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Emerging Built Environments:

Reflections of Culture, Technology and Politics in Space

Faculty of Achitecture Research Unit
University of Moratuwa

Emerging Built Environments

Reflections of Culture, Technology, and Politics in Space

24th & 25th August 2012 at Galle, Sri Lanka

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Emerging Built Environments:
Reflections of Culture, Technology and Politics in Space

The peer reviewed and accepted research papers of the conference are included in this volume

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Editor's Note

It is with enormous pleasure that I note the successful completion of FARU International Research Symposium 2012. The theme, the venue and the presentations were welcomed and praised by many. The event was a landmark in the history of FARU that commenced its research conferences in 2007. This was the 6th time that FARU provided a floor for both local and international researchers to unveil their work and to have fruitful discussions on them.

The theme- 'Emerging Built Environments: Reflections of Culture, Technology and Politics in Space'- was selected mainly to initiate a discourse on the new trends in the conceptualization, organization, procurement and management of the affairs in built environments. As witnessed by all of us, the fourth quarter of the twentieth century has marked the beginning of a new trend in built environments all over the world. The phenomenal shift of affairs caused by these emerging trends has not yet been a subject for a wide discourse to the extent that the European Renaissance in the 1700s, the Modern Movement in the 1950s and the postmodern breakout in the 1970s received. But the fast changing ways of behavior, ever advancing methods of communication and the increasingly sophisticated modes of exchange provide enough evidence for equally sophisticated and transformative trends in producing the environments we live in. The salient features of these trends include contesting twains of global outlooks and cultural specificities, over-emphasis on technological innovations, debatable but great concerns towards nature and the community, and subtle interferences from the emerging political economy. Built environments, from city regions to individual dwellings and their internal components, emerging out of these trends throughout this era, bear evidence of dualities of order and chaos, conformity and contradictions, justice and injustice, and orthodoxy and liberalization, as frequently discussed by many. More importantly, they embody stories of new methods and systems of conceptualizing, designing, procurement and institutionalizing, which had not existed until such time. In order to unfold such stories, it is important to study them at a greater depth, rather than screening them from their outlook. FARU aimed to gather scholarly attempts from all related disciplines such as Architecture, Planning, Landscape, Building Sciences, Facility Management and Product Design into a single forum to highlight the reflections of the cultural, technological and political realities underneath this built environment emerging all around the world.

The peaceful romantic setting of the Galle Fort provided the participants with a an atmosphere, conducive to develop fruitful discussions throughout the symposium. Galle Fort is a UNESCO declared World Heritage Site, of which a majority of the remnants date back to the times of Dutch rule in Sri Lanka, in the 1600s. The VOC warehouse, readopted to the Maritime Museum, was the venue for the inauguration of the symposium and the Hall de Galle, was the venue for the presentations.

The event was graced by the key note addresses of Jon Lang, who is known for his scholarly work on urban design, and Richard Hyde, who has made an enormous contribution to research on sustainable buildings. Both the addresses, presented in this publication, were well received by the symposium as both addresses dealt with the trends emerging in the built environments from the 1980s, in compliance with the theme of the symposium.

There were forty presentations over two days. The presentations dealt with a range of different subject areas, starting from Product Design to Project Management. They also

had a variety of foci ranging from conceptualization of situations, to application of techniques. There was also a wide spectrum of contents, varying from literature reviews and descriptive accounts, to insightful and empirical investigations. All abstracts of the presentations were refereed prior to the symposium. FARU insisted on the quality of the papers resulted in from presentations and invited all presenters to publish their work, improved as appropriate, in the symposium proceedings. All papers received were reviewed by the panel of referees and the authors were notified of the suggested improvements. The best five papers, based on the comments of the referees, have been published separately. Twelve others, selected on the referees' comments and on improvements made by the authors, are presented in this publication. Readers may find these papers open up new areas of knowledge, sources to gain information on, as well as grounds for continuous discussion.

Dr. Jagath Munasinghe
Co-Chair, FARU 2012 International Research Symposium
Editor-in-Chief, FARU 2012 Symposium Proceedings
March 2013

Message from the Dean, Faculty of Architecture

It is a great pleasure for me to have the opportunity to write this massage for the sixth research symposium of the Faculty of Architecture Research Unit (FARU), University of Moratuwa. The research culture in the Faculty of Architecture has been growing over the years and faculty has acquired recognition through teaching, research and consultancies. Research activities are carried out at three levels; i.e Faculty level, Department level and Individual level. Major mode of presenting research carried at Faculty level is to hold the annual research conference on a theme related to built environment. It has been decided by the Faculty to hold an International Symposium similarly to the previous years to provide a platform for wider range of research and scholarly work carried out by local and international researchers and practitioners who are involved in Architecture, Building Sciences, Environmental Design, Engineering, Facilities Management, Landscape architecture, Product design, Project Management Technology and Planning.

The theme of this year's symposium is the "Emerging Built Environments: Reflection of Culture, Technology and Politics in Space." As a result of the modernization and globalization, which had been emerged during the last quarter of the twentieth century, new transformation in built environments has been experienced in all over the world. The prominent issues of this trend includes the loss of identities of places and the socio-cultural inferences, over emphasis on technology and communication, imbalances on natural systems and resultant natural disasters, failure to adapt for climate change , interference of politics and lack of good governance and national and global economic crises. It is important to address theses issues at a grater depth in order to bring out the intellectual discourse at this symposium. It will also deliberate on the emerging issues related to the built environment and outline the future directions to create a sustainable built environment we live in.

I am sure that Faculty of Architecture Research symposium 2012 would be an important milestone to expand the prospect of research carried out by the staff and students of our faculty.

I wish FARU Symposium 2012 all success.

Prof. P.K.S. Mahanama
Dean, Faculty of Architecture
University of Moratuwa
Sri Lanka

List of Paper Reviewers for FARU 2012

1. Dr. Farida Nelufer, Bangladesh University of Engineering & Technology
2. Professor George Offori, Professor, National University of Singapore
3. Professor Harsha Munasinghe, University of Moratuwa
4. Professor Jon Lang, University of New South Wales
5. Dr Lee Lik Meng, University Sains, Malaysia
6. Professor Nihal Perera, Ball State University
7. Dr. Ranjith Dayarathne, University of Bahrain
8. Dr. Ranjith Perera, Sultan Qaboos University, Oman
9. Professor Richard Hyde, University of Sydney
10. Dr. Rohinton Emmanuel, Glasgow Caledonian University
11. Professor Saman Bandara, University of Moratuwa
12. Dr. Zhu Jieming, Professor, National University of Singapore

Keynote address

Sustainable Retrofitting: A Case study in Research Led Teaching (RLT)

Professor Richard Hyde
Faculty of Architecture Design and Planning, The University of Sydney

In collaboration with Dr Indrika Rajapaksha and Dr Upendra Rajapaksha: University of Moratuwa, Sri Lanka

Introduction

The research work reported here describes a project concerning the proposed renovation and retrofitting of a bioclimatic tower in Malaysia though a three day colloquium and charette exercise with students and practitioners. Following the completion of this project it was found that many of the characteristic's of both the activities and the knowledge outcomes during and from this exercise are consistent with what could called a research-led teaching approach (RTL). The paper first defines research led teaching and then describes aspect of the approached used in the project, which have similarities with RTL. Conclusions from this analysis suggest that conventional research processes and methodologies can frame important questions for practice, however often these cannot be resolved easily though conventional methods of architectural science research. RTL, which takes questions from the convention research process and explores these through design, offers a model for future architectural research.

Research-led teaching?

In recent years there has been increasing interested in integrating the research activities carried out in universities and the teaching activities. Angela Brew argues that'research-led teaching lies at the intersection of a number of approaches to teaching. It may involve the use of any number of these dimensions simultaneously.' Importantly she argues the a starting point for RTL is the way we define, frame and carry out "research." More importantly we need to be clear about the nature of the 'discipline and subject content,' and how we view the 'practice of teaching.' The next step she recommends is to articulate this into a pedagogic framework; she defines= a number of models of how we might defineRTL, the first two are framed around activities carried out in research and the second concerns the attainment of knowledge either through the analysis and creative process of thought and our minds or collection of facts which are independent of minds.

1. Research as 'external' activities, i.e. presenting conference papers, posters, teamwork and networking; the RTL would support these activities.

2. Research in terms of 'internal' activities such as analysis of data, conceptual advances of ideas; RTL will take the form of classes in methodology and data interpretation.

3. Research as gaining 'knowledge' in objective terms as external facts independent of minds. The RTL

process here would emphasis the gathering facts.

4. Research as in gaining 'knowledge' in constructivist terms (being as much "made" by knowing agents as "discovered"). RTL will emphasize communication and the social and environmental conditions under which knowledge can occur. (Brew 2003)

Hence the first step in the define how we see our research and then from this we can analyses the RTL approach uses in the Sustainable Retrofitting project apriori though a reflection of the activities and outcomes from the project.

Our view of research

Research comprised a number of themesrelated to reducing the environmental impacts of buildings such as mitigating the effects of climate change though three types of retrofitting, bioclimatic, ecological and technical. Retrofitting is defined as the replacement improved and more efficient of building technical and non technical systems through physical obsolescence. Increasing a driver for obsolescence had from the green imperative.

> 'In recent decades, we have become more aware of increasing damage to the environment and a widening global gap between the rich and the poor. There is a growing realisation that the way we develop is not sustainable.

We need to find a way to improve our quality of life while living within our environmental limits and ensuring a fair society. This is sustainable development.'
http://www.defra.gov.uk/sustainable/index.htm

So for example climate change effects on temperature are happening in tropical climates such as Malaysia with increased temperature on average. Hence the mitigation and adaption response called for provided design opportunities in practice but also there is a need for further action of international policies and standards, economic and social change.

Many bioclimatic and ecologically designed building provide a way of mitigation and adaption strategies to address the needs of climate change. Work on large commercial buildings has seen innovation in the application of green technologies which increase the number of heat sinks in buildings which avoids the problem of using air conditioning to pump heat to the exterior. The Mewah-Oils Headquarters, Port Klang (Westport), Selangor, West Malaysia has a large area of landscape in side the building which is used for passive cooling. The Guthrie Pavilion Shah Alam, Selangor, Malaysiauses a large mega structure parasol roof to increase airflow and shade to the building beneath. The NARA UMNO, Pulau Pinangmodifies the form of the building to improve access to the prevailing se breeze. Finally organics heat sinks are used in the DIGI Technology Operation Centre, Malaysia in the form of green walls.

The main research question that came rom this view of research concerned how to retrofit these green technologies to an existing building.

Research led teaching approach

This research question formed the basis for the RLT. Using the design charette as vehicle a three day research colloquium, site visit and charette was organized. A 20 year old bioclimatic tower which was undergoing renovation was used at the trial

building for retrofitting. The main principles of Eco design were used as the basis for the design brief.

- Eco infrastructure-
  - green- natural systems
  - blue- water systems
  - red- human systems
  - grey- engineering physical systems

- Biointegration –Botic (living) and abiotic (non living) integration

- Ecomemesis- ecosystems mimicking and translation

- Eco design as Restoring Impaired Environments- biodiversity regeneration

- Ecodesign as self- monitoring – life cycle measurement (Yeang, 2012)

The results from the work show that using Ecomemesis it is possible to re-conceptualise the existing building with a new vision. In this case it was possible to use the rain forest a metaphor and reshape the form and spatial organisation of the building accordingly. Furthermore this improved the potential Biodiversity regeneration. A number of principles for Biodiversity regeneration were adopted.

- All species and habitats should be conserved, maintaining 'natural' evolution.
- Eco systems conservation
- The natural stock of ecological resources- soil, ground and surface water, land biomass, water biomass has regeneration limits.
- Interconnectedness
- Improvements in one area of a country should not be at the expense of others.
- Aversion of risk
- Precautionary principles, unknown thresholds to incremental change which could have significant systematic consequences
- Scale of impact
- Human minimisation of energy and material flows into ecosystems (Zarsky 1990).

It was found for this to be successful it was necessary to appropriate areas of the city that were in a natural state such as wild life reserves and natural parks. Recommendations were made to change the zoning of selected areas to improve the connections between the existing areas of nature and the building. In this way species regeneration is possible by building larger habitat areas in the city. Bio integration at the site level resulted in the increase in the Green ratio ie the ration of bioti to abioti, in this case the existing ration was about 8 per cent and through zning of the building this is increased to about 40 per cent of the site and building area. Finally, new Eco infrastructure was recommended support the Eco design retrofitting

Conclusions

The outcomes from RLT approach are consistent with the vision of Sustainable Retrofitting in Commercial buildings.

> 'Despite recent improvements in energy efficiency being made in new build it is important that the existing commercial building sector also take action to meet emission reduction targets. The objectives and challenges of such action will reduce the risk of the sector becoming obsolete due to high-energy use and poor environmental performance. (Hyde et al 2012)'

Through Eco-design and renovation for climate change, Bioclimatic retrofitting, and the us technological and behavioural change it is possible to reduce the energy intensity of large mega watt commercial buildings

Research led teaching in architecture as demonstrate in the case study provides aview of research as practice. That research questions can be examined though design an in many case can be both a creative and speculative process which has wider implication than conventional research. The RLT provides research involving internal and external aspects of the discipline in this case it touches on issues of urban design, planning and ecology. In research terms is seems highly consistent with knowledge generation involving a constructivist view where the charette form the social and environmental conditions for the knowledge creation. However in this case the practice approach of using design principles assists in guiding and focusing the research domain.

Acknowledgments

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Indrika Rajapaksha and Upendra Rajapaksha, University of Moratuwa, Sri Lanka.

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Current Urban Design Paradigms and their Application: Research Needs

Professor Jon Lang
University of New South Wales, Sydney, Australia

During the past fifty years many books and research monographs have been published in the domain of urban studies. Much has been written on urban design. An observer would think the two subjects are independent. This paper argues that they should not be and the mechanism for linking the two is through sets of climatically and culturally appropriate generic designs.

The paper begins with a brief overview of what urban design is and the design paradigms that dominate professional practice today. It then goes on to review a handful of generic solutions, with their strengths and limitations, that form the basic vocabulary of urban designers. This overview establishes the basis for a discussion about the information required to enhance the quality of designs. The argument presented recognizes that most designers adapt generic solutions to the situation at hand rather than following an intellectually detailed program-based, problem-solving process. If this is so what is the information needed to enhance the design process? The design fields need to have generic designs at their disposal that deal with culturally-specific ways of life within different geographic settings.

URBAN DESIGN

Many architects, landscape architects and lay people define urban design in terms of their own interest and expertise. A general definition is, however, widely accepted. Urban design involves the creation of a vision for a city or, more likely, a precinct of city or even more likely, a few blocks of city and then the application of techniques – incentives and controls – to achieve that vision (Lang 1994, Llewellyn-Davies 2000, Lang 2005).

The question is: How is the vision created? Whose interests does it serve? If it is to serve the public interest, what is meant by the public interest? What is the knowledge base required to design well? What does 'well' mean? These questions have to be resolved while designing. What then is the nature of this process? It is certainly, self-conscious and goal driven. Although I have consistently argued for a program-based, problem-solving approach to the creation of that vision, architects in general do not work that way and do not want to do so. They use a paradigm based and/or a generic solution based approach to design. The question is: 'What is the quality of these paradigms and generic solutions?'

CURRENT PARADIGMS

Three major paradigms dominated urban design work during much the twentieth century. A fourth emerged at its end. At the beginning of the century it was the Beaux Arts, City Beautiful. It was displaced in architects' minds by a number of competing images of what the future city should be like. These images came out of two major intellectual traditions: the Rationalist and the Empiricist. Almost contemporaneously, the Empiricist Garden City paradigm and the Rationalist Modernist paradigm were developed during the first two decades

of the century. The first is associated with the Anglo-American intellectual tradition with its roots in English Common Law while the latter is associated with Continental Europe and its intellectual roots in the Napoleonic code.

Photograph by Ruth Durack

a. The City Beautiful
Ceausescu's Bucharest (1977-89 but continuing)

Photograph by Jon Lang

b. The Garden City
Shonzhang Lake, Guangdong, P. R. China (2002+)

Courtesy of Kisho Kurokawa and Associates, architects

c. Rationalism today: Zhengdong, Zhengzhou (2004+)

Photograph by Jon Lang

d. Neo-traditional design: Paternoster Square, London

Figure 1: Four standard urban design paradigms

The City Beautiful

The City Beautiful proponents advocated an urban design of axial plans with radiating roads focusing on specific monuments and/or buildings, grand plazas, wide streets with buildings built to their site boundaries lining the streets. It is an urban design and architecture of display based on Baroque concepts but its proponents also sought an efficient and hygienic city. Haussmann's Paris and the earlier Washington were its precedent. The goal of the City Beautiful was to instil a civic pride in a city's citizens' hearts and minds through the grandeur of the built environment. The inspiration came from the Ecole des Beaux Arts in Paris. The paradigm was widely applied to cities around the world by colonial authorities: the French in the Middle East, North Africa and in Indo-China, the Americans in the Philippines, the British less whole-heartedly in a number of colonies and the Japanese in China.

The City Beautiful was the design paradigm used in two major early

twentieth century capital cities: Canberra and shortly thereafter in New Delhi, both designed in the second decade of the century. Many civic centres (for example, San Francisco) were built in the same vein. Albert Speer sought such a design for Hitler's Berlin. Towards the end of the century the paradigm was applied in Bucharest and Pyongyang both under the aegis of dictators setting out to impress. Merging into the twenty-first century the remnants of the generic City Beautiful plan can be seen in the design of Putra Jaya in Malaysia.

Haussmann's Paris remains the inspiration. It was designed in three dimensions with buildings designs being strictly controlled by very specific guidelines. While having a hegemonic position in specifying what a good city should be like at the beginning of the twentieth century, the paradigm was soon challenged by a number of modernist concepts. They can, perhaps uncomfortably, be divided into two contemporary and opposing groups; the Rationalist and the Empiricist.

The Rationalist Paradigms

Generic solutions designed within the rationalist paradigm are based on a set of assumptions about what is good for people and their creators' images of the modern, future world. They are as good as the linkage between assumptions and reality. In general, they were based on an inadequate model of people, their ways of life and aspirations. This shortcoming has been a particular concern at the urban rather than the building design level. Regarded as the progressive utopians, Rationalists tended to base their designs on Calvinist attitudes (Le Corbusier was raised as a Calvinist), an opening up of spaces, buildings as objects in space, and a celebration of technology. They also focused on eliminating what their proponents perceived did not work in the dirty industrial cities of the late nineteenth and early twentieth century; they failed to look at what worked so the desirable was discarded along with the undesirable, the baby got thrown out with the bathwater.

What emerged was an international style that had a clear internal logic based on efficiency of movement and construction and perceptions of what a sensible modern life should be. The generic solution for housing estates, for instance, consisted of slab blocks facing the sun set in open green space. They were built in large numbers around the world. In many Asian countries they are still being built. In contrast, in parts of Europe and the North America such complexes have been demolished and replaced with housing at the same population density but lower in height and meeting the street – the Neo-Traditional model. Certainly in China the Rationalist solution remains the prevailing housing design model.

Many current urban designs for central cities in the modernising world are also imbued with the spirit of international rationalism but with a more flamboyant architecture. Zhengdong is an example. Generally, however, the limitations of universal modernist design ideologies gave way to post-modernism in architecture during the 1970s and 1980s but not in urban design. Along the way a deviant Rational Model was being promoted. It was the megastructure.

The megastructure is a paradigm in which a city, a university consisting of a number of schools, or a number of what would be individual buildings are encased in a massive, often sprawling, single building. It was a concept advocated by a number of avant-garde designers, such as the Archigram group, during the 1960s (Banham

1976). Place Bonaventure in Montreal and a number of universities such as Bielefeld University in Germany (1969-76; Lang 2005: 125-30) are megastructures. Many megastructures were proposed for precincts of cities and even whole cities by Japanese architects, in particular, but also by such luminaries as Buckminster Fuller (Banham 1976). Only one is actually being built, laboriously bit-by-bit. It is Arcosanti, the dream of Paolo Soleri, being constructed under his direction in the Arizona desert (Soleri 1969, Lang 2005: 125-7).

The Empiricist Paradigms

Empiricists rely on precedents in their designs. It is thus a more conservative approach than the Rationalist. Two major twentieth century paradigms and their consequent generic designs resulted from empiricist thinking. They are the Garden City dating back to late nineteenth century and towards the end of the twentieth century the New Urbanism which is essentially a Neo-Traditional approach to urban design based on a different set of precedents to the garden city. The garden city idea was based on the small English country town that appeared to people such as Ebenezer Howard to provide for a rich life. The New Urbanism models, in contrast, are based on a variety of precedents ranging from small towns to the metropolis of the early to mid-twentieth century.

The Garden City although it no longer attracts much academic attention is probably the most widely used paradigm for suburban development around the world. Its impact on the design of new towns and suburban developments was particularly strong in the years after World War Two. These developments include towns built as part of government decentralization policies such as those in Great Britain. What their plans have in common are major centres and sub-centres (see the discussion of the decomposition model below) and easy access to parks. The model is still applied today but on a much vaster scale in places such as Shonzhang Lake in Gugangong, China (2002+).

Neo-Traditional urban design and the **New Urbanism** are closely related. The latter is generally seen as the core empiricist paradigm today. It takes the principles of traditional, even vernacular, designs and adapts them to modern conditions. Two other approaches can, however, be classified under the rubric Neo-traditionalism. The first involves a love affair with specific forms and desires to reproduce them; in the second the canons of historical sacred texts are applied to architectural and urban design.

A well-known mid-twentieth century example of the vernacular urban design within the first approach is New Gournia (1945-8) designed by Hassan Fathy. Located near Luxor in Egypt, it repeated the traditional forms of village and house patterns of Gournia (Fathy 1973). The village, however, represented ways of life that the villagers were trying to avoid so the new development was largely uninhabited. Today, there has been some interest in the second approach. There has been a revival of interest in applying religious canonical treatises to design. This interest has been particularly prevalent in countries such as India, China and Korea as mechanisms for addressing local and cosmic conditions. Planners tend to dismiss the principles of the canons as being mere superstitions.

The New Urbanism is closely associated with the advocacies of Andres Duany and Elizabeth Plater-Zyberk. Seaside, Florida (1970+), the earliest American example, is based on

the traditions of north-west part of the state. Poundbury, drawing on village types of Dorset, is a British example while the Asiad Village (1980-2) and the Income Tax Colony (1997) in Navi Mumbai drawing on patterns of traditional northern Indian cities, are Indian examples of New Urbanist residential developments. Battery Park City in Manhattan, New York (1979-2012) is a high density urban example. Its precedents were the developments of the 1920s and 1930s much loved by New Yorkers. Louvain-la-Neuve in Belgium is a new town that draws on mediaeval antecedents in its planning although its architecture is neo-modernist. Paternoster Square in London is another urban example.

Observations

Our major ways of thinking about urban design are products of the first half of the twentieth century. The reason is simple. The world was turned upside down in Western Europe and North America by technical, political and social innovations in ways that we have not seen since. Many countries today are trying to catch up. Despite all the research on cities that has taken place in the interim, little has penetrated design thinking. The two major paradigms that rival each other for designers' attention today are the Rationalist Modernist and the New Urbanist.

Neither of these two or other competing paradigms represents whimsical thinking. They are carefully thought out approaches based on a set of assumptions about people and about life. Many of the assumptions about the adaptability of people and the rate of change in the world can, however, be challenged. Each current paradigm addresses some problems well, but not others because they fall outside the concerns addressed by the paradigm. Current paradigms tend to neglect the everyday activities of people (and of other species) that provide the spice of life.

GENERIC SOLUTIONS

A generic solution is a standard way of dealing with a class of problems. The argument is that many situations facing a designer address the same problem so why reinvent the wheel? The Rationalist generic solution for the design of housing estates has already been introduced. Here are some other major generic design solutions that are applied to urban design today.

The urban decomposition model

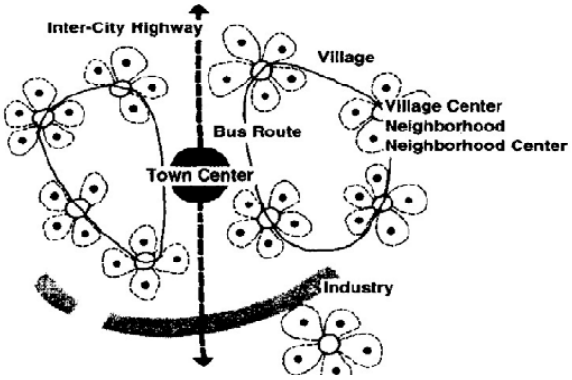
As noted above, in many, if not most, new towns designed during the second half of the twentieth and early twenty-first centuries around the world, the overall concept was to have a major centre at the town's core and the areas around it divided into districts which were then divided into neighbourhoods. Each level in the hierarchy would have a set of facilities serving the area around it.

This was the model for the design of the first and third generation of the government sponsored British new towns, the Soviet new towns and privately developed towns such as Columbia in the United States. In the second generation of the British new towns the model was abandoned because it did not seem to match people's behaviour patterns. It was rehabilitated for the third generation because people in new towns such as Cumbernauld had a predisposition for neighbouring behaviour. In other places the hierarchy was only of two levels; the city and the district which research showed makes more sense in terms of the way people lived their lives. It is more a model for a multi-nuclear city. The neighbourhood unit has been the generic model for the lowest level in the hierarchy.

The neighbourhood unit

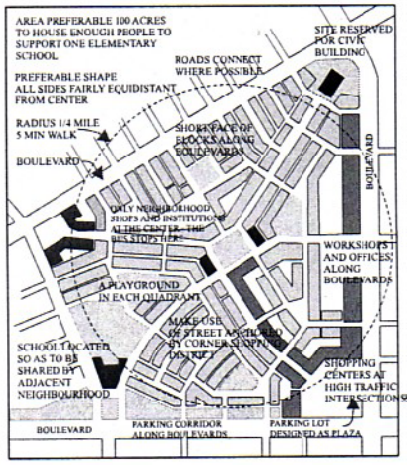
sociologist, as the generic solution for organizing new suburban residential developments. It formed part of the *Regional Survey of New York* of the late 1920s (Perry 1929). The unit consists of a primary school and other local facilities at its core and residential units distributed around it within walking distance. The application of the model took two forms the Rationalist and the Empiricist. In the first, the generic model of housing estates consisted of slab residential buildings laid out in a rectilinear Euclidean geometry. In the Empiricists schemes the roads were curved and the houses were primarily single family detached ones. Recently this basic model was updated by the Duany-Plater Zyberk Partneship so that the facilities are not located at the core but along a street leading into the centre. This change resulted from the recognition that streets can be seams for life and not dividers.

Source: Hester 1975



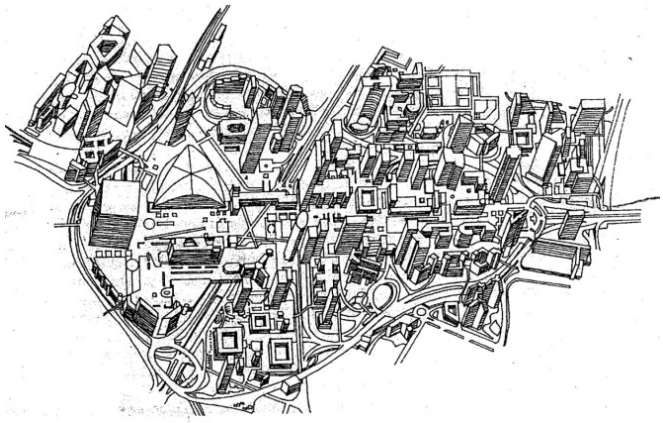
a. The urban composition model

Drawing adapted from various sources by Omar Sharif



b. The neighbourhood unit proposed by Duany-Plater Zyberk

Drawing by Thanong Poonteerakul; Source Lang 2005: 219



c. The superblock: La Défense, France

Photograph by Jon Lang

d. The pedestrian mall: Louvain-la-Neuve, Belgium

Figure 2: Four generic solutions

The superblock and pedestrian malls/streets

A superblock is one in which the vehicular traffic is kept on the peripheral roads with automobile parking (either in surface lots or structures) feeding off them on the interior edge of the block. The remainder of the interior is reserved for pedestrians. The best known model of such designs, although never implemented, is that proposed by Victor Gruen for Fort Worth, Texas (Gruen 1964). The model has been applied to many residential developments in conjunction with the neighbourhood unit, university campuses and to the hearts of many European cities. La Défense on the outskirts of Paris is probably the largest example. The goal has been to provide pedestrians with a safe and more pleasant environment for getting from one point to another and, more generally, for strolling. Automobile owners, however, want to be able to drive directly from point of origin to their destinations.

