ASHRAE, 2004).

Table 5: Conversion of the adaptive acceptable range to thermal sensation scale.

<table>
<thead>
<tr>
<th>Adaptive acceptability range</th>
<th>Vote</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{op}&gt;65%$ upper limit</td>
<td>+3</td>
<td>Hot</td>
</tr>
<tr>
<td>$T_{op}&gt;80%$ upper limit</td>
<td>+2</td>
<td>Warm</td>
</tr>
<tr>
<td>$T_{op}&gt;90%$ upper limit</td>
<td>+1</td>
<td>Slightly warm</td>
</tr>
<tr>
<td>90% lower limit&lt;$T_{op}&lt;90%$ upper limit</td>
<td>0</td>
<td>Neutral</td>
</tr>
<tr>
<td>$T_{op}&lt;90%$ lower limit</td>
<td>-1</td>
<td>Slightly cool</td>
</tr>
<tr>
<td>$T_{op}&lt;80%$ lower limit</td>
<td>-2</td>
<td>Cool</td>
</tr>
<tr>
<td>$T_{op}&lt;65%$ lower limit</td>
<td>-3</td>
<td>cold</td>
</tr>
</tbody>
</table>

Applying the thermal sensation scale above, figure 7 below gives the year time (as percentage of the whole yearly hours) characterized by different indoor thermal conditions induced by the different constructions in Kisumu, Mombasa and Nairobi.
Figure 6: General comfort conditions in Kisumu (a), Mombasa (b) and Nairobi (c). The values show the percentage of the year time characterized by each category of the thermal sensation scale.

Apart from the graphic representation of the indoor thermal condition, EN 15251 proposes several criteria to evaluate the long term performance of buildings based on simulation results. One criterion is “degree-hours criteria” and uses the degree hours beyond the upper and lower boundary for the comfort condition. Considering values for the upper and lower at 90% acceptability levels as boundary for the comfort condition, table 6 shows the discomfort degree hours related to the different constructions.

Table 6: Discomfort degree hours compared to the 90% adaptive acceptability range.

<table>
<thead>
<tr>
<th>Construction</th>
<th>Kisumu</th>
<th>Mombasa</th>
<th>Nairobi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-oxidised GCI Sheets</td>
<td>11,689.17</td>
<td>10,160.39</td>
<td>11,157.28</td>
</tr>
<tr>
<td>Oxidised GCI Sheets</td>
<td>43,051.19</td>
<td>42,263.48</td>
<td>38,719.61</td>
</tr>
<tr>
<td>Wheat Husks boards</td>
<td>26,705.87</td>
<td>24,942.00</td>
<td>22,617.88</td>
</tr>
<tr>
<td>Rice Husks boards</td>
<td>22,606.65</td>
<td>21,023.60</td>
<td>18,912.62</td>
</tr>
<tr>
<td>Coconut husks boards</td>
<td>25,479.04</td>
<td>24,313.37</td>
<td>21,035.20</td>
</tr>
</tbody>
</table>

The discomfort degree hours graphically represent the integral of the distance between the indoor operative temperature obtained in the building and the 90% acceptability limit calculated as according to
the equations in table 4. The degree hour value can be considered a preliminary assessment of the acclimatization need in the building and of the predictable related energy consumption.

It is significant how the acclimatization needs changes for the GCI sheet construction with time, due to the oxidation process, which is a strong indication that the construction materials used should take into account the performance decrease related to degradation. Adaptive model states thermal comfort as sufficient attenuation of the outdoor climatic conditions by the building envelope, and oxidised GCI sheets with rice husks particle boards construction offers the best attenuation performances.

5. Conclusion

The simulation results show that oxidised GCI sheets construction can be improved when particle boards are used as internal insulating layers on the building envelope. More emphasis should therefore be made on local agricultural waste particleboard production. Secondly, the building code should state how this technology can be executed for maximum benefits of the slum dwellers, which eventually will lead to construction of low-cost housing.

References


EN 15251 (2007) *Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.*


ISO 6946 (2007) *Building components and building elements — Thermal resistance and thermal transmittance — Calculation method*


http://www.ecplaza.net/tradeleads/seller/5840014/: Wheat straw particleboard
**Prior Services Strategy in Entry International Construction Market – A Case Study of CICI’s Entry Strategy**

Lin, Z.  
Institute of Project Management and Construction Technology, Tsinghua University, Beijing, China  
(email: linzh03@mails.tsinghua.edu.cn)

Qiang, M.  
Institute of Project Management and Construction Technology, Tsinghua University, Beijing, China  
(email: qiangms@mail.tsinghua.edu.cn)

Chen, J.  
Dept of Civil Engineering and Engineering Mechanics, Columbia University, New York, USA  
(email: Jc3252@columbia.edu.cn)

Song, X.  
Dept of Civil Engineering and Engineering Mechanics, Columbia University, New York, USA  
(email: xs2149@columbia.edu)

**Abstract**

The steady growth of Chinese international contractors (CICs) has drawn great attention from academic and industry professionals. CICs have made great success not only in outsourcing human resources and low-balling competition, but also in the projects with high finance and technology requirements. With the two years’ continuous investigation of the rapid growth CIC - China International Trust and Investment Company International Contracting Inc. (CICI), we find CICI has its own procedures on entering international construction market. We summarized these procedures as a prior services strategy combined with Financial Services, R&D Services and Public Relations Services (“sss” strategy). Based on the data we have collected (interviews and surveys), explanations are given to every sector of this strategy. Finally, this paper proposed the strategy of “SSS”, and concludes that it is an effective and efficient entry strategy, which can improve CICs’ performance in international construction market.

**Keywords:** China; construction management; prior services; entry strategy; case study
1. Introduction

China is one of the largest construction markets in the world, which have a total market value nearly 900 billion dollars (Y., Guo, 2009). Many economists predict China will surpass US and became the largest construction market by 2018, when the market value is expected to worth 2.4 trillion dollars–19.1% of the global construction market. (Global Construction and Oxford Economics, 2009). In 2008 the number of construction industry practitioners in mainland China is 32.53 million and there are more than 1500 international contractors in mainland China (H., Ding, Q., Shen, 2004). This number even higher than 2,000 in other estimations (Z., Zhao, 2009).

Although Chinese contractors benefit from the massive development program on one hand, they have to face the fierce competition on the other. (Z., Zhao, 2009) Interestingly, during the competition, more and more Chinese contractors became winner in International bidding and made great progress in expanding of international market share. In a newly published Engineering News Record (ENR, 2009) of top 225 international contractors of 2009 (based on the revenue of international projects in 2008), China (Mainland) has 50 contractors on the list, shown as figure 1, whose number is increasing quickly year by year and already higher than other countries up to 2007. At the same time, Chinese international contractors’ overseas revenue of 2009 reached 390 billion U.S. dollars, that is 9% of total revenue of 225 firms (shown as figure 2), just ranking after the United States, France and Germany. This is the first time China rank as the fourth place (ENR, 2009).

![Figure 1: Number of CICs on the list of top 225 international firms (ENR, 1992-2008)](image1)

![Figure 2: Percentage of different countries’ international contractors’ total revenue among the top 225 (ENR, 2004-2009)](image2)

2. Background

The fast development of CIC can be attributed to many reasons, such as more experience on large-scale and complex projects and the low cost of workforce, materials and equipment. (Z., Zhao, 2009). However, with the appreciation of the RMB (Chinese currency), the cost advantage has been...
discounted. Thus, new strategy has to be developed to make up the loss on exchange rate advantage. Some scholars are working on the research of new market entry strategies of CICs, such as Chen and Orr discussed Chinese contractors’ successful factors in Africa: more home government support and better coordination mechanisms and market entry strategies. (Chen & Orr) A market entry mode or strategy is defined as an institutional arrangement that makes possible the entry of a company’s service, technology, human skills, management, or other resources into a foreign country (Root, 2007). Chen also pointed out that setting up a representative office or a brunch office/company is more preferred by CICs in Africa, with which CICs are not in the game of “hit and run” but for a long-term development and cooperation. (Chen & Orr, 2009, Chen, 2008). In this paper we are trying to figure out what should be done before the setup of these brunch offices and companies.

3. The research goals and methodology

This study aims at developing an efficient and successful international market entry strategy for CICs, and specific objectives including:

1. To find out what should be done before traditional entry strategy conducting

2. To find out the crucial success factors of every section of conducting this strategy

Since early 2007, our research team has been invited to develop an insight research on international contracting market entry strategy. We want to select a company whose strategy is the best sample for CICs’ successful entry. We collected a list of managers from Top 10 CICs, and required them to rate a best company can provided a successful entry strategy. Finally, CICI were selected by most of judges. After that, we cooperated with CICI for more than two years to look for the best strategies. Through interview memo and survey, we got access to the most useful first hand data. The managers and staffs interviewed by us cover most of important positions in CICI, their position and experience are shown in Table 2 and 3. Table 4 shows all the important projects’ characteristics, which are conducted by CICI and her partners.

Brief Introduction of CICI: CITIC International Contracting Inc. (also referred to as “CICI”) was established in 1986 as the wholly-funded subsidiary of China CITIC Group specializing in domestic and international contracting and related businesses. By the end of 2007, contract amount of projects under construction has achieved US$9.2 billion. In the field of overseas contracting, CICI ranked the third and tenth respectively in aspects of new contract amount and completed turnover among the Chinese contractors. Table1 shows the change of top10 CICs international ranking, and CICI’s fast development can be seen obviously from that.
### Table 1: Top CICs’ international rankings since 2003 (ENR 2004-2009)

<table>
<thead>
<tr>
<th>Year</th>
<th>CIC’s Name</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CCCG</td>
<td>--</td>
<td>32</td>
<td>45</td>
<td>14</td>
<td>18</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>CSCE</td>
<td>17</td>
<td>17</td>
<td>20</td>
<td>18</td>
<td>21</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>CNMIC</td>
<td>37</td>
<td>47</td>
<td>50</td>
<td>55</td>
<td>48</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>CRCC</td>
<td>108</td>
<td>167</td>
<td>73</td>
<td>83</td>
<td>102</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>SC</td>
<td>36</td>
<td>39</td>
<td>68</td>
<td>51</td>
<td>50</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>CICI</td>
<td>225+</td>
<td>225+</td>
<td>108</td>
<td>98</td>
<td>72</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>CMGC</td>
<td>98</td>
<td>101</td>
<td>93</td>
<td>95</td>
<td>81</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>CRG</td>
<td>48</td>
<td>48</td>
<td>67</td>
<td>67</td>
<td>71</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>CCECC</td>
<td>63</td>
<td>69</td>
<td>76</td>
<td>82</td>
<td>100</td>
<td>72</td>
</tr>
<tr>
<td></td>
<td>CNCEGC</td>
<td>112</td>
<td>102</td>
<td>94</td>
<td>88</td>
<td>97</td>
<td>90</td>
</tr>
</tbody>
</table>

### Table 2: The roles of the CICI sample

<table>
<thead>
<tr>
<th>Part</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEO-C</td>
<td>7</td>
<td>16%</td>
</tr>
<tr>
<td>Manager</td>
<td>7</td>
<td>16%</td>
</tr>
<tr>
<td>PM</td>
<td>10</td>
<td>23%</td>
</tr>
<tr>
<td>Staff</td>
<td>20</td>
<td>45%</td>
</tr>
<tr>
<td>Total</td>
<td>44</td>
<td>100.0</td>
</tr>
</tbody>
</table>