The pedestrian mall is a variant of the superblock. In it a ribbon shopping street of a city is closed to vehicular traffic (except at certain hours for serving the buildings along it). The objective has been to enhance business along it by providing a car-free walking area for shoppers. It has failed miserably as a model when the businesses were not doing well before the change was made. Indeed almost half of the pedestrian malls in the United States have been returned to vehicular traffic.

The pedestrian malls that have been successful and even extended in length are those where there was a preponderance of pedestrians anyway. This preponderance occurs in university towns such as Louvain-la-Neuve and vacation resorts where there are many people without cars at their disposal. In the United States, Boulder Colorado is an example of the first and Miami, Florida of the second. Those malls that are dumbbell designs have been the most successful.

A variant of the pedestrian mall is the *woonerf* or shared territory – which is used by drivers and pedestrians alike. Drivers using them expect to see children playing in them and drive accordingly. A major street following much the same principle was opened in London during 2012. It is Exhibition Road in the museum district of South Kensington. Pedestrians have yet to become accustomed to it!

The dumbbell design

A dumbbell is piece of equipment used in weight-training. It consists of a bar with weights at each end. Dumbbell building and urban designs are those in which there is an attraction at each end of a passage way. It is the basic model for shopping centres with their major shops at each end and a string of smaller shops lining a spacious link between them. Pedestrian malls that have elements at each end that generate pedestrian traffic are likely to be successful in terms of both enhancing business activity along them and providing a pleasant environment for pedestrians.

THE ISSUES

How good are these paradigms and generic solutions? Almost all were developed in Western Europe or Eastern United States to deal with designing for human habitats in cool temperate climates and assuming specific cultural norms. These designs have been applied willy-nilly around the world. Sometimes they have indeed worked well but at other times not. Much depended on the similarity of the

context in which they were applied to that in which they were developed.

Why has this situation arisen? The homogenising of architectural education around the world based largely on Western European norms has resulted in standard paradigms being regarded as good ways of thinking about what the future built environment should be like everywhere. This trend is aided and abetted by much significant urban design work being carried out by a limited number of multi-national professional firms on behalf of investment companies that work internationally and municipal authorities seeking a place in the modern world (Olds 2001). Public officials in cities around the world travel and are impressed by what they see and want to have similar places at home. This observation seems particularly to hold in those countries going through a rapid transformation. Public officials and well-to-do citizens take great pride in the scale and, often, the flamboyance of the new urban design projects and architecture of their cities. A number of politicians are, nevertheless, seriously questioning whether the environments achieved are what they really want (Wang 2004).

Many studies show the discrepancy between the design goal of creating well-loved, well used places and what has been achieved. Many research studies on climate and design, culture and design and on transportation and land use have been conducted and published. Many analyses and critiques of building designs have been carried out. They show what works and what does not work. Universities have whole departments of urban studies with academics generating reports on a variety of urban phenomena but little has been applied. Despite all this research and criticism architects tend to continue working within particular design paradigms basing their work on generic solutions. Criticism is often worn as a badge of pride! Knowledge is seen as interfering with the creative act. How can we reduce the applicability gap between research and practice? An alternative design paradigm has been presented but most architects still do not want to work that way. In addition, the process raises concerns that fall outside the short-term interest of property developers. Cities such as Curitiba in Brazil have, nevertheless, closely followed the model proposed here (Lubow 2007).

AN ALTERNATIVE DESIGN PARADIGM

What appears to be emerging on the international scene is a neo-functional, ecological urban design paradigm. It is a procedural rather than an iconic model. The term neo-functional is used to differentiate its concept of functionalism from the much more limited functional aims of the Modernists. Within this approach a functional city is regarded as one that satisfies well-enough the full range of needs and aspirations of its stakeholders. It is also robust enough to undergo change as conditions change without having to be completely demolished and rebuilt. An ecological approach is one that deals both with the everyday lives of people and the workings of the biological environment (Lang 1994, 2000, 2010).

This approach to design involves the setting of goals (always a political act), the translation of these goals into specific design objectives for activities and aesthetic ends, the exploration/invention of patterns of built form that meet these ends based on evidence, the prediction of how these patterns will function in different possible futures and the selection of the way forward. During the process legal and financial issues have to be

resolved. The whole design process is one of conjecturing and testing. It is an argumentative process. Designers argue with themselves, with their colleagues with clients (sponsors and users) on both ends and means. Clarity in arguing requires good evidence. Good evidence comes from knowledge of the affordances of patterns of the built environment. This knowledge comes from the study of cases and from research-based theoretical knowledge. Designers will have to deduce from this knowledge foundation what they should do given an ideological/political position. Designing after all involves a value laden act of will. As it deals with the future and with imperfect knowledge, designers have to stick their necks out. The process involves both the divergent production of ideas and the synthesis of them into wholes and the ability to rationally evaluate the results. It is no easy task. Empirical evidence is what is needed to support it.

Can such an approach to designing be implemented with a high level of intellectual rigour? There is a growing body of knowledge that makes the approach feasible. If one assumes that such a paradigm will develop to a hegemonic place in urban design work then the research effort needs to concentrate on building the neo-functional theoretical basis for design.

Building a Functional Theory for Design

Functional theory deals with how patterns of built form work or do not work for whom in what context. An attempt has been made to outline such a theory using Abraham Maslow's model of human motivations as an armature (Lang 2010). Maslow suggested that there is a hierarchy of human motivations from the most pressing need for survival, to the need for shelter and salubrious environments to the need for physical and psychological security to the need for belonging through the achievement of an identity within a community to the need for self-esteem and self-actualization.

Much empirical knowledge already exists to flesh out this model but much remains to be either corroborated or developed. The basic research task is to come to an understanding of how patterns of built form afford and inhibit the full range of human activities and symbolic ends. Places also have to be comfortable. The temperature, movement and moisture of the air and the olfactory and tactile experiencing of the physical public realm need to be better understood. We need to understand much better the flushing effect of breezes, the levels of sun and shade that provide comfort, and how comfortable levels of humidity can be obtained through the use of vegetation and, in arid areas, the use of water.

The research needs to develop an understanding beyond that of our own experiences, important though they may be, between the patterns of built form and the needs of children and their elders, tourists and habitués, men and women, the middle class and the poor, the able-bodied and the fragile within specific cultural, geographic and climatic contexts. The list of people of concern in any context is long.

A healthy city is one that not only provides a salubrious environment for its inhabitants but also functions in a self-renewing manner (Hough 1989, Barton 2000, Yeang 2006). A sustainable city is one that provides a healthy environment for the lives of humans and other desired species and that itself possesses healthy natural processes. It is one that survives well under change. It sustains the bio-diversity of local eco-systems. It is clear

that designing a fully sustainable city is beyond our present intellectual and political capabilities. To do so will require a considerable shift in attitudes. One of the research tasks is not only to understand the technical issues involved but also the political ones.

Even if we have a fully developed knowledge base few politicians, public officials and urban designers are willing to employ such a demanding procedural model. With some exceptions they wish to copy what they see on their travels or in magazines.

THE POSSIBILITIES

Scholars and professionals have explored two alternatives to having an abstract theory of functions that designers can use as a basis for programming and designing. One is that offered by Christopher Alexander and his colleagues in their pattern language (Alexander et. al. 1977). The second, and the one that I believe has a higher practical utility in everyday design practice, is to have a new set of generic solutions. The objectives and evidence on which the solutions are based must be clear. The second, in many ways, simply extends the first by dealing with bundles of variables simultaneously. In either case the studies need to be carried out region by region.

The pattern language

All architects have a set of patterns in their heads that they use when designing. It is their style. The patterns implicitly follow those in the language developed by Christopher Alexander and his colleagues. The language consists of a series of statements in the following format: to achieve this objective (or solve this problem), use this pattern because this evidence supports the link between objective and pattern. The statements range from design questions at the city level down to details of the environment. The evidence in the work of Alexander and his colleagues is based on research drawn from a number of academic disciplines not guesswork. What their work demonstrates is that there is considerably more rigorously developed research information available to them than most designers are wont to believe. Moreover, the link between objective and pattern is explicitly stated and the argument is transparent. It is up to a designer using the language to examine each statement to determine its utility and to synthesize solutions based on the patterns offered.

Implicit in the language is a specific cultural and geographical context in which the link between problem being addressed and pattern of built form holds. The language as developed by Alexander and his colleagues does bring designers attention to the issues of concern in any situation.

One possible contribution of academic research is to enrich the language by taking cultural and climatic contexts into greater consideration in order to enhance the applicability of the knowledge base of designers. The difficulty is, firstly, that using the language requires considerable time consuming effort and, secondly, that designers want to have their own unique language that gives them an identity. They find it easier to use bundles of patterns implicit already synthesized into generic solutions. They can then individualize the generic solutions to give their designers a sense of being original.

New generic solutions for design

Designers are always working under considerable time and financial pressures and will continue to generate

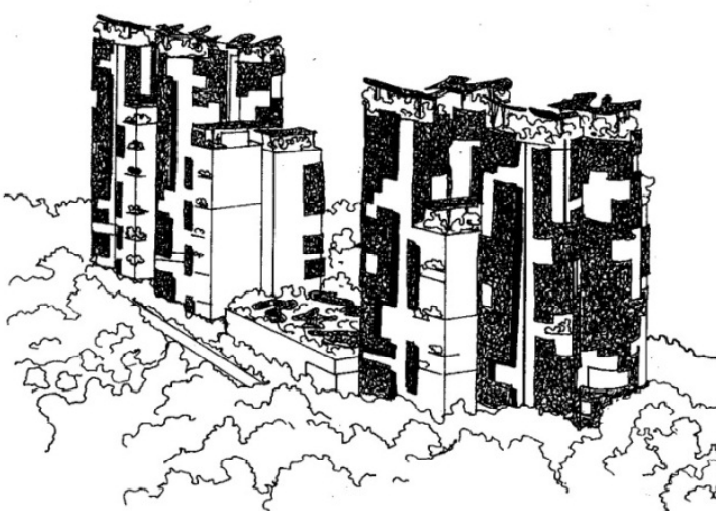
designs based on adapting a handful of particular design paradigm to the situation at hand. The paradigm that is used is generally that in vogue at the time. The problem is that designers often mimic what is bold rather than what works. Indeed the observation that Jane Jacobs made over fifty years ago is still valid:

> The pseudoscience of planning is almost neurotic in its determination to imitate empiric failure and ignore empiric success (Jacobs 1961).

We need to know how our generic solutions work in addressing design concerns in different contexts.

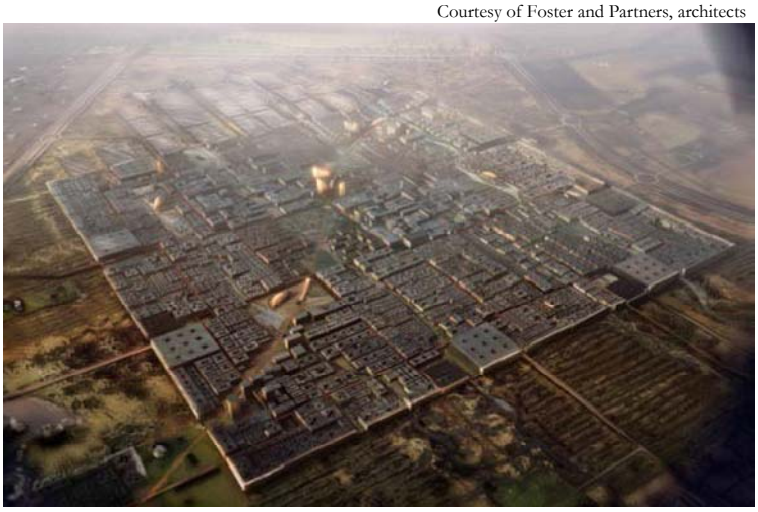
What are needed now are new generic solutions that bring to planners and urban designers' attention the issues of concern and how to address them. Some explorations already exist but they tend to be uni-dimensional – they address only a few design concerns. generic solutions developed within a For instance they may provide patterns for designing within specific climatic zones. What are needed are generic solutions that deal with culture, climate and design goals simultaneously. An example is Ken Yeang's high density housing for tropical environments. Another is the Masdar City (2006) design produced by Foster and Partners. It might be regarded as a prototype for arid environment Islamic cities based on solar energy and other renewal energy sources with a sustainable, zero-carbon, zero waste ecology. A very similar model is that proposed by Rem Koolhaas and his colleagues. The two schemes are similar because they draw on the same evidence. The evidence is much clearer for technical concerns than it is for human concerns. The model of culture on which current explorations are based is unclear.

Drawing by Omar Sharif



a. A generic tropical high rise city by Ken Yeang (2001)

Courtesy of Foster and Partners, architects



b. A generic design for an arid zone Islamic city

Figure 3: Are these two schemes generic designs for the future?

Much the same observation can be made about recent attempts to develop generic solutions to residential area design. The updating of the neighbourhood unit has already been mentioned. There have also been a number of efforts to produce conceptual designs for compact cities with a heavy emphasis on energy savings. If implemented they would require considerable changes in the way we carry out our lives.

It must be remembered that design problems are 'wicked' in nature. Only some variables are understood with any clarity. In addition, there is no stopping rule for saying when the exploration of potential solutions should cease. We generally work until we have a satisficing solution – one that is regarded as good enough. Usually, the time and budget available truncate the search for the best solution. Having good generic solutions to clearly understood problems at their disposal would immensely assist designers in their work.

CONCLUSION

Colin Rowe brought the debate between designing by adapting generic ideas within a specific design paradigm and working using a strong program-based, problem solving process to the attention of those teaching architecture (Rowe 1983). He argued that designers should interweave both approaches. The paradigms that he was considering when he was writing were largely those of the Modernists; Neo-Traditional design although practised, had yet to be recognized as a school of thought by the intelligentsia.

If Rowe is correct, and I believe he is, we need a wider array of generic solutions and diligent case studies that are climate and culture specific. They need to deal not only with who we are but who we might be based on evidence not just hopes. The question is: Who builds these generic solutions? Surely it involves the collaboration of researchers and designers in both the academic and professional worlds.

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The Correlation between Colour associated Thermal Perception and Preferred Human Activity

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Abstract

Research has shown that colour stimuli could trigger certain fixed emotional and behavioural responses within human beings. Consequently, transcending its typical aesthetic value, colours have a greater potential to be integrated into design in a way that can stimulate required emotions and behaviour in the built environment to enable optimum human performance. This attribute is identified in the present study as an important aspect of the 'functional value of colour'. Literature on theory of colour explains the relationship between colour and human's thermal perception (TP), distinguishing warm colours (red, orange, yellow), cools colours (blue, green, purple) and neutral colours (white, grey, black). This study emphasises that every human activity demands a unique thermal condition or environment for its optimum performance. In consequence, it was hypothesised that colours could be potentially used to manipulate human thermal environment as demanded by the activity intended in any built space. Hitherto, the scientific investigations done on the nature and potential of this association are scarce. The present research attempts to provide evidence for TP related to a few selected colours, while identifying certain associated functions for aforementioned colours.

A group of normal sighted, healthy volunteer undergraduates (n=72) of the same age (20-23) were shown computer generated slides of a typical room in seven different colours as specified in RGB colour model, projected on to a wall ; red(255,0,0), orange (255,165,0), yellow (255,255,0), blue (0,0,255), green (0,128,0), purple (128,0,128), white (255,255,255) within a controlled studio environment. While maintaining a constant ambient temperature (26^{o}C), the participants were exposed to each slide for two minutes. They rated their thermal perception (warmness/coolness) of each room on a 5-point likert scale and selected activities they would prefer to perform, in each room out of a list of activities provided to them, imagining that they were actually experiencing each coloured room shown in the slides. Findings of this study provide testimony for colours' ability to alter human's thermal perception. Explicitly, TP of red, orange and yellow colour slides were rated as warm and blue, green, purple slides were rated as cool while white slide was found to have an average TP. Red was found to trigger the highest TP and blue, the lowest TP. The following relationship between TP of the seven colours tested was arrived at; TP Red > TP Orange > TP Yellow > TP White > TP Purple > TP Green > TP Blue.

Supporting the hypotheses, the participants preferred to perform active functions in the rooms which they rated to have a high TP and vice versa. For instance, red room was preferred for exercising and sports, while orange was selected for sports, dining and exercising. Yellow was imagined as suitable to support discussions, dining and sports. The colours identified to have a low TP were significantly preferred for calm activities. Blue and purple respectively were decidedly preferred for sleeping and secondly for relaxing. Green room was dominantly preferred for relaxing. White which was rated to have an average TP was chosen for calm and neutral activities, mainly drawing, reading and meditation.

Key words: Functional value of Colour, Thermal Perception, RGB colour Model,

1.0 Introduction

Since ancient times, colours have been utilised all over the built environment for its well distinguished aesthetic and beautification value. The present study gives emphasis to the ideology that a colour scheme while being an aesthetically pleasing harmonious composition, should aptly support the proposed function of any built space facilitating optimal human performances. Researchers reveal that colour stimuli can trigger corresponding intrinsic emotional and behavioural responses within human beings. Transcending beyond the renowned aesthetic value of colour, the above association has greater potential to be utilised logically and meaningfully to enhance human activity in the manmade world. The use of colour to support human activity in built spaces is identified in the present study as a main aspect of the 'functional value of colour'. Of the diverse emotional and behavioural responses triggered by colour, the present study will be limited to colours associated with the thermal perception of human beings. To be precise, it is a preliminary investigation done to provide scientific testimony for colour associated with human thermal perception and its possibility to support human activities.

Colour theory, though not substantially supported via scientific research, explicates that certain colours; reds, yellows and oranges, are perceived by humans as warm while blue, green and purple hues are perceived as cool leading to the principle differentiation between warm and cool colours. This study attempts to establish the postulation that each colour could trigger a corresponding fixed thermal perception. It's hypothesised that each activity demands a particular thermal level/environment for its optimum performance. Accordingly, it has been attempted to testify the ideology that colours can be used to manipulate the required thermal environment demanded by human activities. As a consequence, the study suggests that colour could be potentially used to cut down energy costs of heating and cooling, via integrating relevant colours as per the required thermal environment demanded by the functions.

This paper at the onset will provide evidence from supportive literature on the nature and emergence of colour associated emotional and behavioural responses in general. Secondly it will zoom in to the emerging means of integrating the above association to support human functions in the built environment via available supportive literature. Moving in to the main research focus, the paper will discuss the relationship between colour and human thermal perception and its potential to be integrated to support human behaviour. To conclude, a research carried out by the author in search of scientific evidence for colour associated thermal perception and the corresponding preferred functions of a few selected colours will be brought to light.

2.0 Background: Functional Value of Colour

According to physics, colour is electromagnetic energy. Each colour is an electromagnetic energy wave oscillating at a unique frequency and wavelength. Every colour will have its unique effects on human beings determined by its corresponding wavelength and frequency. The functional value of colour in the built environment goes beyond its aesthetic value and has many functions based on the myriad effects of colour on human beings. For instance, being an inseparable element of space, colours are being used to convey meanings, ideas or concepts associated with built spaces in order to strengthen the intended message or the expression. They are used as symbols, signals, expressive agents and to convey massages, facilitate orientation and assist

memory (Rihlama 1999). Good colour design is an essential factor in the communication between human beings and architectural space (Meerwein, Rodeck & Mahnke 1998). Colour can differentiate, contain, unite, equalize, and emphasize the design elements of a space (Daggett, et al, 2008).Further; it will function as means of altering the perceived dimension of space. Colours are used to change the impressions of surfaces and spaces (Rihlama 1999). The room surface colour has an impact on the impression of width, height, and depth as well as on more global attributes such as the spaciousness of the room (Neufert & Kister, 2005). Then again, colour can be used logically to manipulate the visibility of objects in the milieu; to dominate and get attracted or to recede and camouflage. The warm colours will advance in space while the cool colours will recede. Explicitly, warm coloured objects appear closer and emphasised in space while cool objects will be de-emphasised and receded (Ham1992). As explained by Daggett et al (2008), warm colours can be used to reduce the scale and size of large spaces, making them more intimate while cool colours visually enlarge a space, making it less confining. Finally and most considerably, colours are used as psychological, physiological or physical agents (Rihlama 1999). In other words colours can be integrated effectively to trigger and manipulate human emotional and behavioural responses as required by the intended function/purpose of any built space.

Therefore, use of colours in a built space could clearly go beyond its usual aesthetic value. The current study will be limited only to the latter and will be focused on the use of colour associated emotional and behavioural responses to support human activity/ performance.

2.1 Emergence of Colour Associated Emotional and Behavioural Responses

The literature available on the nature and emergence of colour associated emotional and behavioural responses provide divided opinion contributing to three principle suppositions. Common theory is that it is a learnt response which is highly subjective and varies as per the individual. Accordingly, each individual may react differently to a particular colour based on memories and experiences gathered via exposing to a particular socio cultural, religious setting in which she/he was brought up. Naz and Epps (2004) explicitly clarify that a colour-related emotion is highly dependent on personal preference and ones past experience. They further explain that colour convention differ from one society to another. For instance, mourning at death is a common emotional reaction among humans, regardless of socio cultural limitations. Even though, the usage of colour to mourn for dead people differ as per the norms learnt from each culture. Colour of mourning in most of the eastern countries including Sri Lanka and China is white. Leopold (1895) elaborates that black is the accepted mourning colour throughout Europe. Ancient Egyptians mourned in yellow while pale brown is the Persian colour of mourning. For inhabitants of Ethiopia it is Grayish brown and in Syria and Armenia it is sky blue (Leopold 1895). On the other hand, it is discussed that colour- human associations is an innate, fixed response generally having universal implications. The emotional response to colour has been found to be quite consistent although there are individual and cultural differences (Oyama, Tanaka and Chiha 19 62: Kastl and Child 1968: as cited in Bellizzi, Crowley and Hasty 1983). Man's reactions to colour are not due solely to cultural training, but to deeper lying reasons (Birren 1969). Humans have a basic biological reaction to colour and

that 'the psychological reaction to colour does not preclude the basic biological reaction that stems from human evolution (Engelbrecht 2003). Specific colour stimulation is accompanied by a specific response pattern of the entire organism (Goldstein as cited in Birren1969).

Accordingly, each colour is found to trigger corresponding fixed responses in humans. For instance colour red is found to be stimulating (Nakshian 1964, Kandinsky 1977, Babbit 1878, Bellizzi, Crowley and Hasty 1983, Stone 2001) while blue is calming (Birren1969, Babbit 1878 and Stone 2001). Depending on the strength of the hue, blue is associated with emotions ranging from sedate tranquilly to a suppression of feelings (Bellizzi ,Crowley and Hasty 1983). Schauss (1981) reported that a certain shade of pink; 'Baker Miller' pink has a measurable and predictable effect on reducing physiological variables associated with aggression in subjects of normal intelligence. Babbit (1878) identified yellow and orange as nerve stimulants. Wohlfarth (1985) revealed that painting classrooms in yellow increases self-esteem of students and decreases in measures of sadness, aggression and absenteeism.

The third supposition identifies that colour associated emotional and behavioural responses to be a complex, combined effect of both learnt and innate responses. How colours are perceived varies to some extent according to ethnic origin, age sex and then psychological phase of development, but mainly people react in the same way (Rihlama 1999). As per the in-depth analysis of Mahnke (1996) a multitude of factors work together in the process of emotions triggered by colour stimuli both on a conscious and an unconscious level. Thus, colour experience cannot be definitively systematized or classified. Mahnke further identifies six interrelated layers that influence this experience which he demonstrates in a "Colour experience pyramid". The bottom layer of the pyramid which forms the firm basis for above association comprises of inescapable innate biological reactions which are beyond one's control. The associations from the collective unconscious, which are primordial and connected to the mankind's entire experience since their origin on the planet can be found in the next level. This association, similar to biological reactions, are not controlled or caused by the intellect or conscious rational thought based on personal experience amassed during our lifetime. The rest of the layers from bottom to top represent all the other learnt responses, namely symbolisms of the conscious, cultural influences and mannerisms, influence of trends, fashions, and styles. Personal relationship to colour which is connected with and influenced by all the other levels could be found at the top.

2.2 Use of Colour Associated Emotional and Behavioural Response to Support Human Activities in the Built Environment

The current study will focus on the innate or universally applicable emotional and behavioural response to colour which has the potential to support human performance in built environments. Researchers suggest that the quality of the environment has a direct impact on human behaviour. In conjunction with this belief, it has been suggested that the appropriate use of colour can enhance the overall quality of the environment and, thus, influence behaviour (Mahnke, 1981). Colour can act as a subtle environmental cue that has important influences on behaviour (Elliot at el 2007). Many prisons, hospitals, companies, and schools have adopted systematic colour schemes which have been designed to produce particular performance states in their inhabitants (Etnier and Hardy 1997). The colour of

the work environment may affect performance (Kwallek & Lewis, 1990). Few examples for the usage of functional value of colour to support a particular human behaviour are as follows.

The arousing effect of colour red has many usages. Red is used to increase appetite and table turnover in restaurants (Gruson 1982). A vey recent study done by Zhu (2009) revealed that colour red can make people's work more accurate cautious and detail-oriented. It helps in enhancing memory (Belluck 2009). Red light has been found to increase strength by 13.5% and is used to increase athletic performance for athletes who need short, quick bursts of energy (Dagget, Cobble and Gertel 2008).

The sedating effect of blue has been used logically to support human performance. Students' blood pressure dropped and their behaviour and learning comprehension soared when architects changed schoolroom walls from orange and white to blue (Barrett 2007). Blue streetlights are found to be useful in preventing suicides and street crime (Shimbun 2008). On the other hand as revealed by Zhu (2009 cited in Belluck 2009) blue can be integrated in the spaces where a person needs to be more creative. Blue light assists in performances of athletes who require a steadier energy output. (Azeemi & Raza 2005)

According to research, pink has a tranquilizing and calming effect within minutes of exposure. It is capable of suppressing hostile, aggressive and anxious behaviour. Pink is also reported to reduce muscle strength in inmates. Pink holding cells are now widely used to reduce violent and aggressive behaviour among prisoners (Azeemi & Raza 2005). At a county jail in Texas inmates are dressed in pink jumpsuits. They sleep on pink sheets and wear pink slippers. Even the walls and the bars of the cells are painted pink (Glaister 2006).Several municipalities are experimenting with passive pink to stop graffiti, while football coaches try the colour in visitors' dressing rooms, to debilitate their opponents(Gruson 1982).

Use of colour in hospital design to support function plays a vital role in terms of patient recovery rates and improving the quality and overall experience of patients (Dalke et al. 2005). The integration of supportive colours in hospital environment may vary as per the illness of the patient. For instance brighter colours may be preferred for patients with depression and some older adults, but they could be over stimulating for highly agitated patients. (Karlin & Zeiss 2006).

On the other hand, several researchers reveal the adverse effects of colours on certain human performances, which is another important facet of this association needs to be considered. Stone (2001) found that, reading comprehension decreased in a red room, which is socially considered to be a warm colour. Red seems to impair performance on achievement tasks, due to its association with the danger of failure in achievement contexts and evokes avoidance motivation. The findings suggest that care must be taken in how red is used in achievement contexts (Elliot at el 2007). Gimbel suggests a possible relationship between violent street crime and sodium yellow street lighting. (Gimbel as cited in Azeemi,S.T.Y & Raza,S.M 2005).

The complete characteristics of the innate, intrinsic or fixed biological responses to colour stimuli is yet to be discovered. However, colour associated fixed emotional and behavioural responses, could be manipulated logically to support human activities/performance in built spaces. Out of aforementioned responses, the present study will predominantly limit its scope to a single aspect of colour which emerges as part

of the whole process of intrinsic response; colour associated thermal perception of human beings. To explain precisely, the study will investigate the potential of integrating colour to enhance the thermal environment demanded by diverse human functions. This association is identified as an underutilised aspect of the functional value of colour.

2.3 Research Focus - Colour and Thermal Perception of human beings

Colour is said to have a relationship with human's thermal perception. In other words, colours can be described in temperature terms (Ballast, 2002). Accordingly certain colours, namely reds, yellows and oranges, are perceived by humans as warm. While blue, green, purple hues are perceived as cool. Yet the scientific investigations done on the nature and potentials of this association is scarce. At this juncture, the current research seeks in fulfilling three main objectives.

1) Providing evidence for colour associated thermal perception using scientific methods.
2) Distinguishing colour as a parameter pertaining to human thermal environment.
3) Establishing a correlation between colour, thermal perception and human functions preferred.

Theory of colour distinguishes a relationship between colour and perceived temperature, thus differentiating between "warm colours" and "cool colours". According to Ballast's (2002) explanation colours can be perceived as "warm" or "cool" related to the dominant wavelength of the colour (Ballast 2002 cited in Daggett, et al , 2008).

Similar to the other entire colour associated emotional/behavioural responses; thermal perception relevant to a particular colour too can be a highly subjective response which differs from person to person. Yet, there are certain common connotations emerging as a consequence of fixed intrinsic, biological or inherited and primordial responses that emerge through the collective unconscious, which is the focus of the present study. On the other hand there can be exceptional situations where these inherited and primordial colour associations may be overridden by personal unconscious reactions that are learnt through the influence of an individual's personal experiences. For instance blue is identified to be perceived as cool. Yet contradicting all research on colour symbolism and psychological effect, a person may associate an ice-blue tone with heat, because as a toddler he burned himself on an object of that colour (Mahnke 1996).
In fulfilling the main objectives, the study has formulated three hypothetical sub questions and looked for evidence from existing literature.

3.0 Hypothetical Sub Questions

3.1 HSQ 01 - Colour Vs. Thermal Perception

Can colour alter human thermal perception regardless of ambient temperature?

Theorists suggest that perception of colours as warm and cool could possess primordial learnt connotations. Warm colours are suggested to associate with the warmth of fire and sun while cool colours are believed to connect with the coolness of the sea, sky, and foliage. As described by Belvalkar (2012), perception of red, orange, yellow and different tints and shades of them as warm could be a depiction of fire, which is characterised by all these colours. The prime purpose of fire discovered by the prehistoric man was warmth and light. Since then, man has associated fire with warmth, and thus all the colours of fire are warm colours. On the other hand, water and trees

always made the atmosphere cooler and calmer; hence blue, green, violet and all the tints and shades of these colours came to be the cool colours (Belvalkar 2012).

Supposedly, as a consequence of intrinsic biological reactions triggered by colour stimuli, warm colours are said to stimulate, arouse and activate human metabolism resulting in increased heart rate, blood pressure and body temperature, while cool colours work in the opposite end to appease and pacify. Validating the above ideology Schaie and Heiss (1964) explain that the high wavelength colours; red, orange and yellow, possess strong excitation potential and high arousal qualities, and they induce elated mood states. Further establishing the correlation between wavelength and felt arousal Plack & Shick, (1974),Wineman (1979), Walters et al (1982), Whitfield &Wiltshire (1990), Stone (2001) and Ballast (2002) claims that long waves (e.g. red, orange, yellow) are arousing and stimulating. Although there is no scientific proof so far, Cornelissen and Knoop (2012) suggest that red can make body temperature rise, thus people experience a feeling of warmth. Therefore the study postulates that high wavelength colours are perceived to be warm as a consequence of the innately fixed arousing effect on humans resulting in an increased body temperature. Thus high wave length colours are distinguished as "warm" colours.

The low wavelength colours, such as green and blue, are associated with more sedate mood states. These colours have relatively low arousal value and limited excitation potential (Schaie and Heiss 1964). The cool colours are generally considered to be restful and quiet (Ballast, 2002). Plack & Shick, (1974),Wineman (1979), Walters et al (1982), Whitfield &Wiltshire (1990), Stone (2001) and Ballast (2002) state that short waves are relaxing. The cool colours have many redeeming properties. They generally soothe relax, and induce leisure and contemplation. They are thought to be calm, secure, peaceful, and restful (Sharpe 1974 as cited in Bellizzi, Crowley and Hasty 1983). In another study conducted by Stone (2001) it was found that the arousal decreased in a blue room.

According to Kopacz(2003) the sight of the colour blue causes the body to release tranquilising hormones. Further he suggests that blue can lower blood pressure, slow the p ulse rate and decrease body temperature. Even though no scientific proof is evident in literature, the theory of chromo therapy explains a relationship between colour and body temperature. Therefore it can be hypothesised that low wavelength colours are perceived to be cool as a consequence of the fixed sedating effect on humans, resulting in a decreased body temperature. Thus low wave length colours are distinguished as cool colours.

Owing to the fixed innate responses it can be theorised that each colour is capable of triggering a different arousal level characterised by a corresponding thermal condition within human beings, consequently effecting thermal perception as well. In other words colour of a room will have a direct effect on ones perception of room temperature. Thus each colour is capable of triggering a relevant thermal perception regardless of the ambient temperature.

Only a handful of researchers have been touched upon this paradigm of colour research and come up with supportive proof. Sundstrom (1987) suggests that the colour of surroundings might have a distinct impact on changing perceptions of room temperature. According to Morton (1995), tests document that people estimate the temperature of a room with cool colours, such as blues and greens, to be 6-10 degrees

Fahrenheit cooler than the actual temperature; warm colours, such as reds and oranges, will result in a 6-10 degrees Fahrenheit warmer estimate. Hutchison (2003) reports that in another study done with work groups, walls painted "cool blue" induced more women to complain of being cold with the temperature set at 75 degrees than when the colour was changed to warm yellows and restful greens at the same temperature. Stone (2001) found that individuals performing within blue partitions perceived the temperature to be cooler than those in the red partitioned workspaces. Plack & Shick found a significant increase in the complaints about the coldness in an office which was painted blue after being yellow even though the actual temperature in the office had not changed (Plack & Shick, 1974). According to the very few supportive findings it can be suggested that colour is capable of altering human thermal perception regardless of ambient temperature.

3.2 HSQ 02 - Colour Vs. Human Activity

Can colours trigger corresponding arousal levels that will consequently support human activity and behaviour?

Every human activity is supposed to demand a unique state of existence for its optimum performance. Existence of human beings generally will fall in to three basic states; stimulated state, pacified state or a neutral state. For instance, humans are very active when they perform activities like dining, shopping, playing and conversing. On the other hand they will be pacified and concentrated when reading, studying and meditating. They will be at a neutral stance when they are relaxing. Human performance within any built space created may fall within any of such category. Shopping malls, dining spaces, gyms, and bars are designed for humans to perform actively while libraries, exam halls, meditation areas demand the user to behave in a pacified and more concentrated pace.

Therefore, designing spaces to facilitate the intended pace of existence; stimulated, pacified or neutral is vital. In doing so, colour can be an effective tool to support the demanded pace of existence or the level of arousal. As mentioned previously, each colour is capable of triggering corresponding arousal levels that will consequently affect human activity and behaviour. Birren (1989) states that warm colours are related to an active behaviour, while cold colours resemble a rather passive behaviour. Affirming this line of thinking, Gerard (1958) as cited in Graham 2000) suggests that psycho-physiological activation increases with the wavelength from blue to red. Therefore the study suggests that warm colours can be integrated to enhance active simulative spaces while cool colours will work well in pacifying spaces.

3.3 HSQ 03 - Association between Colour, Thermal Perception and Human Activity

Can colours trigger corresponding arousal levels that will set the thermal environment to support human activity and behaviour?

The current study is attempting to establish a correlation between three variables, namely colour stimuli, thermal perception and human performance/functions. Even though research conducted thus far do not directly support the above correlation, certain researches done on human responses to temperature conditions have found through the analysis of literature, to trigger parallel effects as colour stimuli.
For a case in point, as reported by (Schoer and Saffron 1973; Fisher 2001) temperature in classrooms affect

schoolchildren's performance. Going into details, Holmberg and Wyon (1969) revealed that student's behaviour was significantly affected by raised classroom temperature; girls became restless while boys began to behave in an undisciplined way and were observed to concentrate less. It was reported that reading comprehension and reading speed were reduced by raised temperature conditions. As per Stone (2001) reading task was lowered in a red environment. Thus both the red environment and raised temperature has affected human behaviour in the same manner suggesting a relationship between colour red and high temperature.

According to the principle of colour therapy, using more of blue colour in the bed room will help insomnia or sleeplessness (Hari 2003). Equally, the right room temperature can play a crucial role for a good night rest. Studies have found that the optimal temperature for sleep is quite cool, around 60 to 68 degrees Fahrenheit. For some, temperatures that fall too far below or above this range can lead to restlessness. A growing number of studies are finding that temperature regulation plays a role in many cases of chronic insomnia (O'connor 2009). Consequently blue colour can be identified to have a correlation with a cool thermal condition as both conditions are found to help insomnia.

Thus logically, there is a clear association between colours, thermal perception and human activities.

4.0 Contributions

4.1 To Create the Thermal Environment Demanded by Human Functions

With the logical and meaningful integration of the above association, colours can be potentially used to create the demanding thermal environment desirable for the function/activity intended in a built space. For instance, as revealed through the above analysis, cool thermal perception of colour blue in a bed room can support insomnia as the thermal environment demanded for sound sleep is quite cool.

4.2 Colour as an energy conservation tool

This association has a greater importance in energy conservation as well. For instance the energy spent on heating or cooling can be cut off to a certain extent by integrating the relevant colours at the right place; cool colours in a west facing room, warm colours in cold climatic regions of the world.

5.0 Research Design

The current research looks in to thermal perception associated with several selected colours namely; white, blue, red, yellow, purple, green and orange while seeking potential human activities which could be supported by the same colours. Eventually, the current study attempts to synthesise the findings associated with the same colour to establish a relationship between colour, thermal perception and human activity preferred.

5.1 Factors Determining Human Thermal Perception.

In formulating the research design the study probes into the already established factors pertaining to human thermal environment which consequently affect thermal perception. The Oxford Dictionary defines perception as the ability to see, hear, or become aware of something through the senses. It is further clarified in psychological & zoological terms, as the neurophysiologic processes, including memory, by which an organism becomes aware of and interprets external stimuli. Heat energy is recognised to trigger human thermal

perception. Therefore thermal perception in general terms is the process of becoming aware of and interpreting the external heat stimuli and become aware of warmness or coolness through human senses; generally the skin.

The physics of heat transfer is straightforward, involving only three primary processes; conduction, radiation, and evaporation, and one auxiliary process, convection (Blumberg 2002, p 20). The combined effect of the aforementioned mechanisms of heat transfer to a greater extent will create the human thermal environment at any given time. Body temperature rises and a person feels warm if the heat generated inside the body is more than the heat lost to the environment. Similarly, body temperature drops and a person feels cool if the heat generation is less than the heat loss (Houdas and Ring, 1982)

Human thermal environment: Human thermal environment as a whole is a combination of several external and personal parameters. In order to comprehend on the aforementioned parameters this study will refer into the well established variables which determine the perception of thermal comfort. To define in general terms, thermal comfort or thermal neutrality is the state that an individual prefers neither a warmer nor cooler conditions, and that conditions are comfortable for the majority of people in any particular group (Wilson and Belshe 2001). Thermal comfort as defined by American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) is defined as the condition of mind which expresses satisfaction with the thermal environment. As defined by Gagge et al. (1967) it is the conscious appreciation of warmth or cold and is an interpretation of thermal information from the skin and the inner body.

Accordingly, the current study logically argues that thermal comfort or discomfort is a decision which is arrived at as a consequence of human thermal perception. To clarify further, once a person is triggered by external heat stimuli through his senses, a neurophysiologic process will be activated and that information will be interpreted and analysed in his mind with the use of stored memory to arrive at the decision whether he/she is feeling too hot or too cold.

Parsons (2003) argued that thermal sensation is both a sensory and a psychological phenomenon. Since sensation is about how people feel, it is not possible to define it in physical and physiological terms. Thus, perception is always a subjective process moulded with past experiences and memories of each individual. Therefore it seems that humans perceive or respond to the thermal experiences in an altered manner (Ogoli 2007). Thermal comfort is essentially an emotional response contrary to the thermal sensation which is a rational response (Tanabe and Kimura, 1994). Thus the study stresses that the variables of thermal perception are same as thermal comfort variables.

5.2 External Parameters of Thermal Perception

A range of environmental and personal factors will work together contributing to this decision which is distinguished as the 'Human Thermal Environment'. Thermal comfort is based on the heat balance between the human body and the environment and is regulated through four environmental and two personal parameters (Zhang et al., 2004). As explained by Parsons (1993), air temperature, radiant temperature, humidity and air movement are the four basic environmental parameters. Combined with the personal parameters of metabolic heat generated by human activity and clothing worn by a person, they provide the six fundamental factors which define human thermal

environment. The general, but fundamental, point is that it is the interaction of the six factors to which humans respond (Fanger 1970, Parsons 1993).

The above parameters are mainly identified based on the means of heat gain and heat loss from a human body. There is a continuous heat exchange between the human body and the thermal environment. For a human being to be thermally comfortable a perfect balance between heat gain from the environment and loss from the body should be achieved. The four external parameters are as follows.

a) Air temperature:
The temperature of the air surrounding the body can be distinguished as a principle factor of thermal perception. As a major component in convective heat transfer, air temperature moderates surface temperatures. These in turn further influence sensed temperature and comfort (Wilson and Belshe 2001).

b) Radiant temperature:
If there are heat sources in the environment radiant heat may be present which has a greater influence than air temperature on how humans lose or gain heat to the environment. The human body is constantly radiating energy to the environment while absorbing radiant energy from heat sources around. Depending on the relative temperature of the surfaces surrounding an occupied space, personal comfort can be greatly enhanced or compromised (Wilson and Belshe 2001).

c) Air velocity:
The air velocity or moving air will provide a cooling or heating effect on human beings (Wilson and Belshe 2001).

d) Humidity:
The impact of humidity levels is another external factor pertaining to thermal perception. At air temperatures above 75°F, the body begins perspiring. If the surrounding relative humidity is low enough, a significant amount of this perspiration undergoes a change of state and evaporates as water vapour. For each pound of water evaporated, the latent heat of vaporization extracts 970 Btu of heat from our bodies, thus providing significant cooling. Similar to cooling by perspiration—heat dissipation by respiration or panting is both a convective heat transfer mechanism as well as a form of evaporative cooling (Wilson and Belshe 2001).

Accordingly, a change in any of the above external parameters will cause a change in human thermal perception.

5.3 Human Parameters /Internal Parameters Pertaining to Thermal Perception

Two main parameters have been identified as related to the occupants' namely metabolic heat production and clothing insulation Fanger (1970), Parsons (1993), Matjaz (2006). Yet analysing the human factors in depth Wilson and Belshe (2001) add four more parameters namely, natural body responses, activity level, reactions to CO and other chemicals and conduction from body.

e) Metabolic Heat Production
Metabolic heat generation is supposed to be the most essential personal variable of the perception of thermal comfort.
Maintaining the core body temperature in the normal range (37ºC +/- 1ºC) is vital for its optimum performance and metabolic heat production plays a major role in this regard. The metabolic heat generated by oxidation of food in the visceral organs and tissues (body core) is a constant source of heat (King, 2004). This food-to-heat conversion process is called metabolism (Wilson and Belshe 2001).Metabolic heat production is a dynamic phenomenon which varies due to diverse factors namely; age, body

temperature, gender, sleep cycle, height, weight and skin surface area, pregnancy, menstruation, lactation, growth, prolonged fasting, infection and other diseases, recent ingestion of food, muscular activity, emotional state, ambient temperature, hormones and other conditions (Vander, Sherman and Luciano 1980 as cited in Wilson and Belshe 2001). Increased metabolic activity will enable a person to perceive an elevated thermal level.

f) Clothing Insulation

According to laboratory studies, a naked person sitting quietly is comfortable at 82.4°F (Fanger, 1970). Clothing insulates the human body from losing heat to the environment. People in all parts of the world existing in widely variable climates have evolved a plethora of clothing styles appropriate for local climate needs to protect themselves from both heat and cold and controlling moisture movement (Wilson and Belshe 2001).

g) Natural Body Responses

As explained by Wilson and Belshe (2001), warm-blooded creatures including human beings are able to adapt and live in a wide range of environments via a complex system by which they generate their own heat and regulate the internal temperatures. This process of controlling body temperature is identified as thermoregulation. Body temperature is kept constant by balancing both heat gain and heat loss. Humans need to maintain a constant body temperature of about 37°C. To maintain this temperature at a constant point throughout the body's internal systems, mechanisms must be in place to accurately measure present body temperature, and to regulate as needed. This system is known as the thermoregulatory system (King , 2004).

Hypothalamus is the basic body controller for thermal comfort. Being a gland at the base of the brain it is essentially a thermostat set at 98.6°F. When it senses that the body is losing heat faster than it is generating it, it secretes hormones and sends nerve impulses to various parts of the body to increase the metabolic rate, constrict blood vessels and other changes. Under over-heated situations, the hypothalamus sends out just the opposite signals. When certain pathogens or disease trigger the brain, many of these same temperance regulators are brought into play to raise the core body temperature to help fight off these viral and bacterial invaders (Wilson and Belshe 2001).

h) Activity Level

The body generates heat at widely varying levels depending on activity: Therefore the activity in which a person is involved will also contribute in determining thermal perception. Eagan as cited in Wilson and Belshe (2001) identifies the relationship between activity and heat generation.

i) Conduction from Body

Conduction of body heat through direct contact with cold surfaces is a far more efficient mode of heat transfer than convective losses to the air. Bare feet on cold floors are clearly more of a source of local discomfort than bare hands in air of the same temperature. Direct contact with cold surfaces allows these heat sinks to draw out body heat (Wilson and Belshe 2001).

j) CO and Other Chemical Reactions

Human bodies are indeed very complex systems with chemical stimuli and responses affecting all biological and physical activities. Besides the known health effects of even low levels of CO, this toxin also influences our perceptions of thermal comfort. Under conditions of reduced oxygen levels and increased levels of carbon monoxide or carbon dioxide, the heart is induced to increase the blood flow in order to try to deliver sufficient oxygen to body tissues. With increased blood flow, there can be a false sense of warmth and comfort with a

feeling of well-being and lethargy (Wilson and Belshe 2001).

To recap, there are four external variables pertaining to human thermal environment namely air temperature, radiant temperature, humidity and air movement. Further there are several human or internal parameters which contribute to the perception of thermal environment. They are metabolic heat production, clothing insulation, natural body responses, activity level, reactions to CO and other chemicals and conduction from Body.

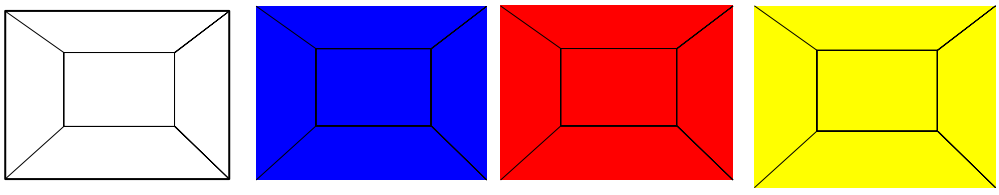
The present study argues that the factors contributing to thermal perception of humans or thermal environment transcend beyond these well established parameters. Significantly thermal perception can be beyond tactile sense. Thermal perceptions are affected by factors that are not recognized by current comfort standards. The factors include thermal history, non-thermal stimuli and psychological expectations (Humphreys, 1996; Karyono, 2000). The current study inquires the potential of colour to be considered as another parameter determining human thermal environment. Similar to seeing colour in music identified as sound, colour synesthesia (Cytowic & Eagleman 2009), thermal, colour synesthesia; perceiving temperature through colours could be possible. Colours can potentially be non-thermal stimuli which have an effect on human's thermal perception. Therefore the study will attempt to investigate the effect on colour on thermal perception. In doing so, the aforementioned external and personal parameters have to be controlled.

6.0 Survey Instrument

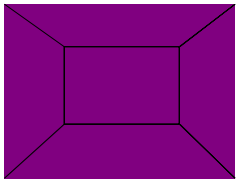
This preliminary investigation was conducted with a group of normal sighted, healthy volunteer undergraduates (n=72, 51 females and 21 males) of University of Moratuwa. The participant's belonged to an identical age group (ranged between 20-23 years) and represented a cross section of the socio cultural religious and topographic contexts in Sri Lanka. It was attempted to control the external parameters which directly effect on thermal perception via conducting the study within an air conditioned controlled studio environment with a fixed lighting level. Controlling the personal factors were not possible due to practical reasons, especially clothing insulation, since it is a preliminary investigation conducted with volunteer undergraduates. Any how the participants' pace of existence and the activity level were essentially the same as they were comfortably seated in the studio while involved in the given tasks. The study was focused on two main parts.

Part one:

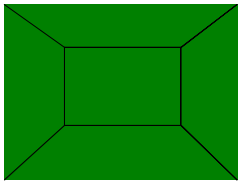
The participants were shown computer generated slides of an identical room in seven different colours (as specified in RGB colour model) projected on to a wall ;namely Red(255,0,0), orange (255,165,0), yellow (255,255,0), blue (0,0,255), green (0,128,0), purple (128,0,128), White (255,255,255). In other words each slide demonstrated an identical room in a particular colour as shown below.



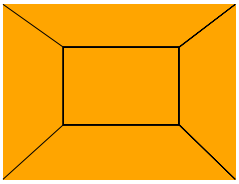
1) White - RGB 255,255,255 2) Blue – RGB 0, 0,255 3) Red – RGB 255, 0, 0 4) Yellow RGB - 255, 255, 0



5) Purple - RGB 128, 0,128



6) Green – RGB 0, 128, 0



7) Orange – RGB 255, 165, 0

The room temperature was maintained at a constant level (26^{o}C). The participants were shown each slide for two minutes and they were requested to rate their TP (warmness/ coolness) per each room on a 5 -point likert scale (Very Cool, Cool, Average, Hot, Very Hot).

Part two:

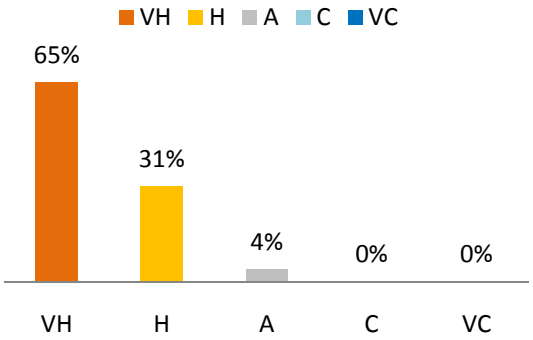
Part two attempted to identify activities they preferred to perform within each of the above projected rooms. Using the guided imagination technique, the participants were guided to imagine as if they are experiencing the above coloured rooms as real and select (√) the activities they would prefer to perform in each room out of a list of activities given to them namely, sleeping, exercising, dining, reading, solving mathematical problems, having discussions with friends, meditation, sports, relaxing and drawing a picture. They were allowed to select the same activity for more than one colour if necessary.

Imagination is one's innate ability to form mental images. It was considered that responding to visual slides with the use of participant's spontaneous imagination is equal to the effects of being in the rooms. The imagination produces strong feelings in most of us as just as fiction does. Findings from brain imagining indicate that the same rejoins of the brain are used in very similar patterns, whether one visually experiences a given object or one imagines such an object (Kandel, Schwartz and Jessell 2000, Kosslyn 1994 as cited in Nichols 2006). As stated by Kein (1985), the brain and nervous system respond only to mental images. It does not matter if the image is self-induced or from the external world. To clarify in detail, once light reflected from an external object hits a perceiver's eyes an electrochemical change will occur producing nerve impulses that are transmitted to the visual centre of the brain where the information is interpreted in the form of visual images. Consequently it can have the same emotional effect be it real or imagined information. Supporting this line of thinking (Mahnke (1996 p. 7) establishes that, colour is not dependent only on the external world but may also originate through the power of imagination of our inner world. Based on supportive literature the responses made to an imagined coloured room were considered as equal to the real experience of the same in the current investigation.

7. Data collection

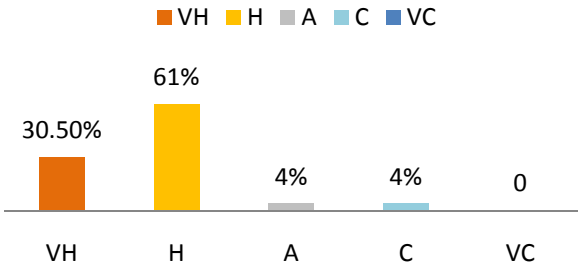
The data was collected and analysed with the use of excel sheets and the findings are represented via bar charts and line charts as illustrated below.

7.1 Data Series 1 - Rated thermal perception per colour



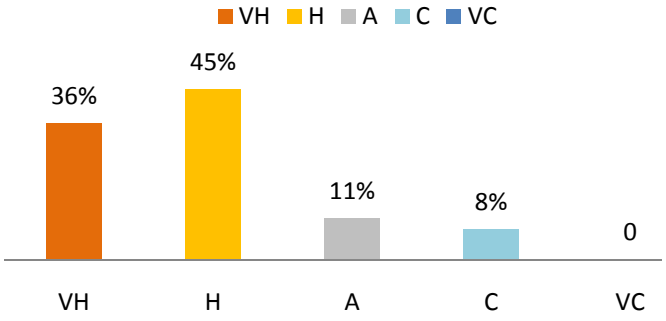
Red was significantly perceived to be very hot (65%). None perceived red as a cool colour.

Graph 1 – Thermal Perception Associated with Red.



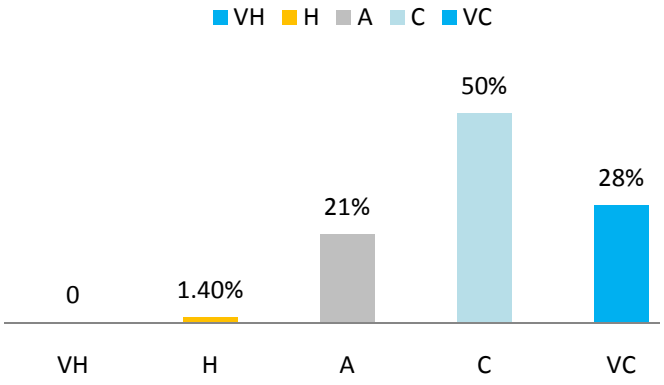
Majority (61%) perceived orange as a hot colour. None considered orange to be a very cool colour.

Graph 2 - Thermal Perception Associated with Orange



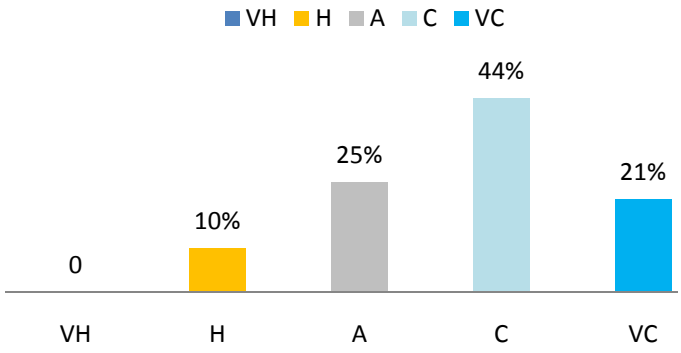
Yellow was mostly (45%) perceived as hot while another 36% perceived it as a very hot colour.

Graph 3 - Thermal Perception Associated with Yellow



Green was significantly perceived to be a cool colour (50%). Green was not considered to be a warm colour.