### Table 3: The work time of the CICI sample

<table>
<thead>
<tr>
<th>Time</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2Y</td>
<td>4</td>
<td>9%</td>
</tr>
<tr>
<td>2-5Y</td>
<td>8</td>
<td>18%</td>
</tr>
<tr>
<td>5-10Y</td>
<td>12</td>
<td>27%</td>
</tr>
<tr>
<td>&gt;10Y</td>
<td>20</td>
<td>45%</td>
</tr>
<tr>
<td>Total</td>
<td>44</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

### Table 4: Statement of CICI projects’ data

<table>
<thead>
<tr>
<th>Name of Projects</th>
<th>Number of interviewers</th>
<th>Start point of contracts</th>
<th>Condition of Projects</th>
<th>Value of Contract (million US dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>3</td>
<td>2001-06</td>
<td>Finished</td>
<td>142.9</td>
</tr>
<tr>
<td>N</td>
<td>4</td>
<td>2003-08</td>
<td>Finished</td>
<td>430.0</td>
</tr>
<tr>
<td>M</td>
<td>4</td>
<td>2004-10</td>
<td>Under going</td>
<td>85.7</td>
</tr>
<tr>
<td>X</td>
<td>4</td>
<td>2005-06</td>
<td>Finished</td>
<td>67.1</td>
</tr>
<tr>
<td>Y</td>
<td>4</td>
<td>2005-12</td>
<td>Finished</td>
<td>44.0</td>
</tr>
<tr>
<td>W</td>
<td>4</td>
<td>2005-11</td>
<td>Under going</td>
<td>905.0</td>
</tr>
<tr>
<td>B</td>
<td>4</td>
<td>2005-12</td>
<td>Under going</td>
<td>427.0</td>
</tr>
<tr>
<td>A</td>
<td>5</td>
<td>2006-05</td>
<td>Under going</td>
<td>6250.0</td>
</tr>
<tr>
<td>F</td>
<td>6</td>
<td>2007-11</td>
<td>Under going</td>
<td>3650.0</td>
</tr>
</tbody>
</table>
4. Data and analysis

Seven members of the chief executive committee accepted our interviews. They were asked the same questions on what are the main factors that attribute to CICI’s rapid development. From their responses, we select strategies that most frequently referred as our strategy candidates.

4.1 Important steps before strategy selection

When being asked the question what should be done before the prior services strategy, the following three steps are the most frequently referred, self evaluation, finding partners and opportunities identification.

4.1.1 Self evaluation

Self Evaluation was the first step for the strategy selection, and there used to be a broad and heated discussion within the CICI in 2003. There were two different opinions about the future direction of CICI. Most of managers thought it was a better choice to stick on the older strategy and win more medium contracts, comparing with other high-risk moves. The rest thought that it was a good chance for CICI to explore the broad international market, and the chance was that in 2003 her parent firm CITIC got the PPP contract of National Stadium for 2008 Beijing Olympic Games, and CICI is CITIC’s only construction brunch firm, which means, CICI will become one of the National Stadium’s contractors automatically.

Facing great opportunities, CICI has to know her advantage comparing with other biggest CICs, such as CSCEC. CSCEC (China State Construction Engineering Corporation) was highly praised as the No.1 CIC in China, which is usually set as the target by other CICs. With the famous blue sea strategy guidance, CICI took strategy comparative analysis between CSCEC and itself.

We ask the members of the chief executive committee and project managers from CICI and CSCEC to compare the following 6 factors between CICI and CSCEC.

F1 is engineering and technology capability, which is evaluated by technique condition and proficiency of construction methods.

F2 is R & D and innovation capability, which is evaluated by the quantity and quality of research institutes and experts, academicians in the company and the innovation award system.

F3 is public relationship capability, which is evaluated by to which degree they can receive support from the government and the public appearance in construction industry.
F₄ is capital operation capability, which is evaluated by the experience of their own financing department, outside company resource and the quantity and quality of financing experts in the company.

F₅ is project management capability, which is evaluated by engineering management experience, level of information-based management and grade of project management standardization.

F₆ is capability of self-owned construction team, which is evaluated by experience, quantity and quality of the company's construction teams and machinery.

Table 5. Comparative analysis between CICI and CSCEC

<table>
<thead>
<tr>
<th></th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>F5</th>
<th>F6</th>
</tr>
</thead>
<tbody>
<tr>
<td>CICI</td>
<td>Lower</td>
<td>Lower</td>
<td>Higher</td>
<td>higher</td>
<td>higher</td>
<td>Lower</td>
</tr>
<tr>
<td>CSCEC</td>
<td>Higher</td>
<td>Higher</td>
<td>Lower</td>
<td>lower</td>
<td>lower</td>
<td>Higher</td>
</tr>
</tbody>
</table>

From above comparative analysis in Table 5, we can find that CICI’s advantages are F₃, F₄ and F₅, which means she has a better public relationship, capital operation and project management capability. As one vice CEO of CICI mentioned, CICI had fewer staffs comparing with CSCEC, they can be more focusing on the management function rather than detail construction affairs. Up to 2008, CICI has a less than 800 people crew, while CSCEC had more than 100,000 workers and employees, which is a heavy burden for the company. Fewer employees are easier to switch between temporary projects team, and staffs’ needs are easier to satisfy than the continuous payment of regular staffs. Having this advantage in hands, CICI can build up a experienced management team with more talent engineers and managers, and accumulate more experience in capital operation and conducting large-scale projects.

Under the encouragement of Chinese government’s policy of “go international” and support from the parent firm CITIC. Finally, CICI confirmed their strategy—through prior services to obtain EPC contracts and to promote development of related industries.

4.1.2 Finding partners

The most critical problem for CICI is the lack of construction teams. Thus, one effective approach for CICI is to find partners who had his own construction team. The ideal partners should be good at engineering and technology, and have their own construction teams majoring in various construction areas. Moreover, the partner should have a strong will to strengthen its own capital operation capability through the cooperation. For example, in the project Algeria East-West Expressway, a mega expressway project in Africa, CRCC (China Railway Construction Corporation) was one of CICI’s partners when preparing for providing suggestions for the client, because CRCC has professional highway construction team and has many experiences of conducting famous transportation projects successfully. However, CRCC need more help on large projects’ capital operations and local guidance during acquisition of this contract, which CICI can supplied. After two
years’ prior services and cooperation, CRCC and CICI got 2/3 of the whole contract, which was the largest highway contract had CICs ever got in history.

Brief introduction of CRCC: CRCC is one of the largest multiple construction corporation in the world. It has ranked 485th in 2006 and 384th in 2007 respectively among the top 500 enterprises.

**Table 6. Partners of CICI in different projects and their strengths**

<table>
<thead>
<tr>
<th>Projects</th>
<th>Types</th>
<th>Partners’ Number</th>
<th>Main Partner</th>
<th>Main Partners’ Strength</th>
<th>CICI’s Advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>TRANSP</td>
<td>3</td>
<td>ZJED&amp;ZNSZ</td>
<td>F1&amp;F2</td>
<td>F4</td>
</tr>
<tr>
<td>N</td>
<td>GEN BLDG</td>
<td>4</td>
<td>JZ&amp;Vinci</td>
<td>F1&amp;F2</td>
<td>F5</td>
</tr>
<tr>
<td>M</td>
<td>INDUS</td>
<td>2</td>
<td>XJ</td>
<td>F2&amp;F3</td>
<td>F5</td>
</tr>
<tr>
<td>X</td>
<td>GEN BLDG</td>
<td>2</td>
<td>BH</td>
<td>F1&amp;F2</td>
<td>F3</td>
</tr>
<tr>
<td>Y</td>
<td>INDUS</td>
<td>1</td>
<td>LC</td>
<td>F3</td>
<td>F4</td>
</tr>
<tr>
<td>W</td>
<td>GEN BLDG</td>
<td>2</td>
<td>BJCJ</td>
<td>F1&amp;F2&amp;F6</td>
<td>F4</td>
</tr>
<tr>
<td>B</td>
<td>POWER</td>
<td>2</td>
<td>HDJ T</td>
<td>F1&amp;F2</td>
<td>F4</td>
</tr>
<tr>
<td>A</td>
<td>TRANSP</td>
<td>2</td>
<td>CRCC</td>
<td>F1&amp;F2&amp;F6</td>
<td>F3&amp;F5</td>
</tr>
<tr>
<td>F</td>
<td>GEN BLDG</td>
<td>10</td>
<td>CRCC</td>
<td>F1&amp;F2&amp;F6</td>
<td>F3&amp;F4&amp;F5</td>
</tr>
</tbody>
</table>

Because the names of projects and partners are sensitive information for CICI, so they are instead of the as some characters.

The most important thing of finding partners is to make a temporary project organization with complementary capabilities. From Table 6, we can find that CICI has at most 10 partners response for one project’s RFP, and the average number of partners is 2. CICI and his partners are working together on prior services to satisfy clients, which is different from satisfying the requests for proposal (RFP). During the prior services section, the clients are usually not clear about what they need urgently and what should be done first. What’s more, they even not clear that the clients also have responsibility in project construction. As the CEO of CICI said, “it was exciting that we could still find so many partners willing to work with us even though the clients didn’t make sure the contracts”. During interviews, nearly every partner has the impression that cooperation with CICI will guarantee the success of the project and a good profit. When asked whether they want to cooperate with CICI again if possible, they have the same answer, “Why not? We only invest very few resources, while the payback is worthwhile. Comparing with ‘blind bidding’, this is much better.”

**4.1.3 Opportunities’ identification**

Another question bothering us during the research is how CICI can identify the potential projects to reduce the risk and make more profits. We made a deep research on the preparation time, info resources and related organizations of each projects as the following Table 7.
Table 7 Original business information sources and relationships

<table>
<thead>
<tr>
<th>Projects</th>
<th>Types</th>
<th>Location</th>
<th>Preparation Time(months)</th>
<th>Original business Information sources</th>
<th>Related Organizations</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>TRANSP</td>
<td>Asia</td>
<td>&lt;1</td>
<td>Intra-group communication</td>
<td>Another subsidiary of CITIC</td>
</tr>
<tr>
<td>N</td>
<td>GEN BLDG</td>
<td>Asia</td>
<td>&lt;1</td>
<td>Intra-group communication</td>
<td>CITIC</td>
</tr>
<tr>
<td>M</td>
<td>INDUS</td>
<td>Asia</td>
<td>-</td>
<td>Partner</td>
<td>XJUT</td>
</tr>
<tr>
<td>X</td>
<td>GEN BLDG</td>
<td>Asia</td>
<td>&lt;1</td>
<td>Cross Companies Communication</td>
<td>CITIC, SMC, CHINCA</td>
</tr>
<tr>
<td>Y</td>
<td>INDUSTRIAL PROCESS</td>
<td>Asia</td>
<td>&lt;2</td>
<td>Cooperation between the governments</td>
<td>CITIC, NDB</td>
</tr>
<tr>
<td>W</td>
<td>GEN BLDG</td>
<td>South America</td>
<td>&lt;1</td>
<td>Cooperation between the governments</td>
<td>NDB, CITIC</td>
</tr>
<tr>
<td>B</td>
<td>POWER</td>
<td>South America</td>
<td>&lt;1</td>
<td>Brazil - China Expo</td>
<td>NDB, NDRC, CHINCA</td>
</tr>
<tr>
<td>A</td>
<td>TRANSP</td>
<td>Africa</td>
<td>&lt;1</td>
<td>Intra-group communication</td>
<td>CITIC, NDB</td>
</tr>
<tr>
<td>F</td>
<td>GEN BLDG</td>
<td>Africa</td>
<td>&lt;1</td>
<td>Intra-group communication</td>
<td>CITIC, NDB</td>
</tr>
</tbody>
</table>

*NDRC, National Development and Reform Commission; MOFCOM, Ministry of Commerce; NDB, National Development Bank; CHINCA, Chinese International Contractors Association. They are all important related organizations helped a lot on business information getting.