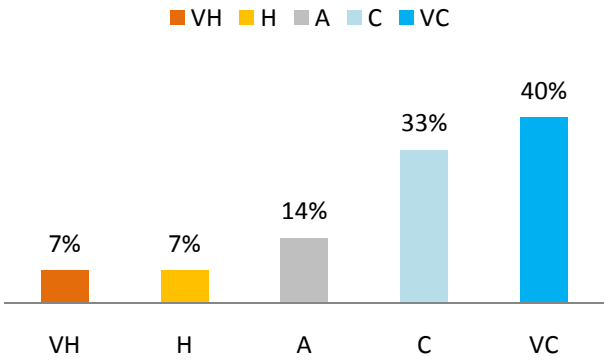
Graph 4 - Thermal Perception Associated with Green



Most responses on purple were to say it was a cool colour. (44%)

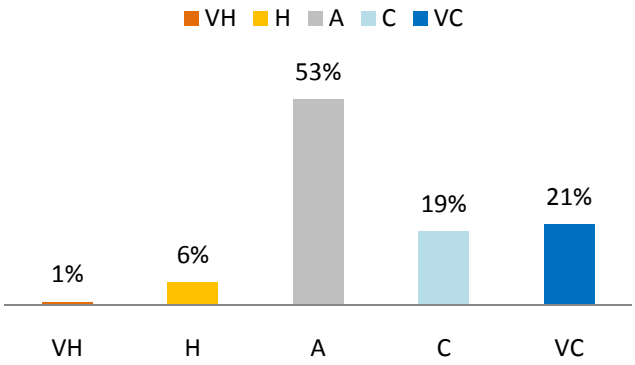
None considered it to be a very hot colour.

Graph 5 - Thermal Perception Associated with Purple



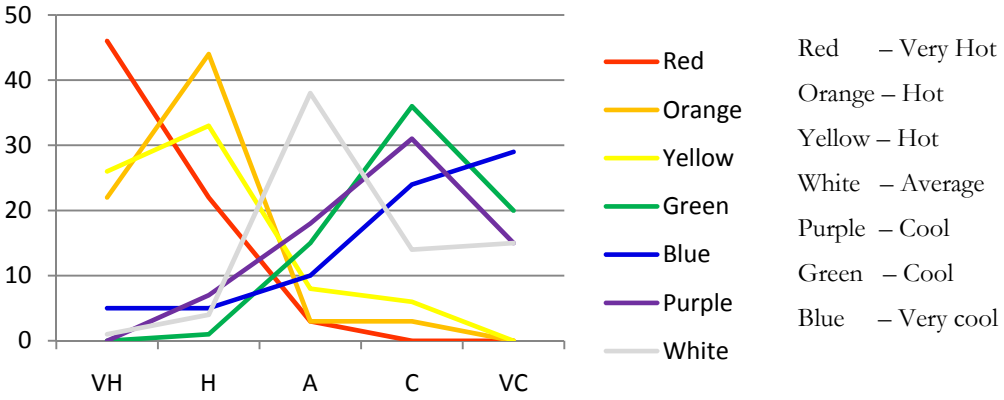
Blue received the highest number of responses as the coolest colour (40%) above all the colours tested.

Graph 6 - Thermal Perception Associated with Blue.



White was identified by a majority to be an average colour; neither hot nor cool (53%).

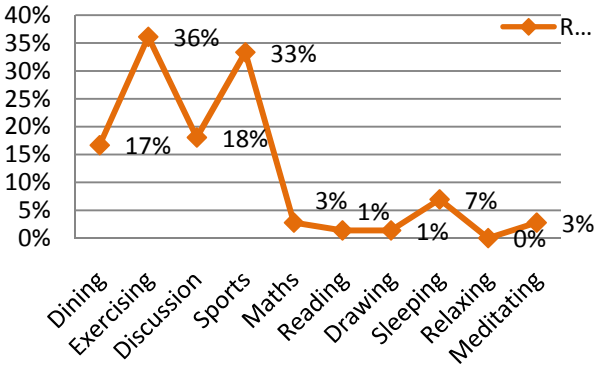
Graph 7 - Thermal Perception Associated with White



Graph 8 – Overall Thermal Perception for the given colours

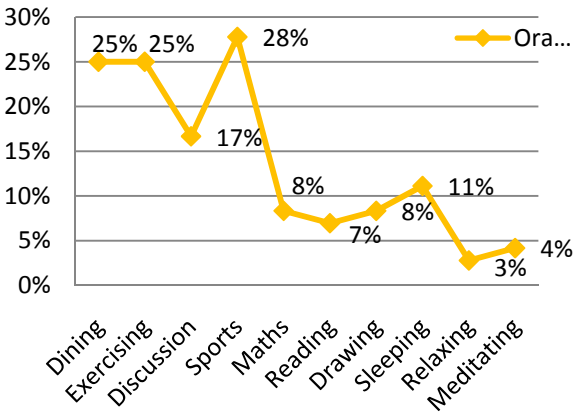
7.2 Data Series 2 - Activities Vs colour

Referring to the graphs representing colour vs. activity preference, activities chosen at the peak level was considered to be mostly favoured per each colour.



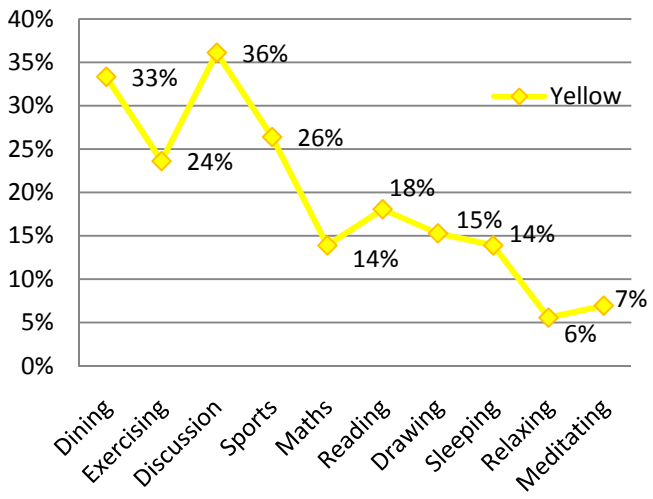
Sports and exercising were dominating at the peak level of the graph as activities preferred to be performed in a red room. Significantly calm and concentrated activities were firmly not preferred in a red room; relaxing, reading, drawing and meditating.

Graph 9 – Activities preferred in **red room.**



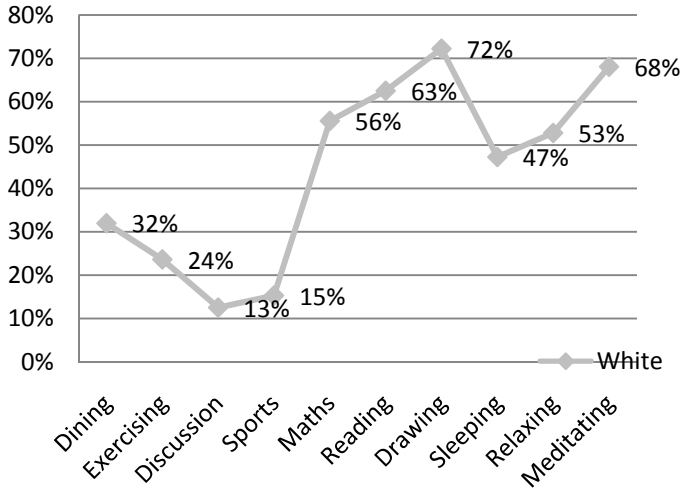
Functions performed in an active pace of existence namely sports, exercising and dining were significantly preferred at peak level in an orange room. Similar to red, calm and concentrated activities were more or less not preferred in an orange room; relaxing, meditation.

Graph10 – Activities preferred in **orange room**



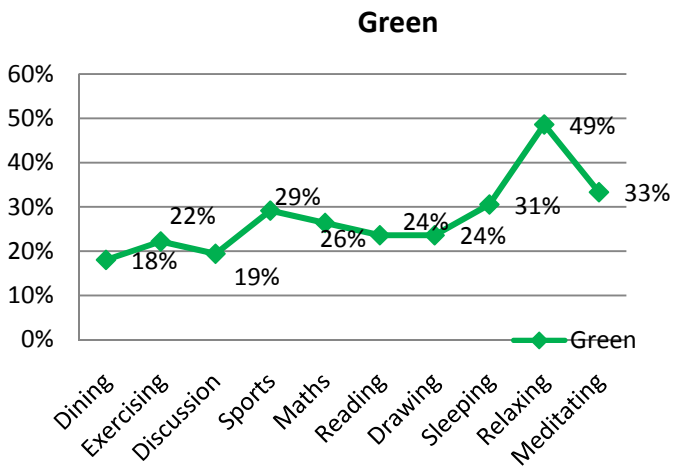
Graph 11 – Activities preferred in **yellow room**

The graph has moved upwards demonstrating a variety of activities which can be performed in a yellow room. Yet active functions namely, discussions dining and sports and exercising had the higher preference at peak level. The participants moderately preferred to read, draw and solving maths problems in a yellow room. Yellow was barely preferred for calm/neutral activities namely, meditation and relaxation



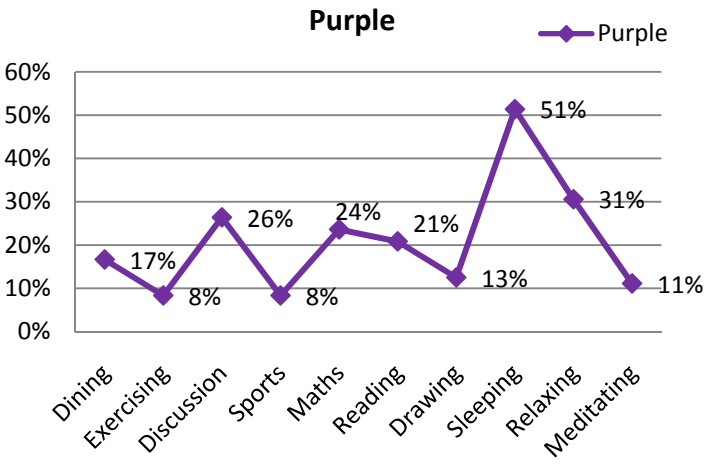
Graph 12 – Activities preferred in **white room.**

White was highly preferred for functions to be performed in a calm appeased state and neutral state of existence than activities of high arousal; drawing, meditations and reading. On the other hand it was not much preferred for active performances like exercising, discussions and sports.



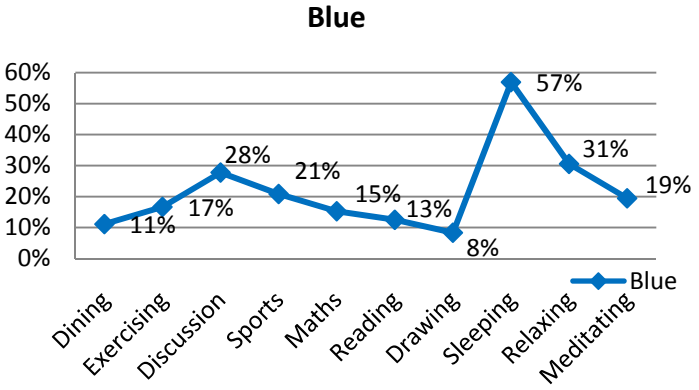
Graph 13 – Activities preferred in **green room**

Green demonstrates a large scope in terms of activities in both active and calm range. But it was highly preferred for relaxing.



As depicted by the graph, purple was preferred by a majority for sleeping. Demonstrates a large scope in termas of activities in both active and calm range.

Graph 14– Activities preferred in **purple room.**



Blue was dominantly preferred for sleeping and moderately for relaxing.

Graph 15– Activities preferred in **blue room.**

8.0 Analysis

Findings of this study provide testimony for colours' ability to alter human's thermal perception. Each colour significantly was found to be associated with a certain thermal perception.

Red was significantly perceived to be very hot (65% -VH, 31-% H, 4%-A, 0%-C, 0%-VC). Accordingly, 96% rated red to be warm. None perceived red as a cool colour (0%). Majority perceived orange as a hot colour (30.5-% VH, 61%- H, 4%-A, 4%-C.0%-VC) and none considered it to be a very cool colour (0%). Orange was another colour significantly perceived as warm (91.5%). Yellow too was mostly perceived to be a hot colour (36% - VH, 45% - H, 11% -A, 8% -C, 0% - VC). 81% rated yellow to be another warm colour. Accordingly, supporting the theory of colour, red, orange and yellow were perceived significantly as warm.

Green was significantly perceived to be a cool colour and was not considered to be a warm colour (0%-VH, 1.4% -H. 21% -A, 50% -C, 28%- VC). Majority perceived purple to be a cool colour (0%-VH, 10% -H. 25% -A, 44% -C, 21%- VC). None considered Green and purple to be very hot colours.

Above green and purple, blue was identified to be the coolest colour (7%-VH, 7% -H, 14% -A, 33% -C, 40%-VC). Thus affirming the colour theory, green, purple and blue were dominantly perceived as cool. Only a very few respondents rated these colours as warm. On the other hand a minor tendency to perceive green (21%), purple (25%) and blue (14%) to have an average a TP was evident in the findings, unlike warm colours.

Aligned with theory of colour, white was identified by a majority to be a neutral colour; triggering neither a hot nor cool perception (1%-VH, 6% -H, 53% -A, 19% -C, 21%- VC). Even though only a handful of respondents rated white as warm (7%), it was considerably marked as a cool colour (C+VC=40%). Recognizing white as a cooling colour could be a learnt association strongly moulded by the Sinhalese, Buddhist religious context.

Red was found to be the colour perceived as the warmest out of all colours tested while blue was found to be the coolest. Accordingly the following relationship between TP of seven colours tested was arrived at; TP Red > TP Orange > TP Yellow > TP White > TP Purple > TP Green > TP Blue.

Referring to the graphs representing colour vs. activity preference, activities chosen at the peak level were considered to be mostly favoured for each colour. Supporting the hypotheses, the participants preferred to perform active functions in the rooms which they rated to have a high TP and vice versa. For instance, red room was preferred for exercising and sports while orange were preferred for sports, dining and exercising. Further, yellow was marked as suitable to have in a space for friendly discussions, dining and sports. The colours identified to have a low TP were significantly preferred for calm activities. Blue and purple respectively were decidedly preferred for sleeping and relaxing. Green room was dominantly preferred for relaxing. White, which was mostly rated to have an average TP was chosen for calm and neutral activities mainly, drawing, reading and meditation.

On the other hand colour and thermal environment were found to have parallel effects on human performance. For instance blue was found to associate with a very cool thermal condition and was found to support sleeping while red was found to be perceived as very hot and correlated with active performances like exercising and sports.

9.0 Conclusions

The current study supports the theory that each and every colour is associated with a particular perceived temperature. TP of red, orange and yellow coloured slides were rated as warm and blue, green, purple slides were rated as cool while white room was rated to have an average TP. Red was found to have the highest TP and blue was found to trigger the lowest TP.

On the other hand, supporting the hypothesis, the study reveals a relationship between colour stimuli, thermal perception and preferred human activities. As mentioned above the responses to an imagined coloured room were considered as equal to the real experience of the same room in the current study. Human functions performed in aroused, active pace were preferred to be carried out in spaces with warm colours while calm and concentrated activities were preferred for spaces with cool colours. Since rating the thermal perception and the identification of preferred activities related to each colour were done

simultaneously a relationship between thermal perception and activity was also established as given below.

Colour	Thermal Perception	Activity Preferred to be performed
Red	Very Hot	Exercising, sports
Orange	Hot	Sports, exercising, dining,
Yellow	Hot	Dining, discussion
White	Average	Reading, drawing, meditation
Green	Cool	Relaxing, meditation
Purple	Cool	Sleeping
Blue	Very cool	Sleeping, relaxing

Table 2: Conclusion - Colour, Thermal Perception Vs Activity Table

The study investigated a particular functional value of colour, to enhance the thermal environment with the use of colour stimuli to support human performance in the built environment. The study established that activities like sports, exercising, dining, and discussion were preferred in a warm thermal environment and thus warm colours can be integrated to enhance such performances; Red and orange colours for sport and exercising , yellow for spaces where dining and warm discussions take place. In the other end the study claims that cool colours can be integrated in spaces for sleeping, relaxation and meditation. In conclusion colour is identified as a parameter pertaining to human's thermal environment. It is suggested to extend this investigation more precisely via controlling the personal variables (clothing insulation), considering different age groups, situational groups and increasing the sample size.

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Dissemination of Academic Research Knowledge to Construction Industry: Insights from Knowledge Management Literature

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Abstract

Academic research in built environment consists of cognitive, affective as well as behavioural components. Existing built environment research does not reveal many encouraging signs of changes in the way that the construction industry and construction research knowledge is exchanged. Different research dissemination mechanisms have at different performance levels in respect to the way they provided for outcome dissemination. However, the effectiveness and the efficiency are claimed to be relatively fewer and under-developed within the construction industry compared to other industries.

The PhD research on which this research paper is based aims to merge academic research with industry development requirements to build a better responsive construction industry. As a preliminary step, this paper reports on the literature findings on the theoretical background of the ways and means of academic research knowledge dissemination to the built environment. The paper also discusses some of the practical and philosophical issues that would need to be considered when transferring academic research to the built environment. In doing so, relevant literature is synthesized to provide a holistic picture of the current knowledge of research knowledge dissemination, by also bringing insights from knowledge transfer literature while highlighting significant gaps in specific areas such as 'academic research and outcome', 'dissemination to construction sector', 'of transfer' and 'pros and cons of the mechanisms' at this initial level of the research.

The paper considers upon the available research knowledge dissemination options in categories such as, write –ups of individual research, collections of written research, e- transfer, public awareness, research related gatherings, collaboration with government and collaboration with industry. Further it analyses the identified mechanisms with reference to their pros and cons in a way which a researcher can make an informed and sensible decisions as to how to proceed on delivering the profound outcome to the interested knowledge clients. The main dimensions of each mechanism are outlined through the synthesis upon merits and de-merits. The paper develops the argument that the use of a single mechanism often could fail in exploring the whole likely receiver base for a particular research outcome. The approach of using multiples is suggested to counteract this weakness and to enhance transfer of academic research knowledge dissemination into built environment.

Key Words: Academic Research, Construction Industry, Dissemination Mechanisms

1.0 Introduction

There are varieties of research produced ranging from more pure research to more applied research. Among these varieties, a broad consensus is present in the literature that successful communication between researchers and research users is crucial for the effective utilization of research in decision-making in policy and practice (Chandanie and Senaratne, 2012). Communication between these researchers, research funders and research users can happen in number of different ways (Alker, 2008). Further research can be used in a number of different contexts: knowledge (contributing to further research); practice; teaching; public policy; and societal. According to Marsh (2010), many are trying to highlight the need to review how research can be more effectively connected to real-world activity and policy setting. Therefore according to Chandanie and Senaratne, (2011), research programs should be judged not just by the quality and quantity of science produced, but by the industry impact and tangible benefit resulting from the research. The changes brought by research will be seen over a long period of time rather than immediately at some points. However, research should focus not only on how to overcome global challenges, but also how to improve individual industries.

Looking into the situation of the construction industry, there are few encouraging signs of changes to the way that construction industry and construction research knowledge exchange operates. In particular, the link between academic research and construction industry practice is under-developed (Abbott, Aouad and Madubuko, 2008). According to Chandanie and Senaratne (2012), despite the growing complaints that the construction industry is slow and less responsive towards innovation, many researchers and practitioners point out that the way forward for the industry is with effective adoption of innovation. In this regard, research institutions such as universities can play a significant role in conducting research that helps the construction industry to innovate (Blackman and Kennedy, 2009).

The wider research study aims to align academic research with construction industry development requirements. This paper is based on literature findings, which were required in order to fulfil one of the objectives of main study; that is to identify and analyse different research knowledge dissemination mechanisms which transfer research knowledge from research institutions to an industry. The paper highlights several research knowledge dissemination options. Further, it offers an analysis of these identified options, detailing their advantages and disadvantages in a way which a researcher would be helped in making sensible decisions upon dissemination mechanisms to deliver their research outcomes to the construction industry.

2.0 Knowledge Management insights

In the case of dissemination of research knowledge into an industry, it could be better understood through referring to knowledge management literature. This section tries to bring in some established knowledge management insights to help the argument of the researchers in finding proper solutions for the research question.

Universities have always recognised their role as the producers of knowledge through research. According to Blackman and Kennedy (2009), knowledge is complex, subtle and often difficult to recognise or capture while

being inextricably linked with communication. However, this has cemented a perspective on knowledge that is intricately entwined with notions of knowledge as output – codified, objective, and static and transferred through simple channels (Sizer, 2001 cited Blackman and Kennedy, 2009). Further Empson (2001 cited Senaratne and Sexton, 2008) identifies two perspectives of knowledge; 'knowledge as an asset' and 'knowledge as a process'. On the 'knowledge as an asset' perspective, knowledge is often viewed as an objectively definable commodity, which can be managed and controlled by certain mechanisms. For 'knowledge as a process' viewers, knowledge is a social construct, developed, transmitted and maintained in social situations. Knowledge dissemination is a sub process of knowledge management and it mainly refers to knowledge transfer to wider communities. Dissemination is the interactive process of communicating knowledge to targeted audiences so that it may be used in order to lead change. The challenge is to improve the accessibility of desired knowledge products by those they are intended to reach. This means ensuring the physical availability of the product to as large a proportion of the target audience as possible and making the product comprehensible to those who receive it (Ordoñez and Serrat, 2009). This has been further highlighted by Davenport and Prusak (1998, cited Senaratne *et al*, 2005), where effective knowledge transfer does not only involve mere transmission, but also absorption. As such, simply initiating the dissemination mechanisms is insufficient. The transfer needs to adopt an end-user perspective. Therefore researchers need to have a proper knowledge dissemination plan. The following section will discuss upon such processes.

3.0 Research Knowledge Dissemination Process

Alker (2008) has come up with the different stages at which, a research could reach in terms of its dissemination capacity.

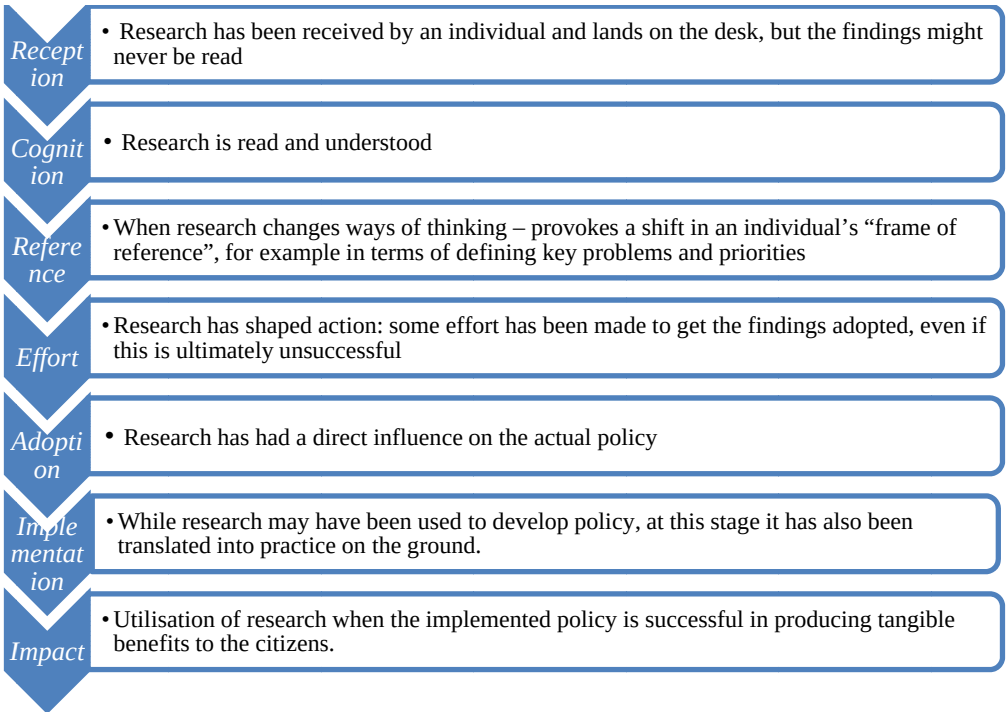

Figure 01 – Chain of utilization (Source: Alker, 2008)

According to Ordoñez and Serrat (2009), efforts to disseminate knowledge products are earnest; however the low impact is mainly attributable to poor planning and the absence of a proper dissemination strategy. In the construction context therefore not much of the research conducted is reaching the lower levels of the above chain.

Central to that is recognition that the dissemination process should be interactive, allowing feedback from audiences according to a cyclical model of communications flow. Therefore Alker (2008) has come up with another model called the pipeline model which explains the different stages of practitioners' use of research.

different communication channels at different stages and for different purposes. Therefore it is important to look in to available research knowledge dissemination mechanisms.

4.0 Dissemination Mechanisms

"Dissemination mechanisms" here are referred to the different media or types of outputs produced by a research programmes which have the potential to disseminate the knowledge beyond the initiators of the research. According to RD Direct (2009), a research communication strategy can comprise of active as well as passive dissemination activities.

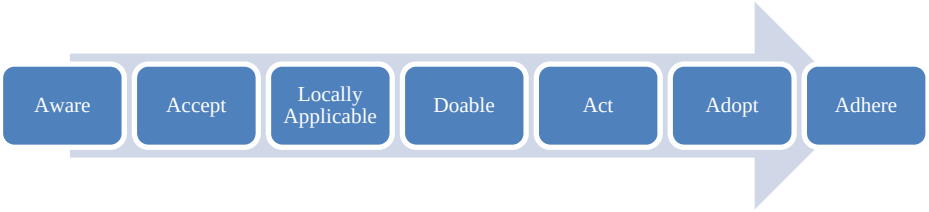

Figure 02 – Pipe line model (Source: Alker,2008)

The pipeline model suggests that research knowledge dissemination could be positioned at seven points starting from awareness to getting adhered to. In between some research outcomes reach the levels, acceptance, local application, accepted as practically feasible, gets in to action and the adoption. As you go deeper in the pipe the success is higher in terms of knowledge dissemination.

However, Alker (2008) has developed the models for water research knowledge dissemination to the particular industry. The situation may be little different in the construction context. However, this provides a good base to start developing such models for the construction industry.

It has to be kept in mind that dissemination can be effective through

Passive knowledge dissemination is mainly untargeted, including unplanned ad hoc forms of communication, or disseminating (explicit) knowledge through publications in academic journals. Active dissemination is characterised by tailoring research findings to a targeted audience and a dynamic flow of information from the source to increase the uptake of research in policy making. Table 1 below presents some of the common dissemination mechanisms used for research knowledge dissemination. Further, they are categorized into seven groups based on the way of initiation of dissemination mechanism for ease of reference. However, the suitability of each method in the construction context is yet to be established through a field survey that is due. Considering the paper length limits, this paper only presents in-depth

discussions upon above mechanisms based on the categories given.

4.1 Write –ups of individual research

Individual research write-ups are in different forms as indicated in the above table. A research report is a carefully structured write-up. It clearly states the purpose, findings and relevance of the research activity. A report may be written for a range of reasons and for a variety of audiences, therefore its length, style and detail tend to vary greatly (RD Direct, 2009). This is typically read by other researchers. The report provides evidence that the research was conducted soundly.

Working documents, manuals and various publications are also done based on individual researches. Publication is a common mechanism for knowledge dissemination used by many researchers. Further, there are some other mechanisms like brochures, flyers, drawings and presentations which are used to convey research findings. Maqsood, Walker and Finegan (2007) explain the worth of drawings and posters in terms of effective knowledge dissemination. It has been proven that the effect of drawing on memory performance is twice much as without drawing.