From Table 7 we can find that CICI draw a high attention on intra-group communication and governments’ cooperation. They read most of the business information from official international affairs, such as government leaders’ visits to foreign countries, strategic agreement two countries signed, and foreign leaders’ visits to China. Comparing with getting business information from RFP, CICI get more fresh and accurate information in advance. Based on the research of advantage of CIC in the international markets, CICI find Asia and Africa market are much easier to enter, because of the long term cooperation and accumulated reputation. Apart from that, CICI confirmed that South America is the second choice because of their increasing infrastructures developing requirements.
Moreover, CICI not only has a good sense of getting business information, but also response quickly. In all of the projects interviewed, the time gap between information arrived to providing the first prior services are no more than 1 month. During preparation step, CICI has to make sure whether the project is profitable for both themselves and the clients. This is a difficult work with limited time. Participants of the project have to work for more than 16 hours per day to collect, summarize and analyze the data and come out a feasible report. After this section, CICI has to convince their partners to supply prior services together based on this report.

Taking Project H as an example, the client would have preferred a project of coastal roads, but after reading CICI’s feasibility report on the transportation projects, they decided to follow CICI’s suggestion of building a cross-border road instead. Sometimes CICI’s feedback research is more insightful than clients did.

### 4.2 “SSS” strategy

Once CICI confirm the opportunity of potential clients, prior services strategy will be executed (summarized as SSS services strategy), which mainly contains Financial Services, R&D Services and Public Relationship Services.

Financial Services contain ownership financing, debt financing, BOT (Build Operate Transfer) project financing, TOT (Transfer Operate Transfer) mode of financing, ABS (Assert Backed Securitization) financing, etc. The advantages of CICs’ financing service mainly concerned in: Chinese government aid loans and preferential loans and export credit.

R&D Services are feasibility study services before project begin. These services are based on the projects’ relevant information, data research, projects’ technical, economic, engineering and environment research, etc. The major aim of these services is to make clear whether the projects are profitable or how to make them profitable. The project feasibility study report is the outcome of this service and will help client to make decisions.

Public Relationship Services contains the advertising through media agency, developing contact with media agency, marketing communications, corporate communications, government relations, crisis management, brand management and media monitoring and evaluation, etc. When serving a client in developing country, it is very important to embed the construction education service in construction projects. This is because there have requirements both in construction and maintenance in contract.

Condition of a client means the clients’ familiarity with the project and its implementation, and the quality and quantity of project-related professionals at clients’ side. We requested CICI’s project managers to rate their clients’ condition when they supplied prior services. 5 stands for the best condition, which means the client had a very clear idea with what they want and how to conducted the project with support from project-related professionals. 1 stands for the worst condition, which means the client had no idea what they want and how to conducted, and there were fewer professionals they can consult.
Table 8: Different Delivery and Financing Methods

<table>
<thead>
<tr>
<th>Project</th>
<th>Type of Construction</th>
<th>Delivery Methods</th>
<th>Financing Methods</th>
<th>security for loans</th>
<th>Conditions Of Clients</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>TRANSP</td>
<td>BOT</td>
<td>Seller's Credit</td>
<td>Operating earnings</td>
<td>2</td>
</tr>
<tr>
<td>N</td>
<td>GEN BLDG</td>
<td>PPP</td>
<td>Both Credits</td>
<td>Operating earnings</td>
<td>3</td>
</tr>
<tr>
<td>M</td>
<td>INDUS</td>
<td>Financing +EPC</td>
<td>Seller's Credit</td>
<td>petroleum</td>
<td>1</td>
</tr>
<tr>
<td>X</td>
<td>GEN BLDG</td>
<td>EPC</td>
<td>Clients’ Funding</td>
<td>--</td>
<td>3</td>
</tr>
<tr>
<td>Y</td>
<td>INDUS</td>
<td>Financing +EPC</td>
<td>Buyer's Credit</td>
<td>palm oil</td>
<td>1</td>
</tr>
<tr>
<td>W</td>
<td>GEN BLDG</td>
<td>Financing +EPC</td>
<td>Buyer's Credit</td>
<td>petroleum</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>POWER</td>
<td>Financing +EPC</td>
<td>Buyer's Credit</td>
<td>Electricity</td>
<td>3</td>
</tr>
<tr>
<td>A</td>
<td>TRANSP</td>
<td>EPC</td>
<td>Clients’ Funding</td>
<td>--</td>
<td>2</td>
</tr>
<tr>
<td>F</td>
<td>GEN BLDG</td>
<td>Financing +EPC</td>
<td>Buyer's Credit</td>
<td>petroleum</td>
<td>1</td>
</tr>
</tbody>
</table>

From Table 8, we can reach the conclusion that following factors are most crucial for SSS strategy, shown as Table 9.

Table 9: Crucial Successful factors of SSS conducting

<table>
<thead>
<tr>
<th>Prerequisites for clients</th>
<th>Financial Services</th>
<th>R&amp;D Services</th>
<th>Public Relations Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Be solvent or have potential to be; Having demands for infrastructure developments; Be lack of financial and engineering experience in implementing a variety of deliveries</td>
<td>Be lack of engineering and technical personnel; Be lack of experience in construction projects; Have not been very clear on the engineering requirements</td>
<td>Be not very familiar with the projects’ preparation and implementation procedures; Be not good at cross-cultural communication and international management</td>
<td></td>
</tr>
<tr>
<td>Professional talents of capital operation; Banks’ support; Partners’ support; National policy support</td>
<td>Professional talents engineering and technology; Collaborative design; Research and development enterprise support</td>
<td>Resources for a wide range of social relationships; Rich experiences of project management</td>
<td></td>
</tr>
</tbody>
</table>

Crucial factors of conducting these services

Firstly, every kind of services should be based on the clients’ real and urgent needs, so it is very important to have clear understanding of clients’ needs.

Secondly, make sure the project should be a win-win project for both clients and partners for a long run.

With 15 potential international projects selected, CICI applied SSS strategy for projects’ acquisition. SSS Applications need patience, continuous resources input and data accumulation is needed. It is not
an immediately available until CICI got the first feasible project in 2003, which is the famous national stadium for 2008 Beijing Olympics Games.

**Table.10 SSS Applications in CICI’s Projects**

<table>
<thead>
<tr>
<th>Projects</th>
<th>Types</th>
<th>Projects’ Beginning time</th>
<th>Intervening time</th>
<th>Lead time /months</th>
<th>PFSC</th>
<th>PR&amp;DSC</th>
<th>PPSC</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>TRANSP</td>
<td>2002-01</td>
<td>2001-02</td>
<td>11</td>
<td>0.3</td>
<td>0.7</td>
<td>0</td>
</tr>
<tr>
<td>N</td>
<td>GEN BLDG</td>
<td>2003-06</td>
<td>2003-04</td>
<td>2</td>
<td>0</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>M</td>
<td>INDUS</td>
<td>2004-10</td>
<td>2003-10</td>
<td>12</td>
<td>0.8</td>
<td>0</td>
<td>0.2</td>
</tr>
<tr>
<td>X</td>
<td>GEN BLDG</td>
<td>2005-06</td>
<td>2004-04</td>
<td>12</td>
<td>0</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Y</td>
<td>INDUSTRIAL PROCESS</td>
<td>2005-12</td>
<td>2005-08</td>
<td>4</td>
<td>0.6</td>
<td>0.4</td>
<td>0</td>
</tr>
<tr>
<td>W</td>
<td>GEN BLDG</td>
<td>2005-11</td>
<td>2005-01</td>
<td>10</td>
<td>0.8</td>
<td>0.2</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>POWER</td>
<td>2005-12</td>
<td>2004-12</td>
<td>12</td>
<td>0.8</td>
<td>0.2</td>
<td>0</td>
</tr>
<tr>
<td>A</td>
<td>TRANSP</td>
<td>2006-05</td>
<td>2004-9</td>
<td>20</td>
<td>0.5</td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td>F</td>
<td>GEN BLDG</td>
<td>2007-12</td>
<td>2004-8</td>
<td>38</td>
<td>0.8</td>
<td>0.2</td>
<td>0</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td>13.44</td>
<td>0.51</td>
<td>0.36</td>
<td>0.13</td>
</tr>
</tbody>
</table>

*PFSC stands for the Percentage of Financial Services’ Contribution, PR&DSC stands for the Percentage of Research and Development Services’ Contribution, PPSC stands for the Percentage of Public relation Services Contribution.*

We requested project managers and related chief executive members to rate the contribution of various services to those projects. Total percentage of contribution from prior services (including financial services, R&D services and public relation services) is 1(100%) for each project. 1 means that kind of service is the only service contributed for getting the project. 0 marks the services that has no contribution to the project’s acquisition.

From Table.10, we find that CICI has an average 13.44 months ahead of projects’ beginning to intervene into the potential projects. Among the three kind services, financial services have stronger positive influence on acquisition of projects for CICI, which reflects CICI has a higher capability on the capital operation.

CICI’s conducting the SSS strategy have led to a great success, and CICI has got great achievements: Success rate of tenders of CICI has reached more than 70% (11 projects of 15 potential projects), especially for mega-projects (such as W, A and F projects) with steady and long-time follow-up prior services, almost achieved 100% access to acquisition of the projects, which three projects total avenue reached 90% of all 9 biggest projects selected.
Generally speaking, CICI’s financial service plays the most important role in the prior services proceeding. Public relations services play a more important role in the domestic projects when clients are foreign organizations who are not familiar with Chinese construction industry environment. Through the SSS strategy, CICI has made a remarkable progress and win her reputation as one of best CICs within five years.

Once SSS are proofed as an effective strategy, CHINCA held a number of conferences and seminars to help more CICs find their positions and encourage them to provide pre-project services to potential clients. With the help of more and more research on CICs, we believe that CICs will get a better score both on their capability and international revenue in the future.

5. Conclusion

CICs’ great achievements can be attributed to many reasons, such as China governments’ encouragement policy of “go international”, the expansion of China Construction Market, and capital supporting from State owned banks. However, according to the case study of CICI’s strategy, it can’t be denied that the prior services SSS strategy is a critical approach in the process of entering and surviving in international markets. CICI have taken series of actions to conduct the strategy with the hope of exploring the broad international market since 2003, when most of the other CICs were still working in domestic market. 6 years later, CICI has risen to be the 6th biggest international contractor in China with less than 800 employees. Actions speak louder than words. More and more CICs tried to learn the applications of prior services strategy, and more and more partnership groups have been set up to satisfy the potential clients before the RFP claimed.