Table 01 – Knowledge dissemination mechanisms

Knowledge Dissemination Mechanism		**Research References**
Write-ups of individual research	Research reports	Alker, 2008 Aouad, Ozorhon and Abbott, 2010 Maqsood, Walker and Finegan, 2007 Marsh, 2010 Meek *et al*, 2009 Ordoñez and Serrat, 2009
	Working documents	
	Manuals	
	Publications	
	Others (Brochures, Flyers, Drawings and Posters)	
Collections of written research	Academic journals	Alker, 2008 Jain and Nfila, 2011 Ordoñez and Serrat, 2009
	Professional journals	
	Libraries	
E- transfer	Networking	Kanninen and Lemola, 2006 Ordoñez and Serrat, 2009
	Internet, intranet and electronic mail	
	Discussion forums	
	Video conferencing	
Public awareness	Promotional campaigns	Ordoñez and Serrat, 2009 Alker, 2008
	Press releases, TV, Radio	
Research related gatherings	Conferences	Alker, 2008 Aouad, Ozorhon and Abbott, 2010 Kanninen and Lemola, 2006 Ordoñez and Serrat, 2009 Ward, 2003
	Workshops and seminars	
	Training programmes	
	CPDs, Lectures and Demonstrations	
Collaboration with government	Participating in policy making and Policy Briefs	Alker, 2008 Aouad, Ozorhon and Abbott, 2010 Meek *et al,* 2009 Ordoñez and Serrat, 2009,
	Partnerships (Public-private, Strategic)	
	Official Reports	
Collaboration with industry	Contracts with industry	Alker, 2008 Aouad, Ozorhon and Abbott, 2010 Kanninen and Lemola, 2006 Meek *et al*, 2009 Ordoñez and Serrat, 2009 Wood, Beckmann and Birney, 2009
	Products, Services and Consulting	
	Knowledge brokers and Simulations	
	Entrepreneurships	
	Practitioners engage in research	

Individual research write-ups are strong in content however the problem in these mechanisms is that a greater focus is given to the research itself and not to the audience.

4.2 Collections of written research

Apart from individual write-ups, research outcomes are available in packs. Academic journals, professional journals and libraries would provide the opportunity to access to outcome of many researches at once.
There are number of publishers involved in research publications. For an example, Emerald, alongside other scholarly publishers, is an intermediary or "translator," capturing, evaluating, organising, and disseminating research output. The scholarly publishing process has been established for centuries and has successfully managed the process of highlighting important research to the wider world, and this has, in turn, contributed to the development of business, science, industry, and culture (Marsh, 2010). A few examples for major journals published by such publishers are; Construction Management and Economics, Engineering, Construction and Architectural Management, International Journal of Project Management, etc.

Moreover, Jain and Nfila (2011) state, libraries and information centres exist to provide access to all types of information, in all different formats, to all individuals to support teaching, learning, research, sharing of knowledge and skills, sharing of information in order to achieve participative democracy and national development.

4.3 E- transfer

E-transferring is a popular mechanism in knowledge dissemination. Networking allows groups of people of different skills, experience and backgrounds to work together closely without being hindered by the physical distance (Ordoñez and Serrat, 2009). E-mails, internet and intranet are peer to peer applications that allow users to communicate in a fast and effective manner. Discussion forums on the other hand are effective mechanism for capturing and sharing knowledge. Further, multi-media tools such as video conferencing support interactive meetings between knowledge deliverer and capturer.

4.4 Public awareness

The focus here is on 'dissemination' and interaction with the 'general public'. Activities as, open days, scientific fairs, involvement in general press and science journals for the public, involvement in the different media, construction of dissemination and interactive websites etc. can be used as effective mechanisms to disseminate knowledge. Besides these structural investments, some involve themselves in given social and cultural events like expos, urban development projects etc. (Meek, 2009).

4.5 Research related gatherings

Conferences, workshops, professional development gatherings of colleagues are events where participants are able to build on their own personal knowledge through the scientific knowledge that is being disseminated in a conference. At the same time it provides an excellent opportunity to further enhance knowledge being gained through socialisation with other experts and knowledge carriers attending the conference. The picture in Figure 03 is a pictorial representation of the related processes, the values and beliefs that usually exist in the organisation (Ward, 2003).

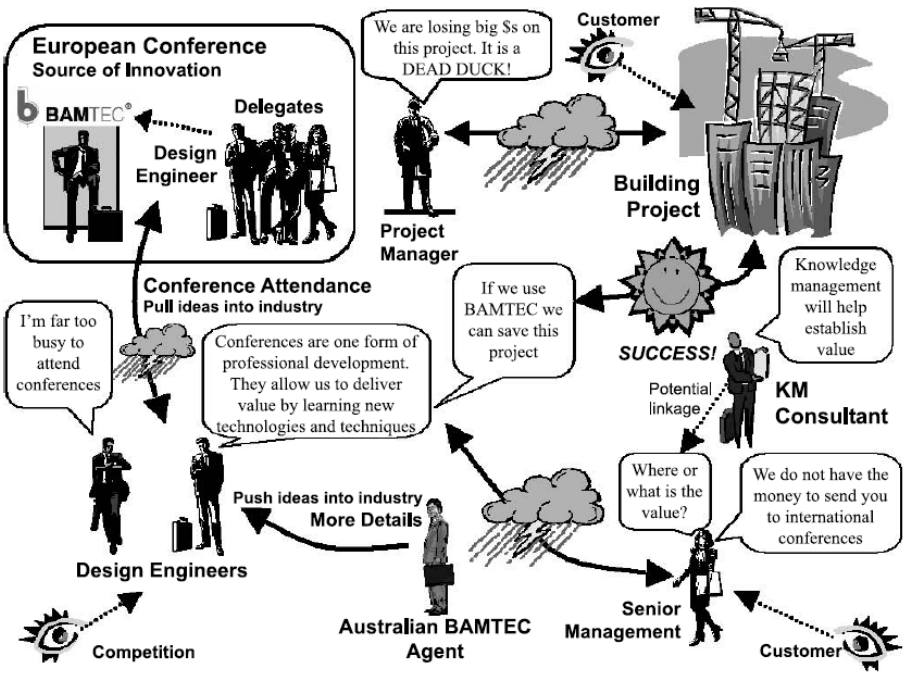

Figure 03 – Knowledge dissemination at conferences (Source: Ward, 2003)

Further, development and promotion of training in innovation as a discipline in its own right is also considered here under this category. Aouad, Ozorhon and Abbott, (2010), suggest familiarity and trust, established through training activities can lead to a better understanding of university capabilities and the consequent identification of a university as a partner in solving pressing business problems.

CPD has been defined by Madden and Mitchell (1993) as the maintenance and enhancement of knowledge expertise and competence of professionals, throughout their careers according to a plan formulated with regard to the needs of the professional, the employer, and society. Many managers belong to professional bodies which seek to encourage or require members to demonstrate evidence of CPD (Jones and Robinson, 1997).

4.6 Collaboration with government

The focus here is the 'public service' dimension of research activities. Meek (2009) suggests, it is important to complement contracts by non-market relations which are often critical in social and cultural dimensions.

Policy briefs, in the form of an executive summary of about five or six pages, are prepared for senior policy makers in Ministries. According to Postlethwaite (2005), these reports present the major findings succinctly and explain, in simple terms, the implications of the findings for future action and/ or policy.

The emergence of public-private research partnerships reflects a fundamental change in the way in which knowledge is generated and applied as well as the changes in approaches to the management of industrial research and development (Howard Partners, 2003 cited Meek, 2009). According to Beath and Siegel (2002 cited Meek, 2009), university-industry partnerships appear to accelerate technological diffusion. It seems that the quality of the relationships and the free flow of information, particularly tacit knowledge, are as important if not more so as the actual commercialization of a research product. Interactive partnerships are becoming

more the norm rather than simple contractual publications.

4.7 Collaboration with industry

Knowledge co-production and circulation to industry happens through contracts with the industry. Increasing the demand for university engagement should be the underpinning activity of an innovation platform (Aouad, Ozorhon and Abbott, 2010). However, several commentators have argued that a major drawback to greater commercialization of university research is the threat it poses to "open science" and academic freedom. However, there has been a growing trend for joint publications between university researchers and those based in industry and government, which appears to have actually increased the significance of the university researchers' contribution (Meek, 2009).

A knowledge broker is a person or a business that examines disseminated information and knowledge for clients and prepares usable, targeted synthesis for the client. They primarily engage in packaging research results to be easily understood by, and be applicable to decision-makers (Alker, 2008), and also perform the traditional task specific simulations focus on the development of domain specific knowledge. The set of new leadership simulations, however, aim at the development of greater levels of flexibility. That has direct implications for the effectiveness of simulations in training and development (Wood, Beckmann and Birney, 2009). This could be applied into the social research knowledge dissemination as well.

According to Aouad, Ozorhon and Abbott (2010) embedding researchers within companies as part of existing research activity is another method of universities engaging themselves within business contexts and problems. In this way, long-term collaboration is agreed with the recognition that the university and companies are strategic partners (Meek, 2009). Practitioners engaged in research transfer embodied knowledge in post graduate research activities to the industry through employment. This screens the transfer of competences trained through research to industry (Meek, 2009). Further, Jones and Robinson (1997) state the advantage of knowledge dissemination as an increasing recognition of the contribution which the effective management of human resources can make to enhance the competitive advantage of organizations.

As discussed above, there are a number of dissemination techniques available. But when selecting a dissemination mechanism by an individual researcher it would be better if one can have an overall picture upon the pros and cons of all possible methods. In support to that, Aouad, Ozorhon and Abbott (2010) have come up with mechanism illustrated below, which represents the university involvement ahead of company engagement for several methods. Strategic partnerships have been identified as the method which have the highest involvement from both sides while seminars and such gatherings are positioned at the very bottom.

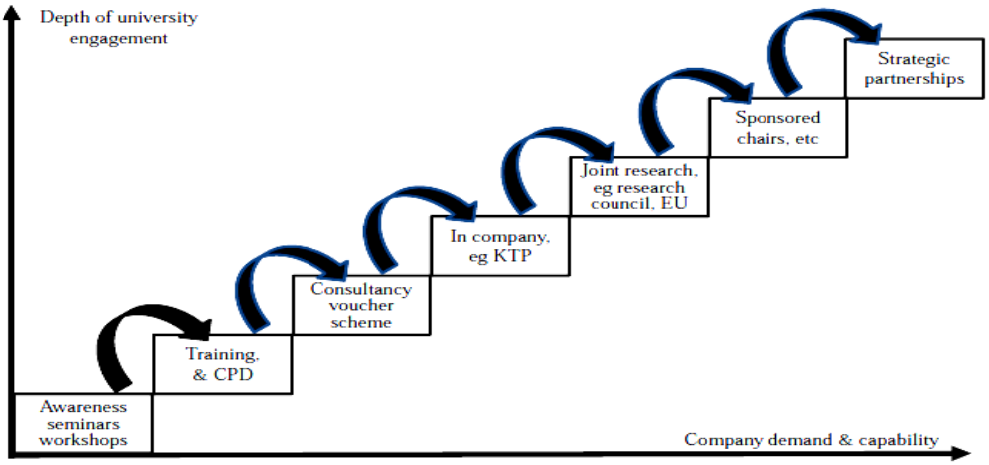

Figure 04 – University–industry involvements in knowledge dissemination mechanisms (Source: Abbott *et al,* 2010)

In this model, only seven mechanisms were considered However, there are many other parameters that need to be considered when an individual research is concerned in terms of effectiveness, cost, quality and time when selecting dissemination mechanisms. Therefore, the table below presents the pros and cons of the dissemination methods which were identified through the research.

Further, the table 03 below presents the pros and cons of each dissemination method by considering them individually.

Table 02 – Dissemination mechanisms: In time, cost quality perspectives

Mechanism	**Effectiveness**	**Time (Researcher's)**	**Time (Receiver's)**	**Cost (Researcher's)**	**Cost (Receiver's)**	**Quality**
Write –ups of individual research	Low	High	High	High	Medium	High
Collections of written research	Medium	Medium	Medium	Medium	High	Medium
E- transfer	High	Medium	Low	Low	Medium	Low
Public awareness	Medium	Medium	Low	Low	Low	Medium
Research related gatherings	Medium	Low	Low	Low	Medium	High
Collaboration with government	High	Medium	Medium	Low	High	High
Collaboration with industry	High	Medium	Medium	Low	High	High

Table 03 – Advantages and disadvantages of different knowledge transfer mechanisms

Mechanism	Advantages	Disadvantages
Write –ups of individual research		
Research report	• Provides a single reference point for all aspects of the research • Read by other researchers • Provides evidence that the research was conducted soundly • Easily understandable • Carefully structured • Clearly states the purpose, findings and relevance of research	• Assumes the report is read by a single audience group • May be written in an inaccessible manner • Not widely read by industry people
Working document	• May target research findings to particular groups	• Limited access
Manual	• Helps translate information into knowledge that can be applied	• Limited audience • Expensive
Publications	• Potential impact on a wide • audience • Potential to influence development of professionals • Highlights important research • Contributed to the development of business, science, industry, and culture	• Difficulty in accessing key texts in developing countries • Not practice oriented • Possibility of exaggerating or even falsifying research findings to get the work published
Write –ups of individual research		
Others (Brochures, Flyers, Drawings and Posters)	• High memory performance	• Needs lot of creativity
Collections of written research		
Academic, refereed journal	• Informs the scientific community of findings • Citations lead to wider impacts on intellectual networks	• Limited audience • May be written in an inaccessible manner • Lacks a practical orientation
Professional journal	• Reaches the wide practitioner • Community	• Academic rigor may be lower than that in a referred journal
Libraries	• Fulfils the intellectual requirements of the community • Provides access to information to all people without discrimination and censorship • Helps in generate sustained national development	• Time consuming

Mechanism	Advantages	Disadvantages
E- transfer		
Networking	• Reaches members who share common interests • Reduces "reinvention of the wheel" Potential for interaction, discussion and review of findings	• Typically low levels of active participation • Requires strong incentives for participation • Time consuming to operate and manage
Internet, intranet and electronic mail	• Immediate, convenient • Wide interest in electronic media	• Access to hardware may be limited in developing countries • Potential may be or is temporarily underdeveloped • Expensive
Discussion forums	• High impact	• Quality of knowledge is may be at question
Video conferencing	• High impact	• Difficulty in gaining access to decision makers • Limited access to hardware • Expense
Public awareness		
Promotional campaigns	• Reaches wide audiences	• Core message may be diluted or misinterpreted during the process of popularization
Press releases, TV, Radio	• Reaches wide audiences at relatively low cost	• No control over interpretation of Message • Difficult to manage the activity
Research related gatherings		
Conference, workshop, seminar	• May allow professionals to learn • More Potential for networking • Participants able to construct own personal knowledge • Translates research results into practical guidance at the community level	• Expense • Time consuming

Mechanism	Advantages	Disadvantages
Research related gatherings		
Training programmes	• Familiarity and trust, established through awareness raising • Leads to the better understanding of university capabilities • Identification of a university as a partner in solving pressing business problems	• Funding problems • Difficulties of creating the interest from industry
CPDs, lectures and demonstrations	• High impact • Identified by the industry • Can be recorded	• Limited audience • Absence of a coherent CPD policy
Collaboration with government		
Participating in policy making and Policy Briefs	• Potential to influence the decision making process • Reports the major findings succinctly • Explains implications of findings in simple terms	• Difficulty in gaining access to decision makers
Partnerships (Public-private, Strategic)	• Effective mechanism • No direct cost • Quality is high	• Time consuming
Official Reports	• Can create a high impact • Quality output	• Costly for the receiver • Tight time lines
Collaboration with industry		
Contracts with Industry	• Knowledge co-production and circulation to industry • Main marker of the attractiveness of universities • Complemented by a "soft" dimension	• Treats "open science" and academic freedom
Products, Services and Consulting	• Ensures that knowledge is translatable based on local norms • Improved flow of information and ideas • Closer collaboration between producer and user	Problems may arise if research agenda of intermediaries is not consistent with the knowledge product
Entrepreneurships	• Universities can emerge within business contexts and problems • Long-term collaboration is agreed	• Descriptors are needed to characterise university involvement and support

Mechanism	Advantages	Disadvantages
Collaboration with industry		
nowledge brokers and Simulations	• Prepares usable, targeted synthesis for client • Increased communication and engagement • Organizing and managing joint forums for policy-makers and researchers • Building relationship and trust • Setting agendas and common goals • Signalling mutual opportunities • Clarifying information needs • Commissioning synthesis of research of high policy relevance • Packaging research syntheses and facilitating access to evidence • Strengthening capacity for knowledge translation • Communicating and sharing advice • Monitoring impact and know-do gap • Development of domain specific knowledge • Flexibility in the application of knowledge	• Role to be played by those at question • Simulation is not much popular among social researchers as a dissemination mechanism
Practitioners engage in research	• Quality output	• Impact would be dependent upon the powers of the researcher • Time consuming • Costly for the researcher

Based on the above tabulated analysis upon each method it could be said that, in individual write-ups the content is high quality but the effectiveness in terms of dissemination is quite low. The collections of research work also provide a better arena for wider knowledge but are marginally high in terms of cost. E-transfer therefore is a good solution for that because of its low cost. However the quality of such outcomes sometimes can be at question. Public awareness mechanisms are another important mechanism to improve the knowledge of the wider community which would create paths for research funding. However, he low level of focus is the major disadvantage. Research related gatherings are strong in disseminating knowledge to an interested set of knowledge clients. But the lack of interest from industry people due to time and cost constrains hinders the effective dissemination. Collaborations with governments creates a direct access to involvement in decision making which can be identified as an important step in the effective use of knowledge. However, the opportunity is low, as research always takes much longer than politics would allow due to poor governance planning. Collaborations between academia and industry provide a good background conditions for dissemination of knowledge.

However, each method calls for its own format and means of dissemination and includes both proactive and reactive channels—that is, it includes information content that the target audiences have identified as important and information content that the audiences may not know how to request but is likely to be interest in. However, the dissemination techniques are more likely to succeed when packaging and information content is aligned with the target audience.

5.0 Research Knowledge Disseminating Strategy for Construction Industry

Dissemination is only achievable and successful if, from the outset, there is a shared vision and common understanding of what one wants to disseminate together with a way of describing that to those who stand to benefit from it (Ordoñez and Serrat, 2009). It is important to clearly identify the target audience and to map it to one of the categories in the awareness, understanding, and action to be taken. Since target audiences tend to be many, it is best to concentrate on whom, at the very least, needs to be informed, and then prioritize for awareness, understanding, and action. Next, it is essential to think about what benefits the knowledge product will offer. One must then examine the knowledge product and think of how it might be presented as a benefit and solution to users. Moreover, dissemination exercises have milestones that must be identified and set early. Further they must also be realistic.

Therefore it would be helpful to have a dissemination plan for any research from the beginning onwards. Ordoñez and Serrat (2009) have come up with some steps for such a plan as illustrated in the figure below.

Figure 05 – Steps for a dissemination plan

However the suitability of these steps need to be checked and improved for the Sri Lankan construction industry related research. Once the structure gets finalized it would be better to include it into initial academic research proposals. It would provide researchers an opportunity to think about knowledge dissemination at the early stages of the research. Further the table below provides some additional actions which could be taken to improve the level of knowledge dissemination between academia and industry.

Table 05 – Characteristics: For Successful Dissemination

Actions to be taken by Academia	**Actions to be taken by Industry**
Balance the characteristics such as teachability, complexity and specificity of research (Bogers, 2011)	Asking project managers to identify and report on innovation opportunities (Ward, 2003)
Improve trust upon research findings (Bogers, 2011)	Research use included in job-descriptions (Alker, 2008)
Using various dissemination techniques such as written, graphical, electronic, print, broadcast, and verbal media (Ordoñez and Serrat, 2009)	Involve senior management and make them aware of the benefits that external knowledge may bring to the organisation in order for them to budget (Ward, 2003)
Include summary documents (Ordoñez and Serrat, 2009)	Capacity building to access and use research (Alker, 2008)
Letters of thanks to study participants (Ordoñez and Serrat, 2009)	Use as a criterion for staff appraisal (Alker, 2008)
Newsletters to study participants (Ordoñez and Serrat, 2009)	Rewarding research-informed decision-making (Alker, 2008)
Effective quality control to ensure that the information content is accurate, relevant, representative, and timely (Ordoñez and Serrat, 2009)	Arrange a seminar or socialising event where employees returning from a conference with particular knowledge could share and transfer it to other employees (Ward, 2003)
	Framework to decide what are the important ideas and techniques to learn from a client's point of view and from an organisational point view that matches organisational strategy and vision (Ward, 2003)
	Devise selection criteria for rewarding employees by selecting deserving candidates for attending conferences (Ward, 2003)
	Publish, how new knowledge has contributed to improved performance at the personal and/or organisational level so that there is an explicit cause-and-effect link between being open to knowledge-pull and adopting an innovation (Ward, 2003)

However, the suitability and practicality of the above actions still to be checked for the Sri Lankan construction context. But once a proper dissemination is set it would draw on existing capabilities, resources, relationships, and networks to the maximum extent. It also builds the new capabilities, resources, relationships, and networks that the target audience needs. Further, the plan identifies the resources required for implementation. The plan provides a framework for monitoring and evaluation. It explains how one will know that dissemination activities have been successful. If data is to be gathered, it describes how this will be achieved, when, and who will gather it.

6.0 Summary

Academic research in built environment consists of cognitive and affective, as well as behavioural components. There is a broad consensus in the literature that successful communication between researchers and research users is crucial for the effective utilization of research in decision-making in policy and practice. It is argued that academic researchers and the construction industry practitioners do not collaborate closely in the construction sector. The need for sharing knowledge between research institutions and industry has become increasingly evident in recent years. Therefore researchers should look into knowledge management literature to understand the background of dissemination of research knowledge into industry. It was revealed that the efforts to disseminate knowledge products are earnest yet have a low impact due to poor planning and the absence of a dissemination strategy. Therefore the common dissemination mechanisms used for research knowledge dissemination were listed for better analysis. Further, they were categorized into seven groups based on the way of initiation of dissemination mechanism for ease of reference.

When selecting a dissemination mechanism by an individual researcher it would be better if one can have an overall picture of the pros and cons of all possible methods. Therefore the pros and cons of dissemination mechanisms were tabulated and discussed. Finally it was concluded that the dissemination techniques are more likely to succeed when used as packages and information content is aligned with the target audiences. Therefore it would be helpful to have a dissemination plan for any research from start. Further, some additional actions which could be taken to improve the level of knowledge dissemination between academia and industry were also suggested as strategic changes.

7.0 Way Forward

The focus of the PhD research which this paper was based on, therefore is on the merging of research and practice to create a better responsive construction industry in Sri Lanka. Proper research knowledge dissemination therefore will be the key in bridging the academia and industry. Thus merging research and practice is clearly the way forward .

Hence this research aims to explain how to merge academic research and industry development requirements to have a better responsive construction industry practice in Sri Lanka.

In order to achieve this aim, the objectives have been set as follows;

- Explain the nature of research undertaken by construction related academics in Sri Lanka.
- Explain the construction industry development requirements in Sri Lanka.
- Study the current link between academic research and industry practice with the reasons for existing gaps.

- Develop guidelines to merge academic research with industry development requirements.

The aim with these objectives will be explored through a "mixed research method." As Cresswell (2006) explains, its central premise is that the use of quantitative and qualitative approaches in combination provides a better understanding of research problems than one approach alone. Surveys will form a part of the mixed method which will be followed here, which is discussed by Fowler (2008) as a method with the purpose to produce statistics, that is, quantitative or numerical descriptions about some aspects of the study population. In order to meet the first two objectives therefore two opinion surveys will be carried out. According to Yin (1994), case study is an in-depth inquiry in its real setting that offers an explanation, exploration or description based on the case study actors, when the boundaries between the phenomenon and the context cannot be separated. Hence, a case study will be followed to achieve the third objective of the research together with an action research component. Based on the findings of the first three objectives, the final objective will achieved at the end. Data which are to be collected based on this mixed method will be analysed scientifically. Conclusions will be to be made thereafter with the use of findings and a guideline will be developed to direct researchers and practitioners to create a better responsive construction industry in Sri Lanka.

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Reflecting Regional Identity in Building Entrances: Reflections on the Emerging Trends in Institutional Gate Houses, Sri Lanka

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Abstract

Reflecting on emerging trends in the built environment is significant in understanding the past, present and future of the local and global aspects of human development. This paper focuses on gate houses in institutional buildings and explores the emerging trends in designing entrances and the underlying factors that forced their change along, with their contribution to regional identity.

The research adopted a qualitative methodology where data generated through a photographic survey and a literature survey were analysed to reflect some thoughts. Through the study four typologies in contemporary Sri Lankan entrances were identified. Reflections included that framing the entrance with a roof on top is a new trend and this is influenced by traditional structures in Sri Lanka, in response to the changing social, economic and cultural trends thus contributing to an authentic regional identity.

Keywords: Contemporary Trends, Regional Identity, Traditional Architecture, Entrance Gate Houses

1. Introduction

'Change' is nature. Everything in the universe is subjected to change. Socio-political, economic and environmental changes within a time frame cause the emergence of new trends. The built environment is always greatly influenced by these new trends as it is a mirror of its ambient society. In the contemporary world there is a trend to create a universal global uniformity through the concept of globalization. In this arena, Sustainable design, Green architecture, Bio-mimicry, Modular design, etc. are becoming the most popular concepts in contemporary architecture. Hence, there is a danger of producing monotonous built environments with no diversity or identity.

Further, cultural diversity and regional identity are also highly appreciated phenomena throughout the contemporary world. It would be true if said that the reason why humanity has survived this long is because of the diversity of languages and cultures. The built environment plays a vital role in reflecting cultural diversity and regional identity in any context. Therefore, all professionals involved in the construction sector are responsible to consciously react to the aforesaid aspects for the betterment of humanity.

Having come out of the thirty year civil war, Sri Lanka is heading towards rapid development in many spheres. Contributions made by the built environment in to this development are crucial and outstanding. There are a variety of trends that make an impact on

the regional identity of the country that could be identified amidst these fast growing built environments. In this context prominence obtained by architectural elements in the built environment are subjected to change. The entrance to a building premise is one such element that is facing such change. At present entrances are becoming prominent with elements such as; grand and solid gates/doors, gable roofs, green terraces on top, cement pots or water usage, etc. Further, they have become complex buildings with additional activities such as; guard room, ticketing out-let, waiting lobby, wash room, food outlet, etc. and are named as 'Gate Houses'. This change is mainly due to the aspirations of the people in the context. Thus it could be identified as a contemporary trend in Sri Lankan entrance designs.

2. Emerging trends in the contemporary built environment: Globalization vs. Regionalism

Among many trends found within contemporary built environments the emergence of regionalism, to counter the impacts of globalization depicts interesting developments.

According to Mostafa Eldemery (2009), the new millennium is confronting the tension between the forces of globalization, which has been widely debated as a distinguishing trend of the present moment, and its impact on local architecture and the efforts to ensure local identity and distinctiveness through architecture, where globalization is seen as a multidimensional phenomenon. Architects very often find themselves at the centre of two opposing forces existing as a result of contrasting past or present cultures and architectures, along with their attendant values and methods of expression.

The Encyclopaedia Britannica defines globalization as the process by which the experience of everyday life becomes standardized around the world. Therefore, theorists see it either as a necessary and positive vehicle of progress and diversity, or as a force of insipid homogenization and destruction.

The tension between anti-global and pro-global forces has long existed, with two opposing forces affecting architectural globalization. One force seeks to safeguard and promulgate established indigenous architectural traditions, forms, decorative motifs, and technologies. It advocates historical continuity, cultural diversity, and preservation of identity, all symbolized by a particular architectural vocabulary, just as spoken languages and local dialects impart identity. The other force promotes invention and dissemination of new forms using new technologies and materials in response to changing functional needs and sensibilities. For some, globalization entails the westernization of the world. Some see globalization as generating increasing homogeneity, while others see it producing diversity and heterogeneity through increased hybridization.

Since the built environment is a strong reflection of cultural diversity, architecture plays a major role in promoting regional identity against rapid globalization trends. Architects around the globe have attempted, through various mechanisms, to bring regionalism into architecture, understanding the criticality of losing an identity and trying to capture the true identity of a region that is inculcated deeply within a culture.

3. Regionalism

There is a fundamental relationship between formal attributes, experience of place, and regional identity. Architecture should be designed through the understanding of these relationships, which can be further divided into built form, natural form, social interaction, and cognitive processes. In this way an authentic sense of architecture and regional identity can be revealed.

In a broader sense regionalism could be achieved in two different ways; 'imposed regionalism' and 'authentic regionalism'. Imposed regionalism is achieved through the direct imitation of historic/ traditional elements and building forms (replicas). In Sri Lanka, soon after independence in 1948, nationalistic movements gave birth to a style called, 'pseudo-traditional style'. The buildings that emerged from this trend were replicas of historical buildings and reflected imposed regionalism. Independence Square in Colombo, Sri Lanka which is a concrete replica of the Kandyan Audience hall constructed during the 14th century B.C. is a fine example of such imposed regionalism.

Fig.5: Imposed regionalism: Independence Square, Colombo, Sri Lanka (Source: Author)

'Authentic regionalism' is not frozen in time. It involves a critical synthesis of a region's history and tradition and their reinterpretation and finally the expression of these in modern terms. One of the key characteristics of authentic regionalism is the way it attempts to revive and reinterpret local building traditions to achieve a synthesis with modern architectural forms. Curtis (1986) states, "at its best, regionalism penetrates to the generating principles and symbolic substructures of the past then transforms these into forms that are right for the changing social order of the present." For Buchanan (1983), regionalism "must be a genuine hybrid, a totally new configuration which may include a remembrance of the past, but transformed or framed in terms of its significance for today."

Frampton (1996) began his essay, 'Prospects for a Critical Regionalism', by identifying the resolution of tradition and modernity as the central paradox of our time. Advocates of regionalism promote the revival and reinterpretation of tradition as an oppositional strategy. For Frampton, regionalism offers "the sole possibility" of resisting the "universal Megalopolis", or that "ceaseless inundation of a place-less, alienating consumerism." Further it is believed that regionalism becomes a constant process of negotiation between the local and the global.

Amidst this ongoing debate between globalization and regionalism, and constant search to reflect regional identity through architecture, the architecture of people (without professional architects) seem to have a greater influence on main stream architectural styles in contemporary built

environments. This has generated more favour for the preservation and continuity of authentic regional identity.

4. Contemporary Trends in Sri Lankan Entrances

Inheriting a long history that runs over 2500 years, the native traditions found within the Sri Lankan context are numerous. Different architectural forms, settlements patterns as well as architectural elements that have risen within native traditions are found around the country. Among many elements in architecture that reflects strong regional traditions, entrances seem to show clear distinctive features in recent times.

The entrance trends have evolved due to various reasons: the historical model, socio- cultural needs, and as reflections of cultural identity. Combinations of these have given rise to entrances that reflect the regional identity as well.

4.1 Historical model

First impressions are important. Even if one cannot recall all the details of a house or garden that has been visited, it is likely one remembers its entrance. Entrances not only provide security and privacy for the interior activities, but also are considered to be transitional spaces that could influence the user's psychology and behaviour.

Eastern cultures seem to place a greater emphasis on entrances with deep philosophical meanings, than in western cultures. Ancient Sri Lankan entrances are fine examples of this emphasis.

Fig.6: (clockwise) Polonnaruwa Vatadage (11thC.AD), Sigiriya rock fortress (5th C.AD), Lankathilake vihara (14thC.AD), Yapahuwa fortress (12th C.AD).

Figure 6 shows ancient entrances from Sri Lanka, and all of them clearly indicate the prominence given to entrances by framing and highlighting them with ornamentation. Contemporary trends have been influenced by these traditional ornamentation and framing of entrances.

4.2 The roofed entrance of hospitality

Further, most traditional Sri Lankan entrances are roofed structures with a sense of intimacy. The roof is a prominent element in tropical climatic regions as it provides protection from harsh weather conditions such as sun, glare and rain. Therefore a roof at the entrance to a building or a building complex provides physical and psychological comfort and reflects hospitality towards the user. Most entrances with roofs are spacious structures that provide users with other facilities such as seating. These entrances are commonly referred to as 'gate houses'.

Fig.7: Entrance gate houses with roofs : (Clockwise) Natha Devale-Kandy(13th C.AD), Maha Saman Devale-Rathnapura(13th C.AD), Ambakke Devale-Kandy (14th C.AD),Lankathilake Vihara-Kandy(14th C.AD).

During the Colonial period (1505-1948), entrances in the Sri Lankan context underwent many changes reflecting many European styles such as Baroque, Rococo, etc. and were never roofed. The gate of the house called 'Lakshmigiri' at Alfred house estate; Colombo which was built in 1911 reflects Baroque style and resembles the gate at Buckingham palace, London.

Fig. 8:Lakshmigiri, Alfred house estate, Colombo.
(Source: Babara Sansoni, Architecture of an Island) and Buckingham palace, London (Source: Author)

Figure 8 and 9 are two examples of colonial influenced entrances without the roofed entrances of earlier times, but where contemporary trends are seen.

4.3 Changing socio-cultural needs

During the thirty year long civil war period (1980s to 2010) the socio-cultural, political and economical needs and aspirations of Sri Lankan people changed drastically, causing many changes to the entrance designs. Generally there was a greater need for a sense of security. As a response to these needs, new entrance trends reflected entrances with an enclosed introverted character.

5. Typologies in contemporary Sri Lankan entrances

Domestic entrances display trends contributing to the regional identity as well. Even though occupants were not keen on reflecting an identity through the house, the entrance was given prominence which reflected the sense of a gate house.

The gatehouses also differ in type and four distinct entrance types were identified: (1) the roofed entrance (2) framed entrance (3) planted entrance (4) gate and porch entrance.

5.1 The roofed entrance

These types of entrances are commonly found with a small roof above entrance gate or door. The roof is constructed with various materials in various forms.

Figure 10: domestic roofed entrances

5.2 Framed entrance

In urban settings where these entrances are commonly found, the entrance is framed within the boundary wall. Sometimes the smaller entrance is recessed with a steel grill gate and timer door.

Figure 11: domestic framed entrances

5.3 Planted entrance

This is an entrance where the roof is planted with flowering plants. Sometimes even pots are kept on top of the entrance. The most commonly found type is the framed entrance with flowers on top.

Figure 12: domestic planted entrances

5.4 Gate and Porch entrance

This type of entrance is a modification to the old type two sashes or sliding gate with a porch or garage built within the garden. These are done in such a way that when taken as a whole the entrance looks as if it is a roofed entrance.

Figure 13: domestic gate and porch entrances

6. Case studies-institutional Gate Houses, Sri Lanka

The four domestic types have influenced the emerging gate houses in institutional buildings and they seem to incorporate these features at a larger scale. Apart from merely being the gate, many gate houses also serve the purpose of security lodging and information counter as well. In addition to the four domestic types identified, institutional gate houses also have another tower type gate house where the entrance is demarcated by two towers on either side of the gate. This is not the usual gate post but a larger tower with a roof.

The domestic entrance types that emerged as a trend are now being adopted by institutions to make a clear mark of their contribution to the regional identity. They also reflect the historical form of the entrance, giving one a sense of Sri Lankan traditional architecture which could rightfully provide the roots for a regionally identity. When looking through older buildings it is commonly found that, the earlier type of the gate entrance had smaller gate posts or no gate posts at all.

Figure 14: older institutional entrances

6.1 Roofed entrance

Roofed entrances are done at a larger scale and with varying styles. In many instances, other services are also included within the gatehouse complex.

Figure 15: Institutional roofed entrances

6.2 Framed entrance

Framed entrances are the commonly used to give dominance to the entrance.

Figure 16: Institutional framed entrances

6.3 Planted entrance

These types of entrances are not commonly found within entry points, but are found in complexes where the security post is situated. However the entry points into the southern expressway have been influenced by this type of entrances.

Figure 17: Institutional planted entrances

6.4 Gate and porch entrance

Again, these types of entrances are not commonly found since entrances into institutions are at a wider scale and therefore it is not practical to have a porch inside.

Figure 18: institutional gate and porch entrances

6.5 Tower entrance

These types of entrances comprise of two separate towers where sometimes the security is enclosed within the tower.

Figure 19: Instuttional tower gates

7. Concluding Remarks

In a time where many regions, countries, cities, and individuals are seeking for an identity lost to the homogenising forces of globalization, a contribution from a trend within the community becomes precious.

These entrance trends have captured the historical model as well as reflect the changing socio economic conditions. Further they are trying to preserve the cultural identity of a nation rich in hospitality.

The adoption of a similar trend within institutional gate houses becomes important in consecrating it as a regional element in the built environment. This is a positive trend that must be nurtured and developed so that our entrances reflect a sense of a different architectural style rooted within our historical forms.

These trends are quite different from the post-independence movements, where we were borrowing elements from history, whereas in this modern trend the social needs have created these unique elements. Historically houses were built with open verandas with an extroverted character. But due to changing social conditions and as there is a greater need for security, modern houses have become introverted and enclosed. However, the entrance has become a key element in communicating and reflecting an identity that could become a regionally salient element.

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Evaluation of Critical Success Factors for Road Construction Projects in Sri Lanka

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Abstract

A construction project is commonly acknowledged as successful when it is completed on time, within budget, and in accordance with specifications and to the stakeholders' satisfaction. However, outside the control of the management, there are many factors which could determine the success or failure of a project. Search for the factors influencing project success is not new in management studies particularly, in the domain of construction and project management. The last two and half decades have witnessed a drastic increase in "critical success factors" (CSFs) research. However, there is no such study on the implementation of CSFs in road construction projects in Sri Lanka.

Massive infrastructure development drives have contributed to the economic growth of Sri Lanka since 2010.The Sri Lankan transportation sector has been identified as a priority by the government of Sri Lanka with major road development projects. However, road projects in Sri Lanka have time and cost overruns and are exposed to risk frequently. Therefore it is essential to improve the success of road projects in Sri Lanka.

This research paper was focused on identifying critical success factors and establishing the most important CSFs for different project phases in the road construction project life cycle. The research problem was approached through an expert survey and a questionnaire survey conducted among the professionals in the road construction sector in Sri Lanka.

The findings revealed all the factors found through the literature survey are relevant to Sri Lankan road construction projects. Further the study established the most important CSFs in each phase of the construction project life cycle of road construction projects in Sri Lanka. This will be useful and aid the Sri Lankan road construction projects towards successful completion.

Key words: Critical Success Factors, Road Construction Projects, Project Life Cycle Phases

Introduction

A project is an achievement of specific objectives, which involves a series of activities and tasks which consume resources within a set of specifications, having definite start and end dates(Munns and Bjeirmi, 1996).Generally, there is no consistent interpretation of the term project success (Baccarini, 1999 cited Ahadzie *et al.,* 2008). In fact, the definition of success is so broad that its meaning differs from one specific branch of science to another. Thus, success is not easily defined or determined (Shokri-Ghasabeh and Kavousi-Chabok, 2009). The focus of most studies of project success is on dimensions of project success (how to measure it) and factors

influencing project success (Wang and Huang, 2006).Outside the control of the management, there are many factors which could determine the success or failure of a project (Belassi and Tukel, 1996).

Search for the factors influencing project success is not new in management studies. Since 1960, various studies have been conducted to explore the really important factors that need to be considered to achieve project success (Cooke-Davies, 2002; Fortune and White, 2006).Belassi and Tukel (1996) pointed out that the success and failure factors were first introduced by Rubin and Seeling in 1967. Rockart (1982 cited Fortune and White, 2006; Koutsikouri *et al.,* 2008; Sanvido *et al.,* 1992; Toor and Ogunlana, 2009) were the first to use the term "critical success factors". The construction industry is considered to be one of the most important industries in the economy. In any modern economy, infrastructure plays a pivotal role often decisive enough in determining the overall productivity and development of a country's economy (Mody, 1997 cited Sharma and Vohra, 2009). In the infrastructure sector, roads play a major role and as such it is the forerunner to all other developments. It is also the backbone of the transport sector of the country (Ministry of highways Sri Lanka, 2010).

However, according to Perera (2006), 80% of road projects in Sri Lanka have time and cost overruns and are exposed to risk frequently. These factors can highly affect the success of road projects and the country's economic growth. Therefore it is essential to improve the success of road projects in Sri Lanka in order to achieve the economic targets of the country.The aim of this paper is to evaluate the implementation of **Critical Success Factors (CSFs) for projects** in the Sri Lankan **Road Construction Sector**.

Project Success

Traditionally, measures of project success reflect three aspects of the "triple constraint" or "iron triangle": cost, time, and quality/ performance and those dimensions are still considered central to measuring project success (Atkinson, 1999 cited Papke-Shields *et al.*, 2010). (Figure 1)

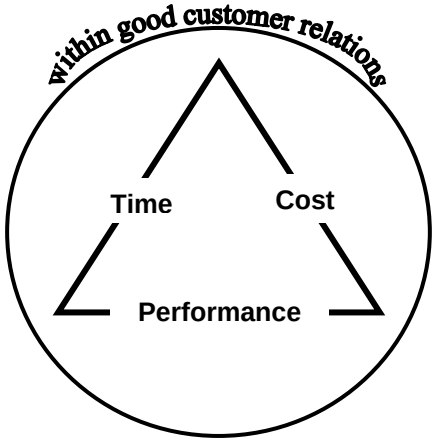

Figure 1: Project success triple constrains
(Source: Kerzner, 2001, p.5)

Kerzner (2000) illustrated how the definition of project success was changed according to traditional and modern project management as illustrated below;

Table 1: Definitions of project success *(Source: Kerzner, 2000, p.162)*

Traditional Project Management	Renaissance period	Modern Project Management
Technical terms only	Time, cost, performance (quality, technical)	Time, cost, performance and accepted by the customer

Ashley (1987cited Sanvido *et al.* 1992) referred that project success results were much better than expected or normally observed in terms of cost, schedule, quality, safety, and participant satisfaction. However, Shenhar *et al.* (1997) explained that project success is meaningful only if considered from two vantage points: the degree to which the project's technical performance objective was attained on time and within budget; the contribution that the project made to the strategic mission of the enterprise. According to Kerzner (2001), the definition of project success as "the completion of an activity within the constraints of the time, cost and performance", has pertained for the past twenty years, thus the definition of project success should be modified to include completion:

- Within the allocated time period
- Within the budgeted cost
- At the proper performance or specification level
- With acceptance by the customer or user
- When the customer's name can be used as reference
- With minimum or mutually agreed upon scope changes
- Without disturbing the main work flow of the organization
- Without changing corporate culture.

Construction Project Success

According Chua *et al.* (1999), it is generally accepted that the major goals in a construction project are budget, schedule and quality, although there are other more specific objectives, such as safety consideration and market entry, depending on the nature of the project and company. Therefore achieving those objectives leads to project success. Toor and Ogunlana (2009) explained that success of a construction project can be considered as achievement of specific objectives through project management system that involves a series of activities and tasks which consume resources.

Success in Road Construction Projects

Kaliba *et al.,* (2009) mentioned that in developing economies much of the national budget on infrastructure development is channelled to road construction projects as a major component of the construction industry. Ministry of Highways Sri Lanka (2010) mentioned that it is imperative that the road sector organizations should be properly coordinated, developed and maintained at an optimal cost and conform to planned schedule, in order to achieve an effective transport system, which meets the development aspirations of the people of this country. Hence, road construction project success can be basically viewed as completing the activity in a properly coordinated, developed and maintained way at an optimal cost and conforming to planned schedule and specifications.
However, Ahadzie *et al.* (2008) mentioned that within the last decade that there was an increasing number of research undertaken towards identifying success criteria within the construction industry in developing countries and the

key significance of those studies lie in their systematic contribution towards developing an understanding of the overall success model. Furthermore Koutsikouri *et al.* (2008) stated that in recent years, researchers in construction and construction project management have become increasingly interested in critical success/failure factors. Hence, in order to further illustrate on the concept of project success criteria and factors it is necessary to proceed with the research.

Project Success Criteria and Critical Success Factors

As mentioned by Wang and Huang (2006), the focus of most studies of project success is on dimensions of project success (or how to measure it) and factors influencing project success. Thus the literature related to 'project success' provides evidence that, most of the researches have touched the concepts of both 'project success criteria and success factors' (Andersen *et al.*, 2006;Cooke-Davies, 2002; Frodell *et al.*, 2008; Lim and Mohamed, 1999; Nguyen *et al.*, 2004; Sanvido *et al.*, 1992; Shokri-Ghasabeh and Kavousi-Chabok, 2009; Westerveld, 2003).

According to the Concise English Dictionary, Lim and Mohamed (1999, p.243) explained a criterion as 'a principle or standard by which anything is or can be judged'; whereas a factor is described as 'any circumstance, fact, or influence which contribute to a result'. Furthermore Cooke-Davies, (2002) stated that it is important to distinguish project success criteria and success factors.

As per Lim and Mohamed (1999) the criteria of project success is the set of principles or standards by which project success is or can be judged and those are the conditions on which judgement can be made. Sanvido (1992) declared that the success criteria related to a building often changes from project to project depending on participants, scope of services, project size, sophistication of the owner related to the design of facilities, technological implications, and a variety of other factors. However, as mentioned by Andersen (2006), expanding the success criteria as the concept overall project success indicates will necessarily postpone the final judgement on the project. The performance on some of these success criteria will be finally decided months or years after the termination of the project.

Westerveld, (2003) stated that project success factors are the levers that project managers can pull to increase the likelihood of achieving a successful outcome for their project. According to Leidecker and Bruno (1984 cited Milosevic and Patanakul, 2005) 'Critical success factors' can be described as characteristics, conditions, or variables that can have a significant impact on the success of the project when properly sustained, maintained, or managed. Rockart (1979 cited Nguyen *et al.*, 2004) defined CSFs as those few key areas of activity in which favourable results are absolutely necessary for a particular manager to reach his or her goals. Within a project context, CSFs can be described as the factors that a manager needs to take into account in order to achieve a successful delivery (Koutsikouri*et al.*, 2008).

Many researchers have conducted their studies based on CSFs in general construction projects (Chua *et al.,* 1999; Savindo *et al.,* 1992), design and build projects (Chan *et al.,* 2001), public-private-partnerships or Build Operate Transfer (BOT) projects (Tiong*et al.,* 1992), urban regeneration projects (Yu and Kwon, 2011), large scale construction projects (Nguyen*et al.,* 2004; Toor and Ogunlana, 2009), collaborative multi-disciplinary design projects (Koutsikouri *et al.,* 2008) and various other project management topics (Chua

et al., 1997; Cooke-Davies, 2002;Fortune and White, 2006).

Exhaustive lists of success factors have been introduced, which vary from less than 10 to over 60 factors. Although different researches emphasized different sets of success factors, Toor and Ogunlana (2008 and 2009) observed that most studies on CSFs for construction projects are context specific. According to Fortune and White (2006), many authors have published lists of factors, sometimes relating them to specific problem domains and types of activity. Therefore, the specific implications of studies on success factors are limited to the countries and cultures where these studies have been conducted.

As a result of the substantial review of the literature, the researcher identified following CSFs tabulated in Table 2.

Table 2: CSFs identified through the literature survey

CSFs	Reference
1. Top management support	Belassi and Tukel (1999); Fortune and White (2006); Locke (1984 cited Belassi and Tukel 1999); Martin (1976 cited Belassi and Tukel 1999); Nguyen *et al.* (2004); Pinto and Prescott (1988 cited Belout and Gauvreau 2004); Toor and Ogunlana (2008)
2. Clear objectives and scope	Baker *et al.*(1983 cited Belassi and Tukel 1999); Chua *et al.*, 1999; Fortune and White (2006); Koutsikouri*et al.* (2008); Martin (1976 cited Belassi and Tukel 1999); Nguyen *et al.* (2004); Toor and Ogunlana (2008);
3. Competency of project manager	Belassi and Tukel (1999); Fortune and White (2006); Koutsikouri*et al.* (2008); Locke (1984 cited Belassi and Tukel 1999); Nguyen *et al.* (2004); Toor and Ogunlana (2009);
4. Adequate funding throughout the project	Baker *et al.*(1983 cited Belassi and Tukel 1999); Fortune and White (2006); Nguyen *et al.* (2004)
5. Sufficient well allocated resources	Belassi and Tukel (1999); Fortune and White (2006); Koutsikouri*et al.* (2008); Martin (1976 cited Belassi and Tukel 1999); Nguyen *et al.* (2004); Toor and Ogunlana (2009)
6. Multidisciplinary/competent project team	Fortune and White (2006); Nguyen *et al.* (2004); Pinto and Prescott (1988 cited Belout and Gauvreau 2004); Toor and Ogunlana (2009);
7. Commitment to project	Baker *et al.*(1983 cited Belassi and Tukel 1999); Belassi and Tukel (1999); Chan *et al.*(2001); Locke (1984 cited Belassi and Tukel 1999); Nguyen *et al.* (2004);
8. Timely, valuable information from different parties	Nguyen *et al.* (2004)
9. Awarding bids to the right designer/ contractor	Nguyen *et al.* (2004); Toor and Ogunlana (2009);
10. Accurate initial cost estimates	Baker *et al.*(1983 cited Belassi and Tukel 1999); Belassi and Tukel (1999); Nguyen *et al.* (2004); Toor and Ogunlana(2009);

Table 2 (cont…): CSFs identified through the literature survey

CSFs	Reference
11. Absence of bureaucracy	Baker *et al.*(1983 cited Belassi and Tukel 1999); Nguyen *et al.* (2004); Toor and Ogunlana (2009);
12. Comprehensive contract documentation	Nguyen *et al.* (2004); Toor and Ogunlana (2009);
13. Effective project planning, control and monitoring	Baker *et al.*(1983 cited Belassi and Tukel 1999); Fortune and White (2006); Locke (1984 cited Belassi and Tukel 1999); Nguyen *et al.* (2004); Toor and Ogunlana (2009);
14. Continuing involvement of stakeholders in project	Nguyen *et al.* (2004); Yu and Kwon (2011)
15. Effective strategic planning	Nguyen *et al.* (2004)
16. Up to date technology utilization	Fortune and White (2006); Koutsikouri*et al.* (2008); Nguyen *et al.* (2004); Toor and Ogunlana (2009);
17. Proper emphasis on past experience	Fortune and White (2006); Nguyen *et al.* (2004); Toor and Ogunlana (2009);
18. Frequent progress meeting	Koutsikouri*et al.* (2008); Locke (1984 cited Belassi and Tukel 1999); Nguyen *et al.* (2004); Toor and Ogunlana (2009); Yu and Kwon (2011)
19. Clear information, communication and coordination channels	Belassi and Tukel (1999); Fortune and White (2006); Locke (1984 cited Belassi and Tukel 1999); Martin (1976 cited Belassi and Tukel 1999); Nguyen *et al.* (2004); Pinto and Prescott (1988 cited Belout and Gauvreau 2004); Toor and Ogunlana (2009); Yu and Kwon (2011)
20. Community involvement	Chan *et al.*(2001); Nguyen *et al.* (2004);
21. Client consultation and responsiveness	Belassi and Tukel (1999); Fortune and White (2006); Pinto and Prescott (1988 cited Belout and Gauvreau 2004); Toor and Ogunlana (2009);
22. Political stability	Belassi and Tukel (1999); Fortune and White (2006);
23. High quality workmanship	Chan *et al.*(2001); Koutsikouri*et al.* (2008); Toor and Ogunlana (2009);
24. Fast trouble-shooting capabilities in the system	Pinto and Prescott (1988 cited Belout and Gauvreau 2004); Toor and Ogunlana (2009);
25. Standard software infrastructure and adequate use of IT	Toor and Ogunlana (2009);
26. Proper dispute resolution clauses incorporated in the contract	Toor and Ogunlana (2009);
27. Developing positive friendly relationship with project stakeholders	Toor and Ogunlana (2009); Yu and Kwon (2011)
28. Client acceptance of plans	Pinto and Prescott (1988 cited Belout and Gauvreau 2004); Toor and Ogunlana (2009);

Table 2 (cont..): CSFs identified through the literature survey

CSFs	Reference
29. Strong/ detailed plan kept up to date	Fortune and White (2006); Martin (1976 cited Belassi and Tukel 1999); Pinto and Prescott (1988 cited Belout and Gauvreau 2004); Toor and Ogunlana (2009); Yu and Kwon (2011)
30. Effective change management	Fortune and White (2006); Koutsikouri *et al.* (2008); Toor and Ogunlana (2009)
31. Defined roles and responsibilities	Koutsikouri*et al.* (2008); Martin (1976 cited Belassi and Tukel 1999); Toor and Ogunlana (2009); Yu and Kwon (2011)
32. Risk and liability assessment	Chua *et al.*, 1999; Fortune and White (2006);

Research Methodology

In order to achieve the ultimate aim of this study, a quantitative research approach was determined to be the most appropriate method for gathering and analysing data. As the first step a literature review was carried out in order to define the project success and identify the CSFs recognized by the previous researchers. An expert survey was conducted as the subsequent step, to identify the CSFs relevant to Sri Lankan road construction industry to identify the importance of CSFs in each phase of the road construction project life cycle, based on a questionnaire which targeted experts with more than ten years experiences in the road construction sector. Questionnaires were distributed among 18 professionals in the Sri Lankan road construction sector who have more than ten years experience in the industry. Out of 18 distributed questionnaires only 15 were collected. The response rate for the expert survey was 83.33%. The Relative Important Index (RII) technique was used to analyse the data collected through the expert survey in order to identify the most relevant CSFs to Sri Lankan road construction projects.

Data Analysis and Research Findings:

Expert Survey Analysis I: Identification Of CSfs Relevant to Sri Lankan Road Construction Projects

To elicit the relevance of the CSFs identified through the literature review to Sri Lankan road projects, as the first part of the expert survey, the respondents were given a questionnaire to rate the identified CSFs against the five-point Likert scale, form "not relevant" (0) to "extremely high relevant" (4). Moreover the respondents were advised to mention any other factors which should be added to the list.

Based on the data collected through the expert survey all the CSFs identified through the literature review were ranked using the RII formula. The following Table 3 illustrates the results.

Table 3: Relevance of CSFs to Sri Lankan road construction projects

Critical Success Factors	RII (%)	Rank	Critical Success Factors	RII (%)	Rank
Clear objectives and scope	100.00	1	Absence of bureaucracy	76.67	17
Competency of project manager	98.33	2	Client acceptance of plans	76.67	17
Top management support	96.67	3	Continuing involvement of stakeholders in project	75.00	19
Adequate funding throughout the project	93.33	4	Frequent progress meeting	75.00	19
Commitment to project	91.67	5	Developing positive friendly relationship with project stakeholders	75.00	19
Sufficient well allocated resources	90.00	6	Up to date technology utilization	73.33	22
Effective project planning, control and monitoring	88.33	7	Political stability	73.33	22
Clear information, communication and coordination channels	86.67	8	Proper dispute resolution clauses incorporated in the contract	70.00	24
High quality workmanship	86.67	8	Client consultation and responsiveness	68.33	25
Defined roles and responsibilities	86.67	8	Fast trouble-shooting capabilities in the system	68.33	25
Multidisciplinary/competent project team	85.00	11	Strong/ detailed plan kept up to date	66.67	27
Awarding bids to the right designer/ contractor	85.00	11	Effective strategic planning	65.00	28
Comprehensive contract documentation	83.33	13	Standard software infrastructure and adequate use of IT	65.00	28
Proper emphasis on past experience	83.33	13	Risk and liability assessment	61.67	30
Accurate initial cost estimates	81.67	15	Community involvement	58.33	31
Timely, valuable information from different parties	78.33	16	Effective change management	51.67	32

As per the data analysis of the expert survey the factor "Clear objectives and scope" was top ranked among the 32 factors in the relevancy rating with a relative importance of 100%, which indicates that all the respondents of the expert survey have identified that as an 'extremely high relevant' factor to Sri

Lankan road construction projects. Moreover the factors, competency of project manager, top management support, adequate funding throughout the project, commitment to project, sufficient well allocated resources, effective project planning, control and monitoring, clear information, communication and coordination channels, high quality workmanship and defined roles and responsibilities were ranked as the top most relevant factors. The factor "Effective change management" which gained relative importance of 51.67% was ranked lowest. However when considering the result of Table 3, none of the factors could be identified as not relevant to Sri Lankan road construction projects. Further, none of the respondents identified additional factors.

Expert survey analysis II: Identification of the importance of CSFs in each phase of construction life cycle of road construction projects

As the second part of the expert survey, expert opinion on the importance of CSFs in each phase of the construction life cycle of road construction projects in Sri Lanka was observed. Basically six phases namely, 'conceptual stage', 'planning stage', 'design stage', 'tender stage', 'construction stage' and 'operational stage' were considered and the respondents were advised to rate the CSFs against these phases based on the five-point Likert scale, form "not important" (0) to "very highly important" (4). Based on the data collected through the expert survey, the CSFs were ranked using the RII formula under each of the identified stages of the construction life cycle. The following Table 4 illustrates the summary of most important factors (top ten ranked) in all six phases and it visualizes how the importance of factors changes at different phases.