CICI’s experience is not only appropriate for CICs, but for most of international contractors, especially those international contractors in developing countries, and they can learn from the case study and take wise and quick strategy for serving the construction market.

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Corruption in Sri Lankan Construction Industry

Hadiwattege, C.
University of Moratuwa, Sri Lanka
(email: chandanieh@uom.lk)

De Silva, L.
University of Moratuwa, Sri Lanka
(email: lalith@becon.mrt.ac.lk)

Pathirage, C.
University of Salford, UK
(email: C.P.Pathirage@salford.ac.uk)

Abstract

Construction industry plays a major role in the Sri Lankan economy. This research has been conducted to examine whether the construction industry of Sri Lanka is corrupted and is there any cost amplification due to corruption. In achieving the research aim and objectives, survey method was followed together with case studies where necessary. Data analysis was carried out mainly with the usage of statistical tools. Results show that the people involved in the sector believe that the construction industry of Sri Lanka is corrupted and corruption amplifies the cost of construction which finally cascade down to the general public. The research is also concerned about the situations where corruption occurs more frequently in the construction life cycles and the reasons for heavy presence of corruption within the industry. Further the researcher has identified the major effects of corruption. Through this research a model to calculate the cost amplification due to corruption has been formed and verified. With the foundation established, it is needed to concern more and discover suitable remedial measures to eliminate corruption from the Sri Lankan construction industry.

Keywords: corruption, construction industry of Sri Lanka, situations and reasons, effects, regression model
1. Introduction

Corruption is defined in a white paper by United States Agency for International Development (USAID 2008, p.4) as, “The misuse or abuse of entrusted power or authorities through practices such as embezzlement, fraud, extortion, bribery/kickbacks, nepotism or favouritism, including theft of state assets and diversion of state revenue, for their personal gain or of others connected to them.”

CIOB (2006, p.23) states “It is apparent that corruption certainly did exist in the United Kingdom (UK) construction industry”. Moderately, the studies done in countries like Africa (Schroth, and Sharma 2003), Hong Kong (ICAC, 1998), India (Vittal, 2002) and so on, have proved the identical reality. As Kawabena and Charity (2007, p.951) stated “The construction industry is often seen as a driver of economic growth especially in developing countries.” In Sri Lanka, the Central Bank Reports (2005) bear the evidence, as almost 40% to 50% of the Gross Domestic Fixed Capital Formation and six percent to seven percent of the Gross Domestic Product is related with construction industry.

The link between the Sri Lankan construction industry and the impacts of corruption has not been scientifically recognized yet and needs to be found out immediately in order to cure and prevent its appalling effects on the economy as well as on society. Therefore this research is aimed to fill the identified knowledge gap.

2. Literature review

2.1 Corruption and Sri Lankan construction industry

Corruption comes in various forms. A study by Transparency International (2005, p.5) describes, “Construction projects normally have a large number of participants linked together in a complex contractual structure.” As USAID (2006) stated, there is widespread perception that both public and private sector corruption is rife in Sri Lanka.

2.2 Situations prone to corruption in construction

Transparency International (2005, pp.39-42) has identified the instances where corruption may occur such as, the environmental impact assessment stage, when getting approval for public construction projects, contractor paying a fee to client’s representative to secure the award of the contract, contractor bribes the consulting engineer who will advise the client that the briber’s bid is the best, tender processes corrupted by international pressure, group of contractors ostensibly in competition may secretly collude, agreeing to share future projects between them so as to keep prices high, group of contractors bidding for a project may secretly agree that each will include a pre-agreed sum in their tender that reflects the estimated aggregate bidding costs of all the tenderers, group of suppliers of material may collude to fix the minimum price of the materials they supply or a bribe may be paid to a client’s representative in order to obtain internal information on the expected budget, or to limit the number of bidders allowed..etc. Further, Kargbo (2006) describes these situations as awarding stage
of a contract, payment of bribes to win operation and maintenance contracts, making cost comparisons difficult, and increasing the opportunities for concealing bribes and inflating claims, in the bidding process may be linked to the over-specification of a project...etc. A study by TI – Bangladesh (2002) has uncovered corruption in procurement contracts in three forms.

In a study by SOFIMUN (2008, p.11), the significance of corruption is discussed follows:

“bid rigging occurs, shell companies are established, and procurement documents are falsified. Substandard materials are used in construction, regulators are paid off, and prices for infrastructure services are inflated.”

These different studies explore a number of opportunities/instances in which corruption can take place in the construction industry. Broadly these can be classified in to five areas as corruption in planning and design stage, in award of contract stage, in construction stage, in operation and maintenance and in procurement. Following section will highlight specific causes for corruption.

### 2.3 Causes for corruption in construction industry

According to Stansbury (2005 cited in TI, 2005) the inbuilt features of construction projects such as the number of contractual links and lack of due diligence...etc makes them particularly prone to corruption. As discussed by Sum (2004) the Principal-Agent problem, complexity and uniqueness of output and its fragmented structure, the physical characteristics of construction output like large and heavy, complex unique and expensive and the fragmented structure...etc are the causes for corruption. As Stansbury (2005 cited in TI, 2005) describes, uniqueness, lack of frequency of projects, entrenched national interests, government involvement with requiring numerous permits and no single organization governing the industry, number of phases makes project oversight difficult involving different management teams, cost of integrity, the complexity of projects...etc are also create room for corruption.

Zou (2003) describes it as due to the large amount of money involved in a single transaction...etc leads construction industry towards corruption. Banfield (1958 cited in Treisman, 2000) the “familism”, which, in turn, may affect the level of nepotism (Treisman, 2000). According to Begovic (2003, pp.4-6), selfish interests of economic agents, law procedural legislation, complicated and non-transparent legislations and discretion of civil servants in the enforcement process, non presence of strong and unconstrained political will...etc creates a tremendous opportunity for corruption.

Chan (1998) argued that the causes for corruptive practices are discretionary power involving the decision-making, large number of approvals required, situations involving security or confidentiality that can be compromised and in situations where the standard operating rules and procedures are not clearly defined...etc. Treisman (2000) explains that the greater flexibility in legal precedent, in countries with greater state intervention in the economy and corruption will be greater in countries that are more ethnically divided...etc. Kenny (2007, p.2) explains that, because the construction industry involves complex and because of its many close ties to government...etc, it is perhaps unsurprising that construction is frequently held up as one of the most corrupt industries worldwide.
The discretionary power of civil servants and decreased wages of civil servants ...etc is another important reason for corruption (Begovic, 2003).

These are the causes identified by various researchers which are being the reasons for corruption existence in the construction industry. The next section discusses about the effects of corruption.

2.4 Effects of corruption

A study by Mauro (1995 cited in Treisman, 2000) states the effects as the failures of certain “developing” countries to develop etc. As Transparency International (2005) describes, the cost of the bribes and false claims will often form part of the final contract price. As Khan (1998) explains the effects can reduce social value. In a study by Chan (1998, p.366-367) it was revealed that the most obvious effect is the directly incensement of the cost of a transaction and other legitimate considerations in the awarding and performance of contracts or in the provision of services. The result is that economic decisions are skewed; quality standards and safety are compromised.

Transparency International (2005) argues that aid to the developing countries will be cut back. As it has been pointed out by Begovic (2005), corruption violates the rule of law. Empirical studies by Kaufmann and Wei (1999) have shown the effects on economic growth, public expenditures, domestic and foreign investment, and the effect of corruption on driving firms to the unofficial economy. Begovic (2005) has identified that countries with widespread corruption cannot expect high growth rates. According to a report by Transparency International (2005), the consumers of a corrupted project will not receive the total expected output up to the quality.

As explained by Chan, (1998, p.367), the moral damage is perhaps more serious. According to Begovic (2005), corruption increases basic business uncertainty. According to Khan (1998), South Asian countries fit more closely with the perception that corruption is associated with poor performance. Corruption is not about an amount of money changing hands. It is about the future of the nation.

3. Aim and objectives

Aim of the research is to identify the impact of corruption in Sri Lankan Construction Industry. The objectives were to identify whether the construction industry of Sri Lanka is corrupted according to the views of the people who are involved in the sector, to understand the situations which are possible to encounter corruption, to investigate the dominant reasons leading towards corruption, to discover its effects in relation to Sri Lankan construction industry and to develop a model to calculate the cost of corruption.
4. Methodology

4.1 Data collection

The study was carried out through a review of the literature available in the field, specifically relating to the construction industry. A questionnaire survey and unstructured interviews were carried out as means of collecting data. The sample was selected based on clustering procedure consisting directors, of consultant, contractor and client organizations for the questionnaire survey and the area was limited to the Western province, being the commercial hub of Sri Lanka. Sixty questionnaires were distributed and the respondent rate was at fifty percent. A lacquered scale of one to five was given to rank the importance of points given in the questionnaire. Thirteen case studies were used for the model formation and verification. Both the documentary surveys and unstructured interviews were carried out to collect the data regarding the cases.

4.2 Method of analysis

The data collected were subjected to frequency and severity index (SI) analysis, Kendall’s concordance test and to the chi-squared tests to establish a rank for the ordering of facts obtained with relevance to each and every objective. Further, the ranks obtained according to the median were considered to identify the most significant situations, reasons and the effects. When ranking according to the median if the same rank obtained for many then the first quartile and the third quartile respectively were considered to finalize the rank. In this study, the cost amplifying effects regarding which the data were collected were supposed to be exhibiting strong correlation coefficient when their $r > +/− 0.71$ (1990 Elifson et al., p.208). Further, variables need to have $r < 0.30$ among them to avoid the presence of multicollinearity effect. T-Distribution was used while testing hypothesis with individual partial regression coefficient for zero and non zero for null and alternative hypothesis respectively. If any of the individual partial coefficients accepts the null hypothesis at a certain confidence level, the model has eliminated it. The coefficient of determination ($R^2$) adjusts the measure of explanatory power for the number of degrees of freedom. Identification of most significant independent variables was achieved by taking all T-Values for each and every coefficient regard to the imminence to the zero, lowest variables is rejected from the model and recalculate the formula. To obtain most significant variables, same procedure was iterated till the model comprises variables all of which partial regression coefficients are not equal to zero at a given level of significance.

5. Survey findings

5.1 Sri Lankan construction industry’s view on corruption

Eighty percent of respondents claimed that they believe the Sri Lankan construction industry is corrupted. The figure 1 clearly exhibits the finding.
When considering the data collected in separated view points of the three categories, as illustrated in figure 2, there is a close similarity between the views of the respondent parties.

However, all the respondents agree with the fact that there is cost amplification in any case of corruption in the construction industry.

5.2 Selection of situations which are highly prone to corruption

Concerning both the Severity Indexes ranking and the ranks according to the median, considering the data set as a whole the followings were identified as the most significant frequent situations which lead to higher cost amplifications in the construction industry.
Table 1: Highly ranked situations

<table>
<thead>
<tr>
<th>Rank</th>
<th>Situation</th>
<th>SI Rank</th>
<th>Median Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Approval of public construction Projects (Corruption in planning and design)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>Contracts granted in response to political party influence (Award of contracts)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>Group of contractors ostensibly in competition may collude, agreeing to share future projects so as to keep the prices high (Award of contracts)</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>Contractor bribes the consulting engineer who will advise the client in such a way to convince him that the briber’s bid is the best (Award of contracts)</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>Contractors allocate too many staff on a claim, charge for many hours, give clients over-optimistic advice (Corruption during construction)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Checkers certify that defective or non-existent work is acceptable (Corruption during construction)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Client bribe the architect to falsely certify that the contractor delayed the project in order to deduct liquidated damages from payments to contractor (Corruption during construction)</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>High-technology projects, monopoly of supply during maintenance period, making the cost comparisons difficult (Corruption during operation and maintenance)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Corruption in the bidding process linked to over-specification of a project, which increases the costs of operation and maintenance (Corruption during operation and maintenance)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>Payments for recommendation and approval of contracts (Corruption in Procurement)</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

5.3 Identification of the foremost reasons for corruption

After considering both the calculated Severity indexes for the reasons identified through the obtained data, ranks obtained from the three parties separately and the ranks obtained by the median consideration followings were identified as the most critical reasons for corruption in Sri Lankan construction industry.

Table 2: Highly ranked reasons

<table>
<thead>
<tr>
<th>Rank</th>
<th>Reasons</th>
<th>SI Rank</th>
<th>Median Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Difficulty in monitoring expenditure</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Government involvement requiring numerous permits</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Non presence of strong and unconstrained political will</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Lengthy and complicated construction process</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Large amount of money involved in a single transaction</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>10</td>
<td>Discretionary power of civil servants</td>
<td>10</td>
<td>5</td>
</tr>
</tbody>
</table>
5.4 Detection of the drastic effects of corruption

Considering the Severity Index analysis rankings and the rankings from the median consideration the following effects were identified as the most drastic effects of corruption in relation to the construction industry of Sri Lanka.

Table 3: Highly ranked effects

<table>
<thead>
<tr>
<th>Rank</th>
<th>Effects</th>
<th>SI Rank</th>
<th>Median Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Loss of faith in the integrity of decision makers</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Increased public expenditures</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>Low growth rates directly related to entrepreneurship and innovations</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Reduction in social value</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>Damage to confidence, reputation and image</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Wrong suppliers and/or contractors are selected; and material, quality standards and safety are compromised</td>
<td>3</td>
<td>6</td>
</tr>
</tbody>
</table>

5.5 Regression model formulation for cost amplification calculation

According to the statistical analysis results, corruption in procurement is maintaining a higher correlation coefficient with the other factors and thus it had to be eliminated from the model. All the other four areas have correlation coefficients higher than 0.71 with the dependent variable of the cost amplification due to corruption.

The first tentative model:

\[
\text{Cost Amplification due to Corruption} = 2345 + 0.09 \text{ cost of planning and design} + 0.12 \text{ cost of award of contracts} + 0.21 \text{ cost of construction} + 0.14 \text{ cost of operation and maintenance}
\]

Model evaluation as a whole:

The ANOVA table which was created with the model has been used to evaluate the model as a whole.

Table 4: ANOVA table for 1st tentative model

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>4</td>
<td>254369</td>
<td>63592</td>
<td>26.52</td>
<td>0.000</td>
</tr>
<tr>
<td>Residual Error</td>
<td>6</td>
<td>14386</td>
<td>2398</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
<td>268755</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The ANOVA procedure was used to test whether at least any one of the independent variables has a relationship with the dependent variable.

H0: All partial regression coefficients are equal to zero

H1: At least one partial regression coefficient is not equal to zero

According to the derived model, the degrees of freedom for which F-test needs to be performed are 4 and 6. At the 5% error level, F value of F0.05, 4,6 derived from the F distribution table was 4.53. Considering the fact that the F-value obtained from the model was 26.52, null hypothesis was rejected at the 95% confidence level. Therefore it can be understood that, out of the four independent variables used to the model, at least one variable having a partial regression which is not equal to zero has been rejected with 95% of certainty. Hence, at least one variable would have the explanatory power of the dependent variable.

**Individual partial regression coefficient evaluation:**

Every individual partial regression coefficients was tested with the T-test to ascertain the significance of each independent variable. The following table demonstrates the results received.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coefficient</th>
<th>Standard Deviation</th>
<th>T-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>2344.965</td>
<td>60.67</td>
<td>0.03</td>
<td>0.003</td>
</tr>
<tr>
<td>Cost of planning and design</td>
<td>0.104</td>
<td>0.76</td>
<td>5.98</td>
<td>0.045</td>
</tr>
<tr>
<td>Cost of award of contracts</td>
<td>0.123</td>
<td>2.67</td>
<td>6.66</td>
<td>1</td>
</tr>
<tr>
<td>Cost of construction</td>
<td>0.221</td>
<td>1.90</td>
<td>6.96</td>
<td>142</td>
</tr>
<tr>
<td>Cost of operation and maintenance</td>
<td>0.140</td>
<td>1.54</td>
<td>8.37</td>
<td>142</td>
</tr>
</tbody>
</table>

The evaluation was done following the hypothesis.

H0: Individual partial regression coefficient of a variable is equal to zero

H1: Individual partial regression coefficient of a variable is not equal to zero

At the 95% confidence level the null hypothesis is rejected and consequently all four factors can be continued with the model. The other relevant statistics which are related with the coefficient determination were the S at 57.8975 and the R-Sq at 85.7%. Accordingly, the first tentative model can be identified as the finalized regression model given below for the research.

**Finalized regression model:**
Cost Amplification due to Corruption = 2345 + 0.10 cost of planning and design + 0.12 cost of award of contracts + 0.22 cost of construction + 0.14 cost of operation and maintenance

Consequently the four independent variables have received the VIFs summation is equal to 4.83 which is > 1 and <5. Therefore it is proven that the effect of multicollinearity is not an existing shortcoming of the concerned independent variables and the residuals are randomly dispersed in a normal distribution with a zero mean. The finalized model was tested with three separate corruption cases from the industry to measure the validity of the model.

6. Conclusions

The construction industry of Sri Lanka is a major sector of the economy. According to the research findings, a majority of eighty percent of the sample believes that the industry is prone to corruption. Hundred percent of the respondents accepted that corruption leads to cost amplifications. Hence the construction industry has created a burden of unnecessary cost to the general public through the corruption prevailing within the industry.

The approval of public construction projects at the planning and design stage, contracts given as a result of political party influence at the award of contracts stage, contractors allocate too many staff on a claim, charge for many hours, give clients over-optimistic advice at the construction stage, High-technology projects, monopoly of supply during maintenance period, making the cost comparisons difficult at the maintenance stage and the payments for recommendation and approval of contracts at the Procurement stage were the highest cost amplifying situations which frequently occur in the Sri Lankan Construction industry.

Since corruption and the due cost amplification are present, it is essential to identify the reasons for corruption. Therefore the probable reasons were outlined and were tested with statistics. According to the obtained results the difficulty in monitoring expenditure, government involvement requiring numerous permits, non presence of strong and unconstrained political will, lengthy and complicated construction process, large amount of money involved in a single transaction and the discretionary power of civil servants were the most significant and dominant reasons for the existence of corruption in the construction industry of the Sri Lanka. Realization of these reasons has a very high worth in relation to the mitigation of corruption.

In relation to the construction industry of Sri Lanka the most dangerous effects of corruption are the loss of faith in integrity of decision makers, increased public expenditures, low growth rates directly related to entrepreneurship and innovations, reduction in social value, damage to confidence, reputation and image, wrong suppliers and/or contractors are selected and material, compromised quality standards and safety. These are very detrimental issues in relation to the reputation of the whole industry as well as the financial system of the industry.

The cost amplification calculation model was finalised as;
Cost Amplification due to Corruption = 2345 +0.10 cost of planning and design + 0.12 cost of award of contracts + 0.22 cost of construction + 0.14 cost of operation and maintenance

Sri Lanka, as a country which is developing in a rapid manner after ending the ethical war and exhibiting exceptional economic performances in such an era where the world economy is under a crisis, will surely be able to remove this hassle of corruption from the country. Therefore the researcher suggests the next step towards development of Sri Lanka is to fight to eliminate the corruption which will not only be a dream.

Acknowledgement

It is need to express the heartiest appreciation to everybody who have supported from the beginning to the flourishing end of this research.

References


Using Plastic in the Form of Ebonite Strips as Reinforcement Bars in Reinforced Concrete Beam

Manu, P.
University of Wolverhampton, Wolverhampton, UK
(email: Patrick.Manu@wlv.ac.uk)

Solomon-Ayeh, K.
Building and Road Research Institute, Kumasi, Ghana
(email: solomonayeh@yahoo.com)

Hatfield, A.
University of Wolverhampton, Wolverhampton, UK
(email: A.Hatfield@wlv.ac.uk)

Adukpo, E.
Black Star Advisors, Accra, Ghana
(email: selorm@primroseproperties.net)

Abstract

Steel, mild or high strength, has been the traditional material for the reinforcement of concrete in Ghana. The high cost of steel and the need to use reinforced concrete in areas of low applied loads have necessitated the look at using materials other than steel for reinforcement. Drawing on that, this study investigates the use of plastic in the form of ebonite strips as reinforcement in concrete beams. Tests were conducted to determine the tensile and bonding strength of ebonite strip and the flexural strength of ebonite strip-reinforced concrete beams, on the assumption that the flexural strength of the beam is derived primarily from the concrete/ebonite strip bonding action. The tests revealed that the failure strengths of ebonite strip-reinforced beam is much lower than that of comparable steel-reinforced concrete beam; the reason being the low bond between ebonite strips and concrete. It is therefore inferred that ebonite strips cannot be used as a complete substitute for steel reinforcement. However, the flexural failure loads obtained revealed that for lightly loaded concrete elements such as lintels over small openings of up to 1000mm, ebonite strip can be used in place of steel reinforcement. The tests also revealed that the top threshold of ebonite strip input was about 5% of the cross-sectional area of the lintel beam. It was observed that ebonite strip would be beneficial for use in flexural members if they could be anchored to the concrete by a suitable mechanical means at their ends, in a manner similar to anchor blocks in steel pre-stressed tendons and, additionally, have their surfaces roughened or ribbed.

Keywords: concrete technology, experiment, structural engineering.
1. Introduction

Concrete is weak in tension and will fail under tensile stresses unless reinforced in the zones of tension by some materials of high tensile strength; traditionally steel (William and Todd, 2000). Steel is relatively expensive, at least in Ghana, and has other problems such as corrosion when in saline environments (British Research Establishment (BRE), 2000; Bamforth, 2004). This latter property of steel reduces its load carrying capacity and durability (BRE, 2000; Bamforth, 2004). Investigations have been carried out the world over at finding alternative materials to steel, which can perform similar functions (cf. Emmons et. al. (1998), Schöck (2006), Durham et. al. (2009)). In line with this trend, this research investigates the use of plastic, in the form of ebonite strips as reinforcement in concrete. The choice of ebonite strips (plastic) is due to its ready availability, comparatively low density and cost (Jackson and Dhir, 1996; Richardson, 2008). Ebonite strips is a thermoplastic, chemically known as polyvinylchloride (PVC) and used in Ghana as dividing strips in terrazzo floors to control movement and shrinkage cracks. They are available in about 6mm thickness and 3600mm lengths. PVC has tensile strength in the range of 40-60N/mm² (Jackson and Dhir, 1996) and it is assumed that when used in place of steel in concrete in areas of low applied loads it should perform functions similar to that of steel in the reinforced matrix. In the performance of that function, the tensile and bond strengths of ebonite strips should be paramount and are thus tested for as part of this investigation. Of foremost importance, in this experiment, are the flexural strengths of the reinforced concrete members (lintel beams in this case). Beams of standard dimensions of 100x100x1200mm were reinforced with increasing percentages of ebonite strip input and loaded to failure in flexure. A comparison of the performance of the ebonite strip–reinforced concrete beam was made with mild steel (10mm diameter) reinforced concrete beams.