According to the results the factor "Clear objectives and scope" was ranked as the most important factor in "conceptual", "planning" and "design" stages. Nevertheless in "tendering stage" the factor "Awarding bids to the right designer/ contractor" was the most important factor and when it comes to "construction stage", the factor "Competency of project manager" was top ranked. According to the experts' opinions in "operational stage" the factor "Adequate funding" was top ranked.

The findings revealed that for a successful project, in the earlier stages it is most important to have a firm and defined direction or aim and acquaintance of the project scope. Better selection of the appropriate designer/ contractor is very important in the tender stage. In construction stage proper coordination, monitoring and leadership of the project manager is most essential and in the operational stage having adequate funding is considered as more essential.

Table 4 Most important CSFs for different project phases in road construction project life cycle

Rank	Conceptual Stage	Planning Stage	Design Stage	Tender Stage	Construction Stage	Operational Stage
1	**1.** Clear objectives and scope			**1.** Awarding bids to the right designer/ contractor	**1.** Competency of project manager	**1.** Adequate funding
2	**2.** Top management support	**2.** Client acceptance of plans		**2.** Comprehensive contract documentation	**2.** Commitment to project	**2.** Political stability
3	**3.** Client acceptance of plans	**3.** Top management support	**3.** Multidisciplinary/ competent project team	**2.** Accurate initial cost estimates	**3.** Effective project planning, control and monitoring	**3.** Commitment to project
4	**4.** Multidisciplinary/competent project team		**4.** Defined roles and responsibilities	**4.** Proper emphasis on past experience	**4.** Adequate funding	**4.** High quality workmanship
5	**5.** Proper emphasis on past experience	**5.** Client consultation and responsiveness	**5.** Timely, valuable information from different parties	**5.** Top management support	**4.** High quality workmanship	**5.** Client consultation and responsiveness
6	**5.** Client consultation and responsiveness	**6.** Timely, valuable information from different parties	**5.** Commitment to project	**6.** Commitment to project	**6.** Defined roles and responsibilities	**5.** Defined roles and responsibilities
7	**5.** Risk and liability assessment	**6.** Clear information, communication and coordination channels	**7.** Clear information, communication and coordination channels	**7.** Proper dispute resolution clauses incorporated in the contract	**6.** Proper emphasis on past experience	**7.** Sufficient well allocated resources
8	**8.** Clear information, communication and coordination channels	**8.** Competency of project manager	**8.** Risk and liability assessment	**7.** Timely, valuable information from different parties	**8.** Multidisciplinary/ competent project team	**7.** Proper emphasis on past experience
9	**9.** Political stability	**9.** Absence of bureaucracy	**8.** Proper emphasis on past experience	**7.** Clear information, communication and coordination channels	**8.** Frequent progress meeting	**9.** Competency of project manager
10	**10.** Timely, valuable information from different parties	**9.** Proper emphasis on past experience	**10.** Client consultation and responsiveness	**10.** Defined roles and responsibilities	**8.** Fast trouble-shooting capabilities in the system	**10.** Fast trouble-shooting capabilities in the system
				10. Clear objectives and scope	**8.** Sufficient well allocated resources	**10.** Risk and liability assessment

Conclusions

Completion of construction project on time, within budget, and in accordance with specifications and to the stakeholders' satisfaction is commonly acknowledged as a successful completion of a project. There are many factors which could determine the success or failure of a project and those factors vary based on different aspects such as project type, countries and cultures where these studies have been conducted. This research study is mainly based on CSFs for Sri Lankan road construction projects.

From the literature survey it was found that no research studies have been conducted based on CSFs for road construction projects in Sri Lanka. Therefore firstly the CSFs relevant to Sri Lankan Road construction projects needed to be identified. Hence an expert survey was conducted among the experts in the industry using the thirty two CSFs identified through the literature survey. The result of the expert survey explicated that all the factors identified through the literature survey are relevant to the Sri Lankan road construction projects and no additional factors were added to the list.

Simultaneously the importance of CSFs in each phase of construction life cycle of road construction projects in Sri Lanka was observed as the second part of the expert survey.

Through the data analysis the researcher could recognize the importance of each factor in the identified six phases of the road construction project life cycle and the most important factors were illustrated in Table 4.

The findings revealed that for a successful project, in the earlier stages it is most important to have a firm and defined direction or aim and acquaintance of the project scope. Better selection of the appropriate designer/ contractor is very important in the tender stage. In the construction stage proper coordination, monitoring and leadership of the project manager is most essential and in the operational stage having adequate funding is considered as more essential.

According to the finding obtained through this research survey, the researcher recommends to practitioners in road construction projects (basically top management), to consider the most important factors in each of the phases of the construction life cycle in order to obtain a successful project completion.

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Connectivity Analysis as an Alternative Predictor of Transit Demand: A Case Study of the Railway Network, Sri Lanka

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Abstract

Rapidly increasing traffic congestion in urban and suburban roads raises the urgent need for an efficient railway service in Sri Lanka. In studies on rail transportation planning, however, travel demand has often taken a back seat to design and engineering features; perhaps due to the lack of adequate data availability. Taking its cues from this insufficiency, this study explores the potential of using "Connectivity Analysis" to serve as an alternative methodology of travel demand forecasting. The connectivity of railway stations in termsof railway and road access were computed separately by using 'Connectivity Analysis' and by analysing the relationship with travel demand for stations within the railway network of Sri Lanka. Results revealed a significant correlation between transit demand and the connectivity of railway stations, such that connectivity values have the capability to explain over 77% of the variation in rail transit demand. Therefore the study suggests that the "Connectivity Analysis" method can serve as an alternative predictor of transit demand, in the absence of good, quality data on trip-making and employment trends.

Keywords: connectivity analysis, transit demand, station, railway network, road network

Introduction

If cities are to be the sites of economic development, then transportation systems have to be, to a large extent, the foundation on which the efficiency and convenience of that development depends (Leda 2010; Singh 2005). The promotion of public transport as the backbone of mobility in urban agglomerations, or at least as an alternative to the dominance of the automobile, has become a prominent policy in some of the largest and medium sized cities around the world. Public transportation is also an essential component for the sustainability of cities (Munshi 2003; Singh 2005; Leda 2010). However, while some cities have been successful in shifting from car journeys to rail and buses, others are struggling, despite considerable efforts, to make public transport more attractive (Scheurer, 2006). Since many cities now emphasize the desirability of increasing the share of public transport (at least in their policy rhetoric, if not in their practical priorities) it has become commonplace for cities with weaker public transport systems to look closely at the success factors in cities with stronger public transport systems. The most important of these success factors are:

- A configuration of the system in terms of network coverage and service frequencies that offer a viable alternative to the car for most, if not all, travel purposes across the urban area (Laube 1998, Nobis 1999)

- A legible network structure that is efficient to operate, easy to navigate and offers a choice of routes wherever possible (Mees 2000, Vuchic 2005)

- A speed advantage of urban rail over road traffic along a city's main corridors (Newman 2005)

- The integration of public transport facilities with supportive urban development, in particular high-density, mixed-use, walkable nodes around rail stations and major interchanges (Bernick and Cervero 1997, Cervero 1998)

- An institutional framework that allows for integrated, publicly accountable capital investment and service planning (Mees 2005, Mees et al 2006)

On the other hand most fast developing Asian cities give greater priority towards railway networks in order to attract more users to railway transport, due to its higher capacity, comfort and speed when compared to bus transport. Similarly, the government of Sri Lanka is attempting to improve the railway network by launching the 10-year Railway Development Strategy in early 2010. The strategy included upgrading the track on the Southern line (which was damaged in the 2004 tsunami), rebuilding the Northern line (which had suffered from three decades of civil war), extending the Southern line from Matara to Kataragama in order to serve the growing city of Hambantota, adding a new railway line to link Horana to Kottawa, and adding an express railway line from Avissawella to Colombo etc .Furthermore there are proposals to construct high speed railway lines to attract more users. Despite these attempts however, the bus still holds a significant share of 68% (in terms of passenger km) of the national modal split,whereas the railway amounts for a minimal of5%(in terms of passenger km).(Kumarage, 2011).This could be because Sri Lanka Railway has not integrated its services with other modes of transport. Unlike transport systems in some other countries, Sri Lanka does not provide dedicated feeder-bus services to the railways, resulting in commuter rail and buses acting as isolated systems in relation to each other that create a loss in efficiency. Furthermore Sri Lanka railway has failed to identify factors which lead to an increase in transit demand for rail transport (Sri Lanka Railways, 2011). This challenge is also an opportunity to develop sustainably, if demand can be adequately forecasted and planned for. In development strategies for the railway network however, travel demand has often taken a back seat to design and engineering features; perhaps due to the lack of an adequate and robust method to forecast demand and lack of data availability. As Iseki et al (2007) points out, the research is inconclusive as to whether improving the design of transit stations can actually increase ridership.

Thus, there is a need to develop alternative methods to measure transit demand in the railway system. Methods that can be relied upon in the face of data and cost constraints, which many Sri Lankan agencies experience. Taking its cues from trends in transportation planning and new policies that emphasize the integration of travel behaviour and land use, this study explores the potential of using the "Connectivity Analysis" method to serve as an alternative methodology to forecast transit demand in the railway system. The 'Connectivity Analysis' is a method derived from the principal of 'Graph theory' (Erdos and Renyi, 1960). Among previous studies done on "Connectivity Analysis" and public transit, none have focused on cities in developing countries, while only a few studies have been carried out to find out the relationship between the urbanization level and road connectivity(Jayasinghe and Munasinghe 2009), where such research is, perhaps, needed the most. As findingsfrom many studies in the developed world are not directly applicable to cities in developing Asian cities (Kishimoto, 2007; Hasuan, 2008; Munshi, 2009), there is a need to look at the applicability of these simplistic models in defining transit demand in the

Sri Lankan context. This research seeks to explore the applicability, if any, of 'Connectivity Analysis' as a method to estimate transit demand for railway transport in Sri Lanka.

Literature Review

1. Connectivity analysis method

'Connectivity' is a subject of interest in many fields of study, and it is particularly popular in areas such as information technology and computer engineering, etc. However, its recent applications can be seen in spatial planning to model, forecast, and explain matters related to accessibility (Jayasinghe and Munasinghe 2009). Connectivity Analysis could be performed in many different forms (such as the simple connectivity analysis, or weighted network analysis...etc.), furthermore, highly advanced and sophisticated mathematical operations could be used to compute and explain the results related to connectivity. Erdos and Renvi's (1960) 'Random Graph' model can be considered as the base on which most of the subsequent analysis on connectivity was developed. In simple terms, the method involved is the computation of relative connectivity among systematically linked points, lines and areas. The relative connectivity is measured in terms of the number, distance, travel time, optimal path, etc. This method has developed into the status of a comprehensive technique with a number of applications in many fields such as geography, demography and economics. Among them Barabasi and Albert (1999) studied the connectivity of physical networks in relation to properties such as robustness and vulnerability. Batty and Shiode's (2000 and 2001) study promoted the development of this field into quantitative analysis within a twofold perspective with special reference to the World Wide Web. Claremont and Jiang (2004) attempted to describe transportation networks by conceptualizing streets into nodes and intersections into edges, and named this method the 'Dual Graph'.

Although not as widespread as its applications in IT and related fields, a few studies on the connectivity of spatial networks, which has a direct relevance to urban and regional planning, can be noted. The study of topology of the Indian railway network (Sen, 2003), the study on the US interstate highway network and airport network (Gastner and Newman, 2004) and study on the Italian power grid (Crucitti et al., 2004) are examples for such studies. Barrat's (2004) studies on 'weighted network' further developed the conceptual base associated with the connectivity analysis technique. 'Weighted graph representation' provided a commendable solution for many existing limitations of the technique, and answered a series of questions that were fundamental to the understanding of spatial networks. Study of the worldwide airport network, including traffic flow and their correlation with the topological structure (Barrat's, 2004) introduced weighted graph representation for spatial analysis. Jayasinghe and Munasinghe (2009) introduced the connectivity analysis as a method to identify the urban agglomeration trend of locations in Regional studies.

In summary, the literature indicates that connectivity has been used as an attribute to measure many aspects such as the accumulation of traffic at intersections and concentration of people at urban centres. Further, they show that the analysis of connectivity of a given location can be a method to ascertain and predict the capacities of that location on many fronts.

2. Factors Affecting Transit Demand

Most of the research identifies different factors that affect transit demand for the various transit modes. Taylor and Fink (2001) pointed out that total ridership will increase as density increases as a greater

number of people have access to transit. Spillar and Rutherford (1998) examined the relationship between urban and residential transit ridership. Similarly, Pushkarev and Zupan (1977) found that residential densities in transit corridors, together with the size of the downtown and the distance of the station from downtown, explained the level of demand for a variety of transit modes. Brons M., Givoni M., and Rietveld P. (2008) found that improving access to the rail network has the potential to increase the use of rail and can attract new passengers. Crockett and Hounsell (2005) reached a similar conclusion, that investments in measures such as those associated with the convenience or ease of rail travel, including better access, might provide greater benefits for rail users. Wardman and Tyler (2000) pointed out that rail use can be strongly influenced by changes to accessibility to the rail network and access is mainly based on distance from the station.

On the other hand as the first point of contact between a passenger and the transit network, transit stops play an important role in travel demand. Their accessibility is a key component in trip travel time (TCRP 1996). Numerous studies have shown that the location of transit stops also affect ridership (Johnson 2003; Holtzclaw 1994; Rodriguez 2009; and Murray and Wu 2003, cited in Foda 2010). Other qualities of transit stops that affect ridership include: land use, design, and measures of accessibility. Land use variables include residential and employment densities, as well as the relationship between land use mix and network connectivity (Cervero 1993; Chung 1997; Crane 2000; CUTR 2004; Gomez-Ibanez 1996; Hendrickson 1986; Kain and Liu 1995; Nelson and Nygaard 1995; Pushkarev and Zupan 1977; Spillar and Rutherfod 1998; TCRP 1996). Design variables include factors perceivedas safety en route to and at the station, as well as overall station legibility (Abdel-Aty and Jovanis 1995; Cervero 1990; Mees 2000; Syed and Khan 2000; Vuchic 2005). Accessibility variables include walkability and the availability of parking near the stop (Abdel-Aty and Jovanis 1995; Bernick and Cervero 1997; Cervero 1993, 1998; Dittmar and Ohland 2004; Syed and Khan 2000; TCRP 1996).

According to findings of the above discussed literates, the factors affecting the decision of transit users in selecting a transit stop have been conceptualized as follows (figure 1). It depicts the essential components of the complete door-to-door journey by public transport. Transit modes used to travel the longest distances (main mode) are indicated in purple (direct journey) or red (with transfer journey) colour arrows, while the mode used to reach the public transit (access mode) is indicated in black colour arrow on the left side circle and the mode used to reach destinations in black colour arrows on the right side circle (egress mode). Selections of an origin transit stop depend on individual or aggregate levels of accessibility, walkability or legibility of the origin transit stop from the origin point (residential or employment area) of use. On the other hand, selection of egress stop depends on individual or aggregate level of accessibility, walkability or legibility of the destination point (surrounding land use; employment location, education location, recreational location etc) from transit stops. Accordingly, transit stops which have greater accessibility, walkability or legibility from surrounding land use attract more transit users than other transit stops. Selection of main transit mode depends on the level of accessibility from origin stop to the destination stop in terms of travel time, service frequency transfers and connectivity of the stop to downstream land use. The other important factor is the availability of parking facilities at the origin transit stop, however, this is less significant in bus transit in comparison to rail transit.

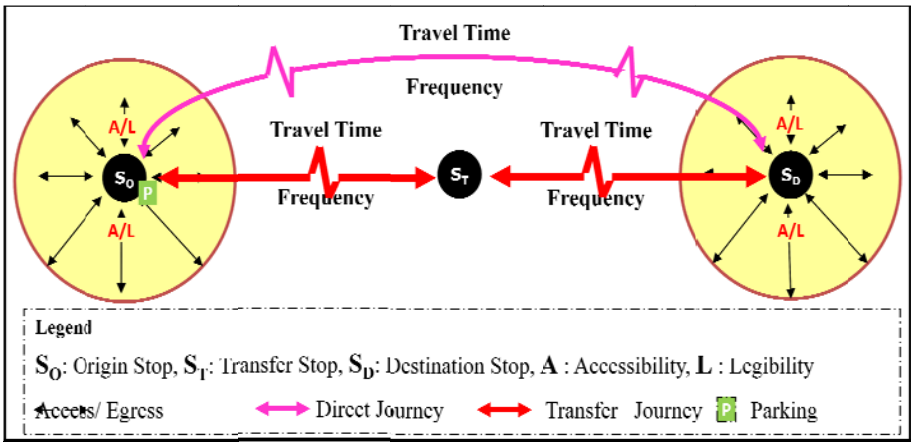


Figure 1: Diagrammatic outline of transit user decision making for selecting transit stops
Source: Prepared by Authors

Study Area

The railway system in Sri Lanka is comprised of 4 railway lines (1449 kilo meters) and 336 railway stations. 300 passenger trains are operating daily and carry 290,000 passengers per day (Sri Lanka Railways, 2011). Rail transport amounts for about 3600 (million) (5%), of the national mode share in passenger kilometres. This case study covered 1/3rd (132 stations) of the railway stations and 1/4th (380.2km) of the railway lines in Sri Lanka. Boundaries are set, along the main line up to Polgahawela,the coastal line up to Galle, the Puttlam line up to Puttlam and the Kelani vally line up to Awissawella. The study area mainly belongs to the Colombo Operating Region (Figure 2).

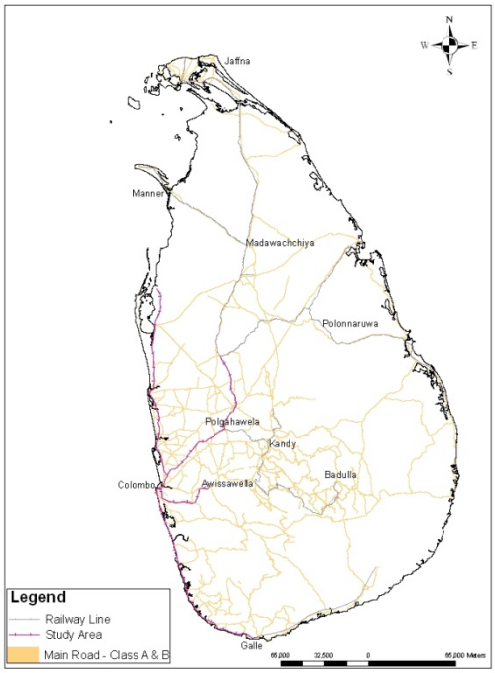


Figure 2: Railway Network in Sri Lanka
Source: Sri Lanka Railways

Methodology

In this study, the transit demand for railway stations were only evaluated for their accessibility effect in terms of connectivity and the methodology was designed to measure this effect (Figure 3). Accordingly the level of accessibility from one railway station to anther was measured in terms of the 'level of connectivity of the railway station though railway network with other stations', while level of accessibility to a railway station from the surrounding areas were measured in terms of the 'level of connectivity of railway station through road with surrounding areas' (refer figurer 3). Therefore the study developed two connectivity indexes separately for the railway station to measure the level of connectivity of the railway station through the railway network and road network.

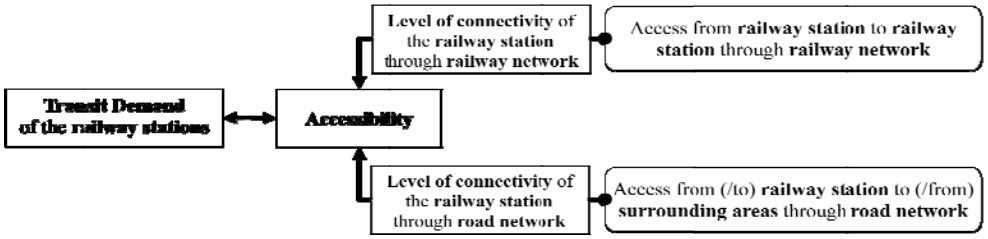


Figure 3: Designed methodology relating to transit demand of the railway stations and connectivity Source: Prepared by Authors

To do so, the first step was to prepare a nodal axial map for the road and railway network. Thus axial maps were prepared in two different ways namely axial map type A and axial map type B and the connectivity of railway station were calculated.

1. Assessment of Connectivity of Railway Stations Through Railway Network

In order to analyze the connectivity of certain railway stations through the railway network in comparison to other stations in the network, the selected area (indicated in a map) is reduced in to a 'node-axial' diagram.The 'nodes' are stations, and 'axial' are the segments of railway lines between those nodes which are represented as straight lines. The diagram is called an 'axial map'.

lines that one has to pass through to get into the particular node selected from all other nodes.

The computation was based on an 'interactive matrix' of nodes. The connectivity value of each node is computed by the following formula. Accordingly, those that obtained a high Dj value have a high level of connectivity and accessibility while those that obtained low Dj values have a low level of connectivity and accessibility.

$$Dj = \frac{1}{\sum_{i=1}^{n} \left(\frac{A_{ij}}{\sum_{i=1}^{n} A_{ij}} \right)}$$

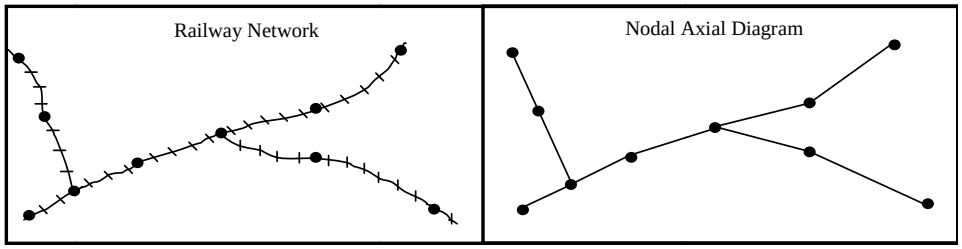


Figure 4: Steps of the preparation of Axial Map – A Source: Prepared by Authors

This axial map is used to compute the 'relative connectivity' of each station with other stations through the rail network (refer figure 4).

The relative connectivity is considered as the sum of normalized values of the relative connectivity of nodes that are computed in terms of the number of axial

Dj : relative connectivity of the node 'j',

Aij: level of accessibility/adjacency between node 'i' and 'j'

Here, the virtual connectivity is still 'relative' because the accessibility or adjacency depends on the selected area of

influence. The area of influence is decided by setting up a radial distance from each node in consideration. When the radial distance is 'n', only the nodes that fall within the area demarcated by that circle are taken into account for the computation of connectivity of the node at the centre. The relative connectivity, analysed in this manner, can be considered as an indication of the topological centrality of a node. This computation can be made more effective to achieve results with a higher level of accuracy by assigning weights to the axial connections. The weight factors may be decided upon the distance between centres, travel frequency, etc.

However, as stated earlier, in this study only simple connectivity analysis was adopted with no weights assigned to the connections.

2. Assessment Of Connectivity of Railway Stations Through The Road Network

First, centrelines of all motorable roads (road networks available within a 10km buffer area from the railway network are taken to prepare an axial map), where they are converted into links and nodes. In order to do so, each road centreline was broken at the intersection; place where two or more centrelines meet. Then, the railway network was overlaid and the centrelines were further were broken at stations. Finally as 'Axial Map – B' indicates, road intersections and railway stations represented as nodes; while links which connect two nodes are represented as axial lines.

Then 'Axial Map –B' is used to compute the 'relative connectivity' of each station with other nodes through roads. The computation was based on an 'interactive matrix' of nodes and the connectivity value of each node that is presented by the same formula used at the stage discussed above. Simple connectivity analysis does not consider the effect of distance; rather it is based on the number of nodes. The demarcation of the areas of influence is done at the local level (10 km radius area from the railway station), based on the authors' observations in the study area.

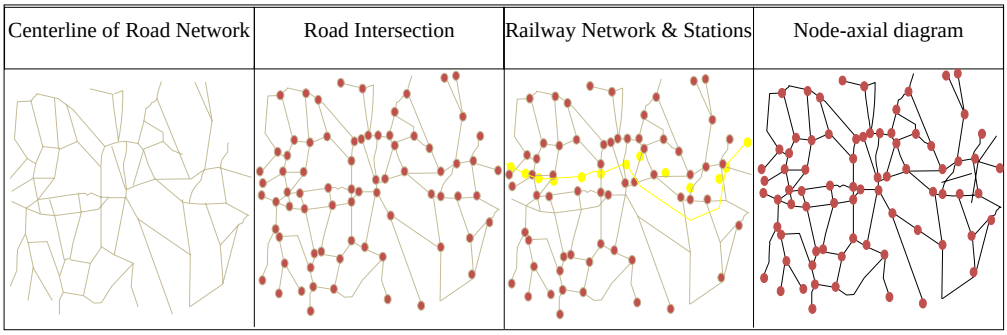
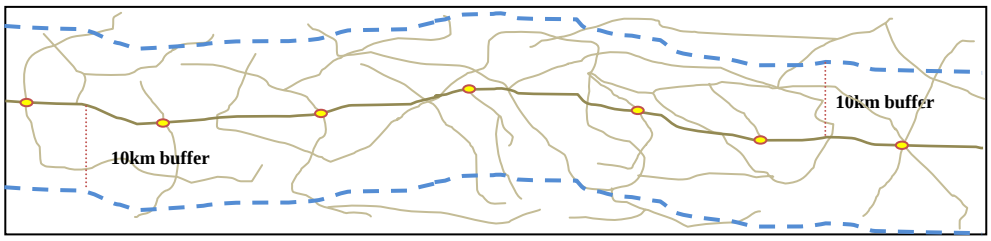


Figure 5: Steps of the preparation of Axial Map – B Source: Prepared by Authors



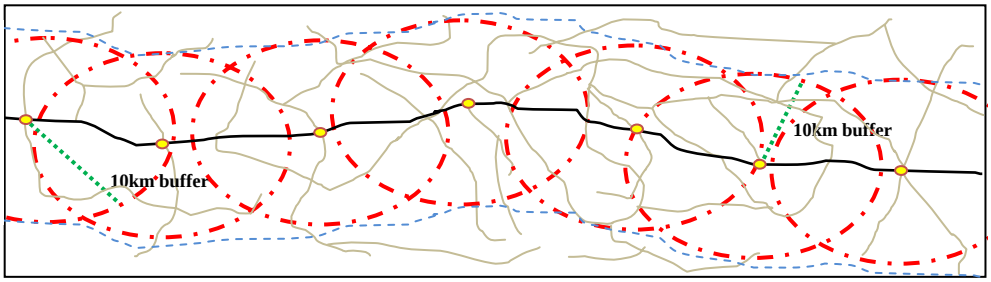


Figure 6: Conceded Area for radius area from the railway station Source: Prepared by Authors

The following table shows that the represented objects by nodes and links in axial maps Type A & B.

Table 1: Represented objects by nodes & links in axial map A & B

	Axial Map – A	**Axial Map – B**
Nodes	Railway Station	Railway stations & Road intersections
Links	Railway track/ line	Railway track/ line &Road
Data Source	1: 50,000 topographic map, 2001 Survey Department. Sri Lanka	1: 50,000 topographic map, 2001 Survey Department. Sri Lanka

Source: Prepared by Authors

3. Preparation of Transit Demand Index

The 'Transit Demand Index' was prepared based on railway passenger boarding information. The study used both daily tickets sales and season tickets (monthly pass) issued at each station in 2010. By taking the average of all daily tickets and season tickets which were sold at each station within the one year period, the average daily transit demand index was prepared.

$$TransitDemandatStation = (Toalnumberofdailyticketsoldinyear\ 2010)/365 + (TotalNumberofmonthlyseasonssoldinyear\ 2010$$

4. Analysis

Finally, the study compared the two connectivity indices with the transit demand index, in order to test their correlation. First, the study analyzed the two indices' results visually using maps. Next, the study used regression analysis to estimate the nature and strength of the relationship between the indices.

From this initial analysis, the study was then able to focus on connectivity values that had relevance and develop additional regression models to explain and predict travel demand at railway stations.