2. Methodology

Experiments carried out were in two categories: those investigating some engineering (mechanical) properties of ebonite strip and those establishing the suitability and reliability of the use of ebonite strip as reinforcement in a concrete beam in flexure. The concrete used for the tests was of grade C21 and was designed in accordance with the design of normal concrete mixes (Marsh, 1997). The concrete was made up of 20mm maximum size granite coarse aggregates and fine aggregate (of granite origin), obtained from pits near rivers at Aputuogya, west of Kumasi, Ghana. The particle size distribution of the coarse aggregate is shown in Figure 1 and that of the sand is shown in Figure 2, and lies in Zone 2 of BS 882:1992. The sand was shown by tests to have very low silt/clay content and a total sulphate/chloride content of less than 2%. Both fine and coarse aggregate were clean and were expected to produce dense concrete of good strength, when mixed with portable water and ordinary portland cement (OPC). The experiments were carried in accordance with standards including BS 882:1992, BS 1881-125:1986, BS 8110-1:1997, BS 1881-207:1992, BS EN 12390, and BS EN 12350-1:2000.
2.1 Engineering properties

2.1.1 Tensile strength test

In the direct tensile tests, three randomly selected specimens of ebonite strips, each 300mm long, were used. The strip was clamped at one end into a manual tensile test machine and loaded with weights at the free end until failure occurred. The failure load was recorded. As a control, three specimens of 10mm diameter mild steel bars, cut to 300mm length, were used. The specimens were mounted in the jaws of an electronic tension test machine and hydraulically subjected to direct tension until failure; the yield, maximum and failure loads being recorded.
2.1.2 Bond strength (pull-out) test

Three ebonite strips cut to 450mm length were centrally embedded over a length of 150mm in a fresh 150mm concrete cube. The cubes were cured in water for 28 days. After curing, the 150mm concrete cubes specimens were placed in an electronic tension test machine, but the pullout test could not be carried out due to difficulty in achieving a secured grip of the free end of ebonite in the test machine. A similar arrangement was done for 10mm diameter mild steel rods, cured for 28-days and subsequently stressed to failure and the failure load recorded. 100mm concrete cube specimens were prepared from the same concrete mix used for the pull-out concrete cubes and were cured in water for 28 days, and subsequently tested to failure to determine the compressive strength.

2.2 Flexural tests

Concrete beams of 100x100x1200mm, reinforced with ebonite strips, and concrete beams of the same dimensions reinforced with 10mm diameter mild steel bars were used for the flexural tests. The ebonite strips and steel reinforcement were both 1200mm long. Three arrangements of ebonite strips were used as reinforcement as shown in Figure 3 and Table 1. Two, four and eight pieces of ebonite strips were arranged in the tensile zone of the beam with a concrete cover of 20mm. Each strip had an approximate cross-sectional dimension of 20mm x 5.6mm. For mild steel, two 10mm diameter rods were placed in the tensile zone of the beam. The concrete beams were cured in water for 28 days prior to test. The beams were tested by a third-point loading arrangement system (shown in Figure 4) and a dial gauge was placed at mid-span to record the deflections as loading took place. The third point loading method was adopted because it ensures a uniform maximum bending moment in the one-third middle zone, unaffected by changes in shear (as illustrated in Figure 6 in the appendix). As loading was increased the formation and location of cracks were noted and at failure, the failure load was recorded and the widest crack was measured by means of a vernier calliper. 100mm concrete cube specimens were prepared from the same concrete mix used for the beams and were cured in water for 28 days, and subsequently tested to failure to determine the compressive strength.

Table 1: Ebonite strip and steel reinforcement content

<table>
<thead>
<tr>
<th>Bar Arrangement</th>
<th>Cross Sectional Area (mm²)</th>
<th>Ebonite Strip &amp; Steel reinforcement Content (expressed as a percentage of concrete) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two Ebonite Strips</td>
<td>224</td>
<td>2.24</td>
</tr>
<tr>
<td>Four Ebonite Strips</td>
<td>448</td>
<td>4.48</td>
</tr>
<tr>
<td>Eight Ebonite Strips</td>
<td>896</td>
<td>8.96</td>
</tr>
<tr>
<td>Two 10mm Ø Steel</td>
<td>153</td>
<td>1.53</td>
</tr>
</tbody>
</table>

Approximate Cross Section of Ebonite Strip = 20mm x 5.6mm; Mean Diameter of Steel Bar = 9.87mm
Figure 3: Arrangement of ebonite strips (a, b, c) and steel bars (d) in concrete beam

Figure 4: Experimental set up for beam subjected to third-point loading
3. Results and discussion

3.1 Compressive strength test

As indicated in Table 2, the mean compressive strength of the concrete used for the beams embedded with ebonite ranged from 25.7N/mm² to 36.1N/mm². That for the beam embedded with steel was 25.7N/mm². The mean compressive strength of the concrete used for the pullout test was 36.1N/mm². All the concrete used therefore achieved the designed strength of 21N/mm² at 28 days.

Table 2: Compressive test results of 100mm concrete cubes

<table>
<thead>
<tr>
<th>Concrete Cubes</th>
<th>Density (kg/m³)</th>
<th>Failure Load (KN)</th>
<th>Compressive Strength (N/mm²)</th>
<th>Mean Compressive Strength (N/mm²)</th>
<th>s (Standard deviation) (N/mm²)</th>
<th>f.c. Characteristic Strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S 1</td>
<td>2642</td>
<td>354</td>
<td>35.40</td>
<td>34.27</td>
<td>1.10</td>
<td>32.46</td>
</tr>
<tr>
<td>S 2</td>
<td>2471</td>
<td>342</td>
<td>34.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S 3</td>
<td>2431</td>
<td>332</td>
<td>33.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B 1</td>
<td>2688</td>
<td>396</td>
<td>39.60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B 2</td>
<td>2688</td>
<td>384</td>
<td>38.40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B 3</td>
<td>2792</td>
<td>304</td>
<td>30.40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C 1</td>
<td>2594</td>
<td>282</td>
<td>28.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C 2</td>
<td>2862</td>
<td>254</td>
<td>25.40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C 3</td>
<td>2598</td>
<td>236</td>
<td>23.60</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Concrete S for beam E2. Concrete B for beam E4 and pull-out cubes. Concrete C for beam E8 and beam S.

3.2 Tensile test

The mean yield strength of the 10mm diameter steel bars was 411.79 N/mm² with a characteristic strength of 370.53 N/mm². The mean ultimate strength of the 10mm diameter bars was 478.92 N/mm². The yield and ultimate strength of the ebonite strip could not be determined due to difficulty in securing a grip of the ebonite strip by the electronic tensile test machine. The mean failure strength of the 10mm diameter bars was 232.67 N/mm². The mean failure strength of the ebonite strip was 133.3 N/mm². The mean failure strength of the ebonite strip is thus about 57% of the mean failure strength of the steel bars. The tensile capacity of ebonite strip is thus much lower than that of steel reinforcement.
3.3 Bond (pull-out) strength test

The mean bond strength of the 10mm steel bar was 8.21 N/mm². However, during the bending test of the beams reinforced with ebonite strip, it was observed that the concrete slipped away from the embedded ebonite strip. The smooth surface of the ebonite strip could have been the cause. This sliding behaviour shows that the bond between the concrete and the ebonite strip was low. This weak bond most likely resulted in the low loads recorded in the flexure test. Had the surface of the ebonite strip been roughened, a better bond would most likely have resulted leading to higher bending failure loads.

3.4 Flexural test

3.4.1 Load-deflection response

The deflection of the soffit of the beam increased with increase in the ebonite strip input and with increase in applied load as indicated in Figure 5. The rate of increase in deflection however was not linear with increase in ebonite input, though no particular non-linear relationship could be established. The load at first crack (yield) increased with increase in ebonite strip input till a threshold was reached after which there was a steep decline in value. Though the threshold was not investigated, observation has it between four and five ebonite strips. It could be inferred from the failure load values that the flexural strength of the beams is not from the bonding of concrete to ebonite strip since, if this were so, an increase in the ebonite strips will increase the area of bonding and thus increase the strength.

![Load-deflection response for beams E2, E4, E8 and S](image)

_E2=Beam reinforced with 2 ebonite strips, E4= Beam reinforced with 4 ebonite strips, E8= Beam reinforced with 8 ebonite strips, S= Beam reinforced with two 10mm diameter mild steel bars_

Figure 5: Load-deflection response for beams E2, E4, E8 and S
This inference is also strengthened because an observation of the broken beam showed a very smooth hole through which the ebonite strips slipped. The flexural strength is also not completely dependent on the tensile strength provided by the ebonite strip as an increase in ebonite input did not increase the flexural strength beyond a certain level. It is postulated that with the arrangement of the ebonite strips in these particular tests, the flexural strength of the beam is contributed primarily by the concrete to concrete bonding and interlock, with a low contribution from the tensile strength of the ebonite strip. Ebonite strip-concrete bonding offered a negligible contribution to resistance to flexure in this test. An increase in applied load simply caused the ebonite strip to slip through the hole in the concrete, once the threshold of bonding offered by the ebonite, small as it is, is exceeded. Since the ebonite strips are not anchored (by whatever means) to the ends of the concrete beam (as one may have in the case of end anchors in steel tendons of prestressed concrete), the contribution of ebonite, in terms of stretching, to the resistance to tensile stresses could not be mustered. The load-deflection response of the steel-reinforced concrete beam shows that the steel-reinforced concrete beam offered a better resistance to flexure.

### 3.4.2 Ultimate failure load

Beam E2 failed at a mean load of 3.92KN with a mean central deflection of 0.9 mm as shown in figure 4 above. Beam E4 failed at a mean load of 5.88KN with a mean central deflection of 6.9 mm. Beam E8 failed at a mean load of 5.88KN with a mean central deflection of 8.92 mm. At the ultimate failure loads of beams E2, E4, and E8, Beam S had only reached mean central deflections of 0.62mm, 2.07mm, and 2.07mm respectively. Beam S failed at a mean load of 27.46 KN with a mean central deflection of 15.94mm. The ultimate failure load of beams E2, E4 and E8 were 14%, 21% and 21% respectively of the failure load of beam S. The relative values of the ultimate failure load for steel and ebonite-reinforced beams go to reinforce the observations made as regards the very negligible strength contributed to the flexural capacity of the beam by ebonite/concrete bonding.

### 3.4.3 Crack development

The steel reinforced concrete beams initially developed cracks on the tension face and propagated to the compression face when the tensile strength of the concrete was exceeded. With subsequent increase in loading, cracks appeared within the constant moment span of the beam and developed rapidly. Crack development in the beams reinforced with ebonite strip was faster than that of the beams reinforced with the steel bar. The width and length of the crack increased till failure and extended to the top fibres of the beam. Two specimens of beam E2 developed the first crack at 3.92 KN and the other beam at a load of 1.96 KN as indicated in Table 3. The mean maximum crack width was 2.47mm with a mean maximum crack length of 100mm. Beam E4 developed the first crack at 5.88 KN with a mean maximum crack width and crack length of 3.13 mm and 102.67mm respectively. Beam E8 developed the first crack at 1.96 KN with a mean maximum crack width and crack length of 3.07 mm and 115 mm respectively. Two of the steel-reinforced beams developed the first crack at 5.88N and the third beam at 7.84N (indicated in Table 4). Thus, the development of crack and the propagation of cracks are as expected with beams. The load at which these cracks started only reinforce the observation that an increase in ebonite strip content did not necessarily produce an increase in tensile resistance; a threshold (between four and five strips) being the limiting
factor. The load at which cracks were initiated also goes to prove that the steel-reinforced beams provided better flexural resistance.

Table 3: Crack development for ebonite strip reinforced concrete beam

<table>
<thead>
<tr>
<th>Load at First Crack (KN)</th>
<th>2 Ebonite</th>
<th>4 Ebonite</th>
<th>8 Ebonite</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.9 2 1.9 3.27 1.1 5.8 8 5.8 8 5.88 0 1.9 6 1.9 6 1.96 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max crack width (mm)</td>
<td>2.4 3.7 1.3 2.47 1.2 4.1 2.6 2.7 3.13 0.8 4 2.8 4.2 2.2 3.07 1.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. crack length (mm)</td>
<td>105 102 93 100 6.2 4 112 103 93 102.6 7 9.5 100 140 105 115 21.7 9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sp = Specimen. Ave. = Mean. Std. = Standard Deviation

Table 4: Crack development for steel reinforced concrete beam

<table>
<thead>
<tr>
<th>Specimen 1</th>
<th>Specimen 2</th>
<th>Specimen 3</th>
<th>Average</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load at first Crack (KN)</td>
<td>5.88</td>
<td>7.84</td>
<td>5.88</td>
<td>6.53</td>
</tr>
<tr>
<td>Max. crack width (mm)</td>
<td>1.30</td>
<td>1.00</td>
<td>1.50</td>
<td>1.27</td>
</tr>
<tr>
<td>Max. crack length (mm)</td>
<td>234.00</td>
<td>195.00</td>
<td>250.00</td>
<td>226.33</td>
</tr>
</tbody>
</table>

4. Conclusions and recommendations

The possibility of the use of plastic in the form of ebonite strip as reinforcement in reinforced concrete has been investigated in terms of the tensile strength of ebonite strip, the bonding of ebonite strip with concrete, and the flexural strength of beam reinforced with ebonite strip. From the test results and analysis, the following conclusions can be drawn at this stage of the study:

1. The failure or breaking strength of ebonite strip is about 57 % of the failure strength of 10mm diameter mild steel bar.
2. The bonding of ebonite strip with concrete is very low and much lower than between ribbed mild steel bar and concrete. Although the actual bond stress between ebonite strip and concrete could not be determined, the slipping action observed during the flexure test of the beams reinforced with ebonite strip shows that the bond between ebonite strip and concrete is negligible.

3. An increase in ebonite strip content from 2.24 % (2 strips) to 4.48 % (4 strips) results in about 60 % increase in flexural strength. However, subsequent increase in ebonite strip content from 4.48% (4 strips) to 8.96 % (8 strips) produces a decrease in strength. It is inferred that a threshold to ebonite strip input is between 4.48% (4 strips) and 5.60 % (5 strips). The contribution to the flexural strength of the beam provided by ebonite strip is not by concrete/ebonite strip bond and most likely more by the tensile stretching of ebonite strip anchored in some manner to an end ‘zone’ in the beam.

4. Beam flexural strength for 2.24%, 4.48% and 8.96% ebonite strip content is about 7%, 21% and 21% respectively of the beam flexural strength for 1.53% steel content.

5. Ebonite strip possess a considerable amount of tensile strength. However, since the direct ebonite strip/concrete bond of the existing strips is poor, the beneficial attributes of the ebonite strip can only be fully realized if the ebonite strip is secured by some anchorage system to the ends of the beam. This devise may be in a form of a threaded end, secured by steel or plastic nuts and washer plates. The subsequent behaviour of the beam will therefore be that of a ‘pre-stressed’ nylon tendon cables in ‘smooth ducts’. Any contribution expected from concrete/ebonite strip bonding may likely be facilitated by surface-roughened or ribbed ebonite strips.

It is recommended from this study and the foregoing conclusions that:

1. Ebonite strip is not a good substitute for steel.

2. However, 100mm x 100mm concrete beam reinforced with 2 ebonite strips (2.24% ebonite content) can be used as lintel supporting concrete blockwork over an opening (window/door) of up to 1000mm wide (as illustrated in the appendix).

3. To further enhance the flexural strength of the ebonite strip reinforced concrete beam, the surface of the ebonite strip should be roughened to improve its bond with concrete.

4. Also an anchoring device, most likely in the form of a threaded and bolted end of ebonite strips will further enable a contribution to flexural strength of concrete beams, by ‘pre-stress’ action of the ebonite strip as a high tensile capacity material.
References


Appendix

<table>
<thead>
<tr>
<th>REF</th>
<th>CALCULATION</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>USE OF TWO EBONITE STRIP-REINFORCED CONCRETE BEAM</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ M = \frac{P}{2} \times \frac{1}{3} = \frac{P}{6} \]

Failure load of beam reinforced with 2 ebonite strips (P) = 3.92 KN.

Maximum moment due to failure load (\( M_p \)) = 3.92/6 = 0.65 KNm

Considering a lintel for an opening (door/window) of 1000mm.

Allowing a bearing end of 100mm at both ends of the lintel.

Therefore span of lintel (S) = 2(100) + 1000 = 1200mm.

Cross section of lintel = 100mm x 100mm

\[ \text{Area of block work} = 0.5 \times 1.2 \times 0.6 = 0.36 \text{ m}^2 \]

\[ \text{Unit mass of 25mm thick concrete block work} = 54.7 \text{ kg/m}^2; \text{ Acceleration due to} \]

\[ \text{Figure 6: Shear force and bending moment diagrams} \]

\[ \text{Figure 7: Triangular load on lintel due to concrete blockwork} \]
<table>
<thead>
<tr>
<th><strong>gravity</strong> = 10m/s²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit weight of 150mm thick concrete block work = 3 x 54.7 x 10 = 1641N/m²</td>
</tr>
<tr>
<td>= 1.64KN/m²</td>
</tr>
<tr>
<td>Dead load due to block work = 1.64 x 0.36 = 0.59 KN</td>
</tr>
<tr>
<td>Density of concrete = 24KN/m³</td>
</tr>
<tr>
<td>Dead load due to lintel = 0.1x 0.1 x 1.2 x 24 = 0.288 KN</td>
</tr>
<tr>
<td>Total dead load on lintel, Gk = 0.59 + 0.288 = 0.879 KN</td>
</tr>
<tr>
<td>Ultimate load (F) = 1.4Gk = 1.4 x 0.879 = 1.23 KN</td>
</tr>
<tr>
<td>Maximum bending moment due to ultimate load (Mf) = F x Span/4 = 1.23 x 1.2 / 4 = 0.369 KNm</td>
</tr>
</tbody>
</table>

Comparing the above failure load and ultimate load, the ultimate load on the lintel is only 31% of the failure load of the beam reinforced with 2 ebonite strips. Also, comparing the moments generated by the two loads, the moment due to the ultimate load on the lintel is 56% of the moment due to the failure load of the beam reinforced with 2 ebonite strips. This analysis shows that a 100mm x 100mm x 1200mm concrete beam reinforced with two ebonite strips can be used as a lintel supporting 150mm thick concrete blockwork over an opening of up to 1000mm wide.
The Effect of Corrosion on the Strength of Steel Reinforcement and Reinforced Concrete

Adukpo, E.
Black Star Advisors, Accra, Ghana
(email: selorm@primroseproperties.net)

Oteng-Seifah, S.
Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
(email: soseifah@tiesoinc.com)

Manu, P.
University of Wolverhampton, Wolverhampton, UK
(email: Patrick.Manu@wlv.ac.uk)

Solomon-Ayeh, K.
Building and Road Research Institute, Kumasi, Ghana
(email: solomonayeh@yahoo.com)

Abstract

The strength of steel-reinforced concrete greatly depends on the adequacy of the bond between the concrete and the steel reinforcement. Bonding is enhanced by adhesion and frictional resistance between the steel/concrete interface and can adversely be affected by corrosion of the reinforcing steel. In Ghana, steel is the conventional material for the reinforcement of concrete, but there are instances where the steel reinforcement bars used on site have corroded to some extent. This study considers the effect of corrosion of mild steel bar on the tensile strength, bond strength and bending strength of steel-reinforced concrete beam. Tests were conducted to determine the tensile and bonding strength of non-corroded and corroded mild steel bars, and the flexural strength of concrete beams reinforced with non-corroded and corroded mild steel bars, on the assumption that the flexural strength of the beam is derived primarily from the concrete/steel bonding action. The research revealed that the tensile and bond strengths of non-corroded steel bar and the flexural strength of non-corroded steel-reinforced concrete beam are greater than that of corroded steel bar. The findings of the research demonstrates that corrosion of steel reinforcement adversely affects the strength of steel reinforcement and steel-reinforced concrete and it is thus recommended that non-corroded steel bars should be used for reinforcement in reinforced concrete construction.

Keywords: concrete technology, experiment, structural engineering
1. Introduction

Concrete is a composite material consisting of fine aggregate, coarse aggregate and a binding material, usually cement, and water, with or without admixtures (Marsh, 1997; Chudley et al., 2008). It is a universal construction material that plays a key role in modern construction as a structural material. The ease with which, while plastic, it can be deposited and made to fill forms or moulds of almost any shape is one pronounced factor that makes concrete a widely used construction material. Concrete being weak in tension fails under tensile stresses unless reinforced in the zones of tension by some materials of high tensile strength such as steel (Chudley et al., 2008) and fibre reinforced polymer (cf. Emmons et al. (1998), Schöck Bauteile GmbH (2006) and Durham et al. (2009)). The performance of steel-reinforced concrete element is greatly influenced by the bond between the steel and the concrete (Turban, 1995), and this bond can adversely be affected by corrosion of the steel (British Research Establishment (BRE), 2000). Corrosion can also reduce the tensile capacity of the steel and the steel’s resistance to fatigue damage (BRE, 2000). Once corrosion of steel reinforcement adversely affects the steel-concrete bonding action and the tensile capacity of the reinforcing steel, the performance of the steel-reinforced concrete element in resisting flexure, shear, etc, is thus likely to be affected. Steel, mild or high strength, is the conventional material for the reinforcement of concrete in Ghana, but there are instances where the steel reinforcement bars used on site have corroded to some extent, and thus necessitating a look into the effect of corrosion on the tensile and bond strength of steel reinforcement and the strength of reinforced concrete, which in this study is the flexural strength of reinforced concrete beam.

2. Methodology

Experiments consisted of a tensile test and bond test for corroded and non-corroded 12 mm diameter mild steel bars and a flexural test for beams reinforced with corroded and non-corroded 12 mm diameter mild steel bars. Going by conventional practice (cf. Aldajah et al. (2008), Mahoutian et al. (2008)), three specimens were used for the tensile and bond test, and two specimens were used for the flexural test in each case of corroded and non-corroded mild steel bar.

Just to confirm the presence of corrosion, a standard piece of 12mm diameter mild steel bar (9000mm) was randomly selected from a batch of 12 mm diameter steel rods that showed signs of corrosion (by visual inspection) along their entire lengths. Three steel bar specimens, each 555mm long were cut from the standard piece and the amount of corrosion was determined by measuring their weights, before and after wire brushing of the scales on them. The amount of corrosion that was determined in terms of percentage loss of steel was 1.483 %. Concrete grade C25, designed in accordance with the design of normal concrete mixes (Marsh, 1997), was used in the bond and flexural tests. The concrete was made up of 20mm maximum size granite coarse aggregates and fine aggregate (of granite origin), obtained from pits near rivers at Aputuogya, west of Kumasi, Ghana. The particle size distribution of the coarse aggregate is shown in Figure 1 and that of the sand is shown in Figure 2, and lies in Zone 2 of BS 882:1992. The sand was shown by tests to have very low silt/clay content and a total sulphate/chloride content of less than 2%. Both fine and coarse aggregate were clean and were
expected to produce dense concrete of good strength, when mixed with portable water and ordinary portland cement (OPC). The experiments were carried out in accordance with British Standards such as BS 882:1992, BS 1881-125:1986, BS 8110-1:1997, BS 1881-207:1992, BS EN 12390, and BS EN 12350-1:2000.

2.1 Tensile test

A standard piece of 12mm diameter non-corroded mild steel bar (9000mm long) was selected from a batch of non-corroded mild steel reinforcement rods and three specimens, each 450mm long, were cut from it. The 450mm long specimens were each clamped in the jaws of an electronic tension test machine and hydraulically subjected to direct tension until failure; the yield, maximum and failure
loads being recorded. Similarly, three specimens, each 450mm long, were cut from a standard piece of 12mm diameter corroded mild steel bar, selected from the above-mentioned batch of corroded 12 mm diameter mild steel reinforcement rods, and were subjected to direct tension until failure; the yield, maximum and failure loads being recorded. To ensure consistency, the remaining cut pieces from the standard length of corroded and non-corroded steel bars were subsequently used in the bond and flexural test.

2.2 Bond strength (pull-out) test

Three specimens, each 555mm long, were cut from the remaining piece of the non-corroded steel, and were each centrally embedded over a length of 150mm in a fresh 150mm concrete cube. A similar arrangement was done using three specimens, each 555mm long, cut from the remaining piece of the corroded 12 mm diameter steel bar. The cubes were cured in water for 28 days. After curing, the specimens were each mounted in the electronic tension test machine and strained to failure; the failure load (i.e. pull-out load) being recorded. 100mm concrete cube specimens were prepared from the concrete mix that was used for the pull-out concrete cubes and were cured in water for 28 days, and subsequently tested to determine the compressive strength of the concrete.

2.3 Flexural test

150x150x1600mm concrete beams were used; two for non-corroded steel-reinforced concrete beam and two for corroded steel-reinforced concrete beam. For the non-corroded steel-reinforced concrete beams, two non-corroded 12mm diameter steel bars, each 1600mm long, were cut from the remaining piece of the non-corroded steel bar, and they were placed in the tension zone of the beam. For the corroded steel-reinforced concrete beams, a similar arrangement was done using the remaining piece of the corroded 12mm diameter steel bar. For both corroded and non-corroded steel reinforcement arrangements, two 10mm diameter mild steel top bars and 6mm diameter mild steel links (both reinforcement unaffected by corrosion) were used to keep the 12mm diameter bars in position. The complete reinforcement arrangement is as shown in Figure 3. The concrete beams were cured in water for 28 days prior to test. The beams were tested by a third-point loading arrangement system (shown in Figure 4) with a dial gauge placed at mid-span to record the deflections as loading took place. The third point loading method was adopted because it ensures a uniform maximum bending moment in the one-third middle zone, unaffected by changes in shear. As loading was increased the formation and location of cracks were noted and at failure, the failure load recorded and the widest crack measured by means of a vernier calliper. 100mm concrete cube specimens were prepared from the same concrete mix used for the beams and were cured in water for 28 days, and subsequently tested to determine the compressive strength.
3. Results and discussion

3.1 Compressive strength test of concrete

As indicated in Table 2, the mean compressive strength for the pull-out concrete cubes was 32.8 N/mm$^2$. The mean compressive strength for the beams reinforced with the corroded mild steel bars...
was 33.2 N/mm² and that for the beams reinforced with the non-corroded mild steel bars was 34.40 N/mm². All the concrete used therefore achieved the designed strength of 25N/mm² at 28 days.

Table 2: Compressive strength test results of 100mm concrete cubes

<table>
<thead>
<tr>
<th>100mm Concrete Cubes</th>
<th>Density (kg/m³)</th>
<th>Failure Load (KN)</th>
<th>Compressive Strength (N/mm²)</th>
<th>Mean Compressive Strength (N/mm²)</th>
<th>s (Standard deviation) (N/mm²)</th>
<th>f_c Characteristic Strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S 1</td>
<td>2531</td>
<td>345</td>
<td>34.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S 2</td>
<td>2776</td>
<td>334</td>
<td>33.4</td>
<td>32.8</td>
<td>2.12</td>
<td>29.29</td>
</tr>
<tr>
<td>S 3</td>
<td>2454</td>
<td>304</td>
<td>30.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B 1</td>
<td>2529</td>
<td>320</td>
<td>32.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B 2</td>
<td>2580</td>
<td>350</td>
<td>35.0</td>
<td>34.4</td>
<td>2.16</td>
<td>30.85</td>
</tr>
<tr>
<td>B 3</td>
<td>2548</td>
<td>362</td>
<td>36.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C 1</td>
<td>2361</td>
<td>322</td>
<td>32.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C 2</td>
<td>2470</td>
<td>358</td>
<td>35.8</td>
<td>33.2</td>
<td>2.31</td>
<td>29.38</td>
</tr>
<tr>
<td>C 3</td>
<td>2340</td>
<td>315</td>
<td>31.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Concrete S = pull-out cubes. Concrete B = beams reinforced with non-corroded mild steel. Concrete C = beams reinforced with corroded mild steel

3.2 Tensile test

The mean yield strength of the corroded 12mm diameter steel bars was 349.01 N/mm² with a characteristic strength of 334.61 N/mm², a mean ultimate strength of 387.51 N/mm², and failure strength of 304.51 N/mm². The mean yield strength of the non-corroded 12mm diameter steel bars was 387.85 N/mm² with a characteristic strength of 373.10 N/mm², a mean ultimate strength of 412 N/mm², and failure strength of 348.45 N/mm². Comparing the strength values for the corroded and non-corroded steel bars, it is evident that corrosion reduces the tensile capacity of steel reinforcement, as the strength values for the corroded steel bar are lower than that of the non-corroded steel bar.

3.3 Bond (pull-out) strength test

The mean bond strength of the corroded 12mm diameter bar and the non-corroded 12mm diameter bar were 7.29 N/mm² and 8.26 N/mm², thus indicating that corrosion has an adverse effect on the bonding action between concrete and steel reinforcement. Bonding between concrete and steel is substantially influenced by the surface characteristic of steel reinforcement and the bends/hooks which provide anchorage of the steel within the concrete (Tubman, 1995). As a result of the action of corrosion, it was observed that some of the ribs on the surface of the corroded 12mm diameter steel had become
loose, in the form of scales left on the steel’s surface. Given that reinforcement ribs contribute to bonding, the loosening of the ribs on the corroded steel’s surface (as a result of corrosion) must have impaired the gripping of the corroded steel bar within the concrete and thus giving rise to a weakened bond between the concrete and the corroded steel, as mentioned for instance by BRE (2000).

### 3.4 Flexural test

As expected, the deflection of the soffit of the beams increased with increase in applied load as indicated in figure 5.

![Load-deflection response for reinforced concrete beams](image)

*NC = Non-corroded steel-reinforced concrete beam. C = Corroded steel-reinforced concrete beam*

Figure 5: Load-deflection response for reinforced concrete beams

For the same amount of applied load, the corroded steel-reinforced concrete beams attained higher values of deflection than the non-corroded steel-reinforced concrete beams. The corroded steel-reinforced concrete beam failed at a mean load of 46KN with a mean central deflection of 25.88mm while the non-corroded steel-reinforced concrete beam failed at a mean load of 52KN with a mean central deflection of 20.87mm. Comparing the failure load values and deflection values, it is evident that the non-corroded steel-reinforced concrete beam performed better in resisting bending than the corroded steel-reinforced concrete beam, and thus demonstrating that corrosion adversely affects the flexural strength of reinforced concrete.

Regarding crack development, all the reinforced concrete beams initially developed cracks on the tension face and propagated to the compression face when the tensile strength of the concrete was exceeded. With subsequent increase in loading, cracks appeared within the constant moment span of
the beams and developed rapidly, their widths and lengths increasing with the increase in loading until failure of the beams. The corroded-steel reinforced concrete beams developed the first crack at 16KN, and had a mean crack width of 3.45mm and a mean crack length of 20.25mm. The non-corroded-steel reinforced concrete beams developed the first crack at 20KN, and had a mean crack width of 2.60mm and a mean crack length of 15.30mm. The loads at which crack started, also go to prove that the non-corroded steel-reinforced concrete beam provided better flexural resistance than the corroded steel-reinforced concrete beam, thus demonstrating again that corrosion adversely affects the flexural strength of reinforced concrete.

4. Conclusions and recommendations

The effect of corrosion of steel reinforcement on the tensile strength and bond strength of steel reinforcement, and the flexural strength of steel-reinforced concrete beam have been investigated and from the analysis of the test results, the following conclusions can be drawn from the study:

1. Corrosion of steel reinforcement reduces the tensile strength of steel reinforcement.

2. Corrosion of steel reinforcement impairs the bonding between steel reinforcement and concrete.

3. Corrosion of steel reinforcement reduces the flexural capacity of steel-reinforced concrete and this reduction is primarily due to the reduction of the tensile strength and bond strength of steel reinforcement as a result of the corrosion.

4. The effect of corrosion of steel reinforcement on other strength properties of steel-reinforced concrete (e.g. resistance to shear) has not been investigated in this study. However, given that corrosion adversely affects the tensile strength and bond strength of steel reinforcement, and such strength properties are greatly influenced by the tensile and bond strength of steel reinforcement, then such strength properties are also most likely to be adversely affected by corrosion of steel reinforcement.

It is thus recommended from this study and the foregoing conclusions that:

1. Non-corroded steel reinforcement should be used in favour of corroded steel reinforcement in steel-reinforced concrete construction.

2. Steel reinforcement, especially those kept in long storage (on site, or with suppliers/manufacturers, etc) before being finally used in construction, should be protected from corrosion inducing environments/substances such as moisture, and chlorides.

3. Further investigation should be undertaken to consider several degrees/ extents of corrosion of steel reinforcement and how they affect the strength of steel reinforcement and the strength of steel-reinforced concrete. Such a study could be useful in providing
insight for some kind of allowable threshold of corrosion of steel reinforcement and more importantly for prompting remedial action in the case of corrosion of steel reinforcement during service.

References


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e-mail: secretariat@cibworld.nl
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