The Analysis and Results

1. Transit Demand of the Stations (TD)

According to the transit demand index prepared for railway stations, the highest transit demand is recorded in Colombo Fort railway station (18,829). The second highest transit demand is recorded in Gampaha Railway station. The histogram indicates that mean transit demand value for the railway station is 766 and standard deviation is about 2017.159. (Ref. annexure 1)

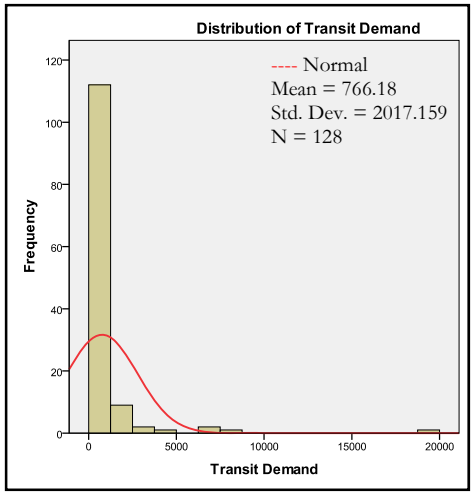


Figure 7: Distribution of transit demand
(Source: Prepared by Authors)

Approximately 90 %(115) stations obtained values less than the mean value (i.e.776). A very few stations (about 10%) recorded the highest transit demand, with more than 1000 passengers per day. Those stations are Fort, Gampaha, Ragama, Maradana and Veyangoda. This means that the highest transit demand recorded in a few railwaystations act as major transit modesin the network; while the lower transit demand recorded at the majority of station indicate that they act as regular stops in the network.

2. Analysis of Connectivity of Railway Stations Through Railway Network

The relative connectivity of nodes, which measure the connectivity of each station to all other station through the rail network has a range between 0.607 (Piyadigama) to 1.692 (Maradana). The mean value of this data range is 1.088 and the standard deviation is 0.325. The highest peak is recorded within the range of 0.75 – 1.0 and the second highest value is recorded within the range of 0 – 0.75. (Ref. annexure 1)

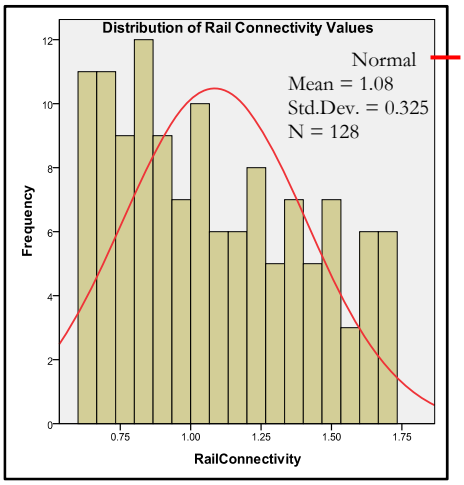


Figure 8: Histogram of distribution of railway connectivity values
Source: Prepared by Authors

3. Analysis Of Connectivity Of Railway Stations Through Road Network

Road connectivity values represent the degree of connectivity of stations to the surrounding areas through the road network. According to the histogram, the average values for the data distribution is about 0.56.and the Standard deviation is 0.289. Similar to section (5.3) discussed above, the highest value is recorded in a small number of railway stations, while the majority of stations recorded lower values for road connectivity. The Peak is represented in the data range 0 – 0.5. (Ref. annexure 1)

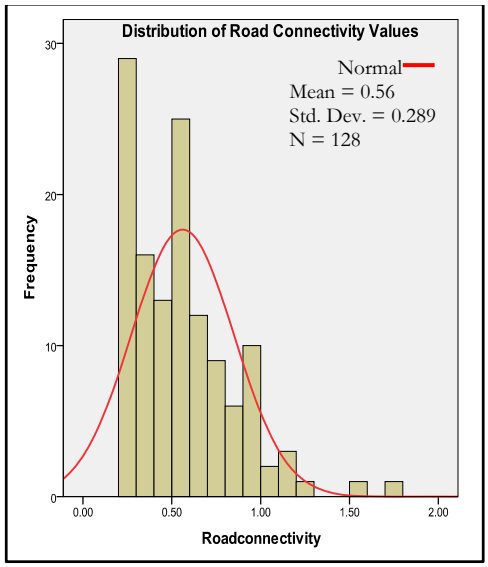
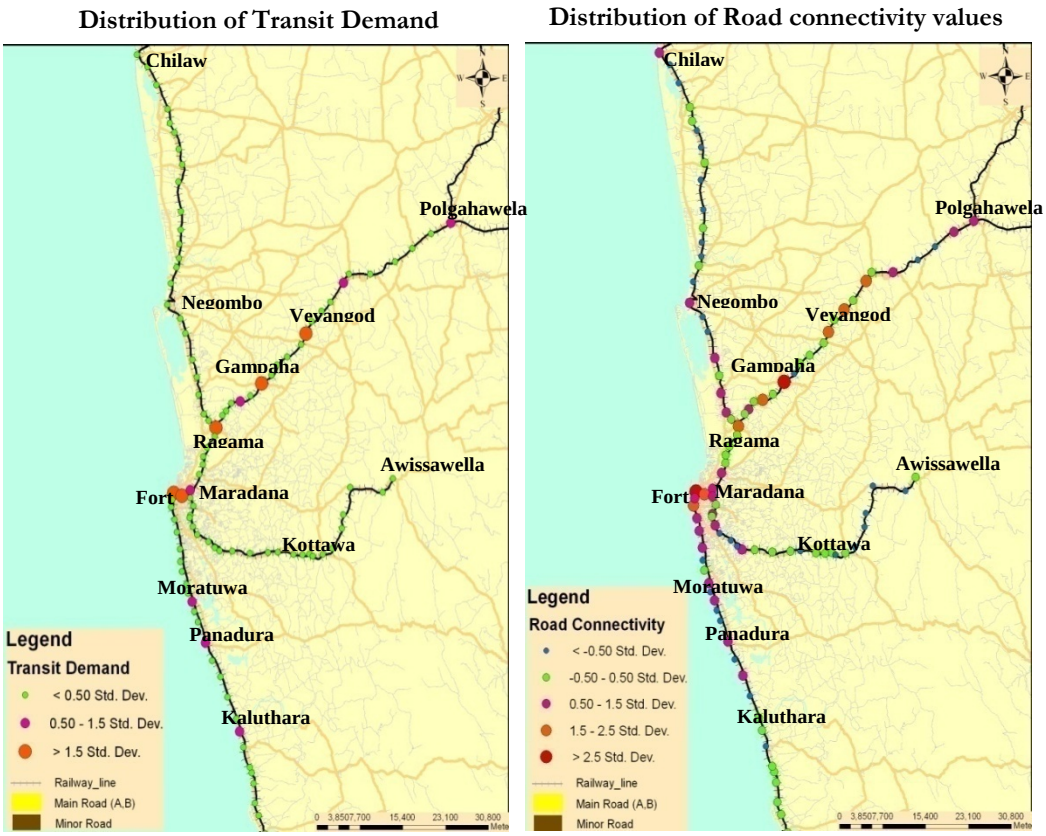


Figure 9: Histogram of the distribution of road connectivity values
Source: Prepared by authors

4. Visual relationship analysis between transit demand and the connectivity values of stations



Distribution of Railway Connectivity Values

		Railway connectivity				
						Total
Transit Demand		50	34	23	9	117
		2	3	2	1	8
		0	0	1	4	5
	Total	52	37	26	14	130

		Road connectivity					
							Total
Transit Demand		46	49	20	2	0	117
		0	1	5	2	0	8
		0	0	0	3	2	5
	Total	46	50	25	7	2	130

Figure 10: Visual representation Of Distribution of Transit demand and Connectivity Values

Source: Prepared by authors

The results indicate that there is a good visual correspondence between transit demand and road connectivity values. The stops that belong to the first category which represent low values of road connectivity and transit demand (standard deviation below 0.50) reveals more than 41% similarity. The second category which represents medium values of road connectivity and transit demand (standard deviation between 0.50-1.5) records 62% similarity. The third category which represents high value of road connectivity and transit demand (standard deviation above 1.5) records 60% similarity. Accordingly, 43% of all railway stations recorded very good visual correspondence between transit demand of railway stations and connectivity values of roads.

However, the visual correspondence between railway connectivity and transit demand is lower than the visual correspondence between transit demand and road connectivity. The stops that belong to the first category which represent lower values of rail connectivity and transit demand (standard deviation below 0.50) records more than 28% of the similarity. The second category which represents medium value of rail connectivity and transit demand (standard deviation between 0.50-1.5) records 25% of the similarity while the third category which represents high value of rail connectivity and transit demand (standard deviation above 1.5) reveal more than 80% similarity. Accordingly, 32% of total railway stations recorded very good visual correspondence between transit demand of railway stations and connectivity values of railways.

5. Correlation Analysis between Transit Demand and the Connectivity Values

The results of the connectivity analysis relates to each station correlated with the correspondent values of the transit demand. This analysis was carried out to investigate whether stations that a record higher transit demand had higher connectivity values though road or railway network.

For this purpose a bi-variant correlation coefficient test on SPSS version 19 was employed to test the strength of the relationship between transit demand and the connectivity values. The following table summarizes the correlation values.

Table 2: Correlation results between connectivity values and TD

Variables	Correlation with TD
Level of connectivity of the railway station through railway network (RiC)	.382**
Level of connectivity of the railway station through road network (RoC)	.689**
	Correlation with Ln(TD)
Ln(RiC)	.623**
Ln(RoC)	.790**

**. Correlation is significant at the 0.01 level (2-tailed).

Source: Prepared by authors

The results indicates that correlation values between Ln(TD) and the Ln(RoC) as 0.790 and correlation is significant at the 0.01 level. Correlation values between Ln(TD) and Ln(RiC) is 0.623 and significant at the 0.01 level. Accordingly, the highest correlation value is recorded between transit demand and the level of connectivity of the railway station through the road network.

The outcome of Log values and actual values are different. The correlation coefficient of the RoC is 0.689 for the actual values and 0.790 for the log values. This shows that log values have a higher correlation coefficient value than the actual values, because, the numerical variation of log values is lower than that of actual values. However the result demonstrates the same initiatives, indicating there is the significant correlation coefficient of the RoC which is higher than the RiC for transit demand.

6. Regression Analysis between Transit Demand and Connectivity Values

A regression analysis was carried out to find out the relationship between transit demand and station connectivity. For this purpose a linear regression model was used. The model summery illustrates the linear regression model with a confidence interval at 99% level. It shows that railway is also significant for the change in transit demand. However when compared to road connectivity, rail connectivity has obtained insignificant F change and beta values.

Together the two variables, Ln(RoC) and Ln(RiC), explain over 77% of the variation in transit demand Ln(TD). Individually, Ln(RoC) explains 64% of Ln(TD) variation and Ln(RiC) explains only 34% of the variation (Table 4). This result indicates that the most significant factor to change the transit demand is road connectivity.

Table 3: Regression model summery of the road and railway network

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.790[a]	.624	.62	.9370233	.62	209.0	1	126	.0	
2	.845[b]	.773	.70	.8214624	.08	38.9	1	125	.0	1.03

a. Predictors: (Constant), Ln(Road Conn)
b. Predictors: (Constant), Ln(Road Conn), Ln(Rail Conn)
c. Dependent Variable: Ln(TD)
Source: Prepared by authors

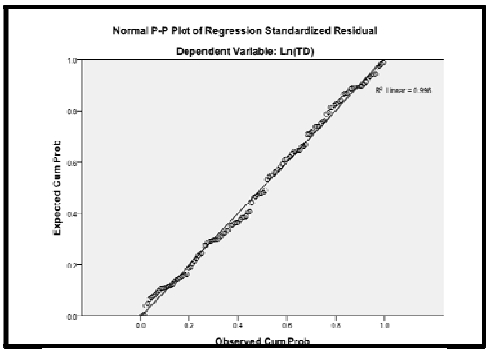


Figure 12: Normal P-P Plot of regression Standardized residual
Source: Prepared by authors

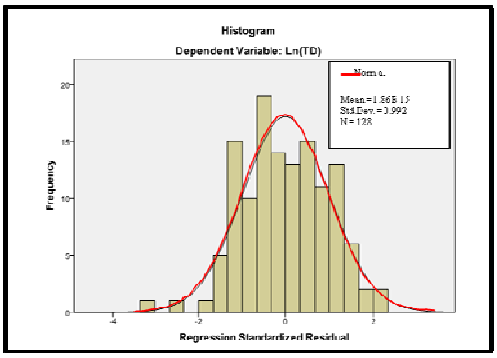


Figure 13: Histogram of the regression standardized residual
Source: Prepared by authors

Table 4: Coefficients – Regression Model

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.	Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	10.489	.142		73.903	.000					
	Ln(RoC)	2.363	.163	.790	14.458	.000	.790	.790	.790	1.000	1.000
2	(Constant)	10.110	.138		73.015	.000					
	Ln(RoC)	1.912	.161	.639	11.910	.000	.790	.729	.570	.797	1.255
	Ln(RiC)	1.683	.270	.335	6.241	.000	.623	.487	.299	.797	1.255

a. Dependent Variable: Ln(TD)
Source: Prepared by authors

Results indicate that travel demand at railway stations can be predicted through the developed regression models, which have more than 77% accuracy.

Ln(TD) = 10.110 + 1.912 Ln(RoC) + 1.683 Ln(RiC),
(R Square = 0.773)

Accordingly, the influence of connectivity values on transit demand varies on railway stations accordingly:

- The connectivity level of railway stations through the road network to the surrounding areas or the level of accessibility to railway stations from surrounding areas determines 64% of the transit demand for the station.

- The connectivity level of railway stations though the railway network with other stations or the level of accessibility from one railway station to another determines 34% of the transit demand for stations.

Conclusion

The main objective of this research was to study the applicability of utilizing the connectivity analysis technique as an alternative predictor of transit demand for the railway network in Sri Lanka. Results indicate that the connectivity analysis technique is useful as an indicator of transit demand. These findings might inform future plans to extend the railway network; specifically, with reference to the rail-road integration.

In view of that, connectivity values of railway stations through the railway network and through the road network were identified as appropriate indicators to measure the transit demand of railway stations. Results of the visual analysis demonstrate that there is a significant and equal distribution of values in transit demand and connectivity values of railway stations through the road network in comparison to the connectivity values of the railway station through railway network. Through the results of the correlation analysis it was identified that there is a significant correlation coefficient (0.790) between connectivity values of railway stations through the road network and transit demand in comparison to connectivity values of railway station through the railway network (correlation coefficient 0.623). The regression analysis also concluded that there is a significant change in transit demand that influence the connectivity values of railway station through the road network. This accounts for about 64% of change while the connectivity values of railway stations through the railway network explain 34% of the change in transit demand. This, regression model, which was developed to explain transit demand of railway stations based on connectivity values, is more than 77% accurate.

Building on these preliminary findings, future studies might explore the relationship of connectivity analysis to passenger transfers, as well as the effect of temporal change in transit demand. This research has contributed a robust, dynamic planning tool that offers promise for spatial planning and transport planning applications in a Sri Lankan context. Specifically, this application may have relevance in identifying the impact of adding stations or altering existing stations, as well as for locating future railway lines or integrating stations with road networks or bus systems.

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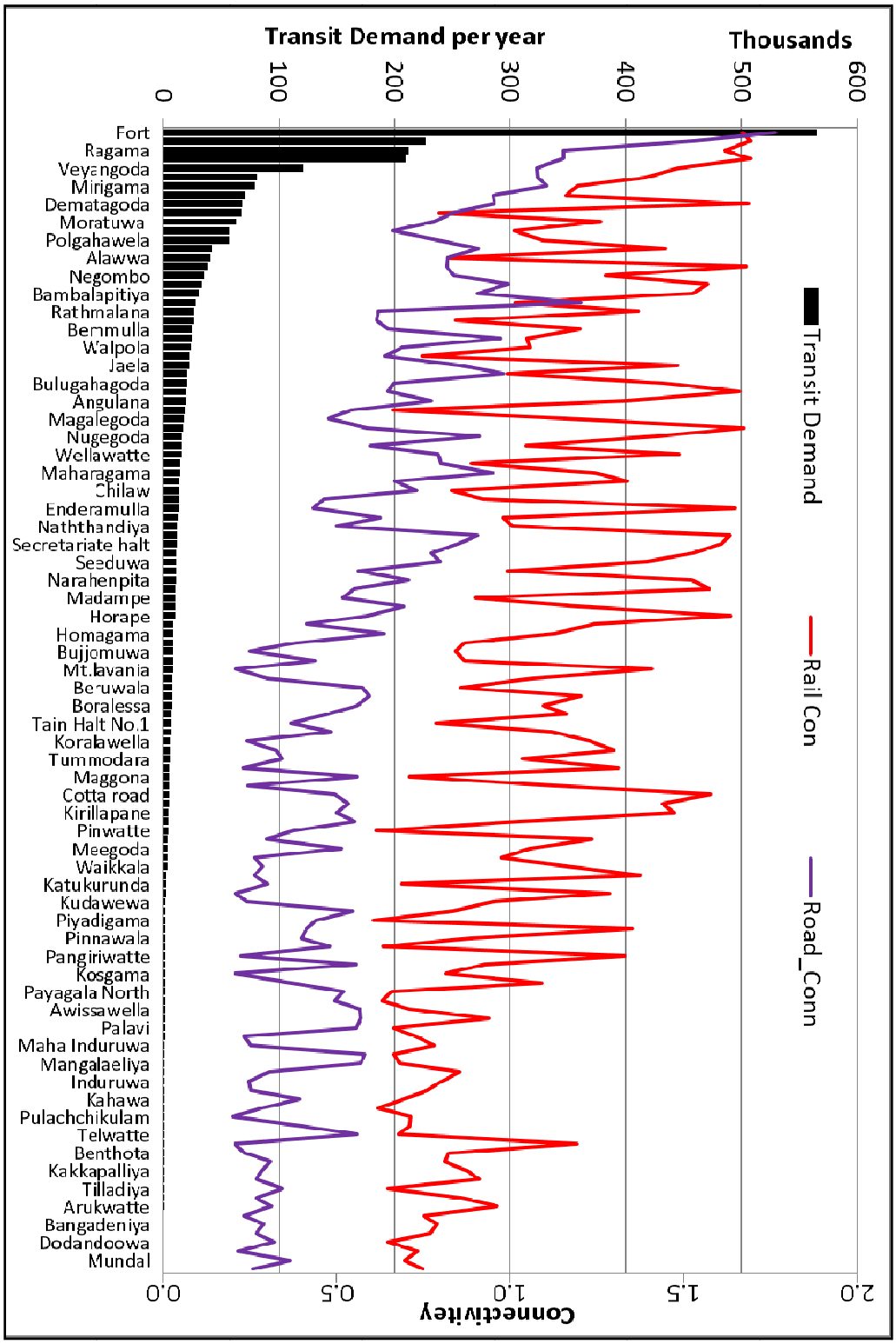
14. Transportation Studies,1 3250 School of Public Affairs Building, Los Angeles, CA 90095-1656, United States

Annexure 1: Distribution of Station according to the Transit Demand & Connectivity
Source: Prepared by authors



Reading the Patterns of Transport Network and Population Distribution; Fractal Geometry Application in Kurunegala Township and its Surrounding Areas, Sri Lanka

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Abstract

The Reciprocal relationship between the population distribution and the transport network pattern has been widely discussed, for example when the population increases; demand for transport related infrastructure increases and vice versa. But the relationship between the road network pattern and population distribution has not been adequately investigated and lacks the appropriate method especially in Sri Lankan spatial and transport planning studies. In such a context, this research explores the feasibility of an emerging method called 'Fractal Geometry' to explain the relationship between road network patterns and population distributions. Thus, this study calculated the road and population distribution fractal dimensions based on the 'mass radius' fractal geometry method and analyzed the relationship between these two variables. Findings of the study have revealed a strong correlation and liner relationship between the fractal dimensions of road and population distribution. Accordingly, the study concludes fractal geometry as a useful tool in understanding the relationship between population distribution and the road network.

Keywords: fractal geometry, road networks, population distribution, spatial planning

Introduction

'Transportation network is a subsystem of spatial form', which shapes the skeleton for the physical growth of the city (Rodin and Rodina, 2000; Shen, 1997). Population distribution is an integral component of spatial form which describes its socio-economic dimension. Roads, as interactions between urban elements, give a very strong effect to urban growth and population increase (Tang, 2003). Furthermore Forman and Alexander (1998) point out that road networks alter the landscape spatial pattern; for example, people tend to live along the road for traffic convenience. Thus, road distribution and its network structure are informative urban topics. On the other hand, complex transport systems fracture cities more and provide greater accessibility into cities, attracting increased population movements over less accessible locations. Another striking feature in the urban system is its population. Population research, especially population density research, provides a potentially strong, scientific framework for socio-economic analysis of the urban form and spatial distribution (Mandelbrot 1983). Therefore the reciprocal relationship between the population distribution and the transport network pattern has been widely discussed; for example when the population increases the demand of the transport related infrastructure increases and vice versa. But the relationship between road network pattern and population distribution has not been adequately investigated, especially in Sri Lankan spatial planning and transport planning studies. This limits the spatial planner's ability to model the changes in population distribution pattern followed by the proposed transport networks as

well as the transport planner's ability to plan transport networks considering future population distributions.

In such a context, this research attempted to demonstrate the applicability of 'Fractal Geometry' to explain the relationship between road network patterns and population distributions through a quantitative method. Fractal analysis (i.e. a method developed by Batty et al in 1989) is an effective approach to describe the disorder and irregularity of natural or manmade spatial forms. In fact, fractal geometry has been tested in demonstrating its ability to illustrate spatial patterns of a wide range of geographic areas.
Although the relationship between road patterns and population is clear, and fractal geometry has been identified as an effective technique, it has not yet been tested as to whether it is suitable in a Sri Lankan context. The main objective of this study is to find the applicability of this technique in a Sri Lankan context. This research was designed to test the applicability of fractal geometry in a Sri Lankan context, using Kurunegala as the initial case study area within the long-term research agenda to cover the other areas in the country. It was assumed that there is a definite relationship between road patterns and population distribution and that fractal geometry as an effective technique to study this relationship. Thus, if the technique proves that there is a strong relationship between road pattern and population distribution, it will definitely say that the technique is applicable in the Sri Lankan context.

Literature review

1. Fractal Geometry

Geometry is a concept thatevolved over centuries by considering the shape, size, relative position of figures, and the properties of space. Most of the real properties of naturedo not have simple geometric shapes such as points, lines and planes which can be described by traditional Euclidian geometry. According to Batty and Longley (1994) dimensions of any real system is fractional. Fractal geometry is one of the non Euclidean geometry methods which describe non-integer dimensions of fractal properties. Fractals are found in nature as scale in variant, self-similar objects (Hastings and Sugihara, 1993) and fractal is a term which was first coined by Mandalbrot (1967; 1977; 1982). The word fractal has been developed by the Greek word "frangere" which gives the meaning of "breaking". Fractals are created from the iteration process as such, "Fractals are of rough or fragmented geometric shape that can be subdivided in parts, each of which is (at least approximately) a reduced copy of the whole" (Zmeskal et al, 2001).

Fractal geometry is the method to calculate and express the geometry of these fractal objects. 'Fractal geometry is a mathematical procedure for calculating the geometry of more complex natural or manmade geometric shapes which are not easy to explain using simple Euclidian geometry. So it can be used to calculate the fractal geometry of urban systems (urban morphology) or its subsystems (which create urban morphology) and to analyze their relationships' (Lu,Tang, 2004;Lia, Dub andCaixin, 2007 ;Frankhauser, 1997;Zmeskal et al, 2001)

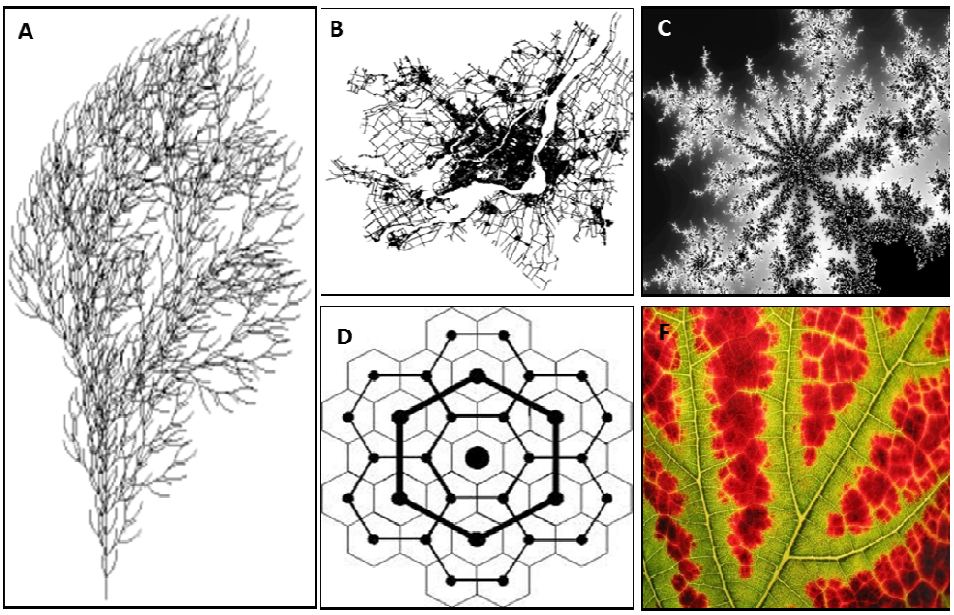

Figure 1: A; Dendritic structure of a tree that Describes fractal geometry (Source; Lindenmayer, 1968)B: A road map of a city showing fractal nature (Source;Morency C., Chapleau R. (2003), C; Art of fractals described by the mathematical concept of geometry(Source; Curious, 2010)D; Iteration process of cities(Source; Christoller, 1930)E, fractal nature of a deciduous leave (Source; Lymn*, 2010*)

2. *Application of Fractal Geometry in Spatial Planning*

Mandelbrot (1967) introduced fractal geometry to calculate the length of the British Coastline. He argued that the coastline has a dimension somewhere between 1 (a straight line) and 2 (a plane), for example, 1.75. This is commonly referred as fractal dimension. Later Nystuen (1990), Frankhauser (1988, 1992) and Shen (1997, 2002) discovered that 'not only natural geographical phenomena but also artificially designed and planned concrete spatial objects can be typical fractal objects'. The use of fractal geometry for spatial analysis was started with this finding. Batty et al(1989), Manrubia et al (1999), Peterson (1996), and Shen (2002) emphasized that 'cities are fractal in nature and are not Euclidian'. Christoller (1930), in his central place theory, explained that cities have been created through the iteration process. Appleby (1996), Longley et al (1991), Sambrook & Voss (2001) noted that 'both city form and the functions are also fractals which are irregular, scale in variant and self similar'.'City form shapes the functions of the city and vice versa.' (Yongmei Lu, Junmei Tang, 2004). Therefore the geometry of form and functions could be analyzed together to find a relationship between them. Batty et al (1989), Manrubia et al (1999), Peterson (1996) and Shen (2002) identified 'fractal geometry as a process of space filling'. They noted that 'When the roads are adding to the city, it fractures the city more and if the city is considered as a plain (2D), adding roads covers more areas of the 2D surface'. Tang (2003)used fractal geometry to analyze the relationship between road pattern and population distribution in quantitative figures. He concludes that 'identifying the fractal geometry of road pattern and population distribution as well as their relationship, will provide the ability of predicting both factors according to the changes done for the other factor'. Lu and Tang (2004) used fractal geometry to study urban sprawl and suggested measures to manage urban sprawl in a predetermined way.

3. Methods of Calculating Fractal Geometry

There are different methods in calculating fractal geometry. Box Counting Method is the most famous which includes two sub methods. The first sub method is the normal box counting method. The second method is the Mass-radius method. These cond method is used in this study to calculate the fractal geometry. Below Figure 2 shows how the box dimension works. Circle (a) has four unit squares, if radius of the circle is doubled (b1), the circle will meet 16 unit squares, alternatively the cell size of unit squares in (a) is reduced by a linear factor of ½ (b2), it will meet 16 unit squares as well." This is called the telescope principle and it is used in calculating the geometry of fractal properties. The first method (b1) shows the box dimension while the second method (b2) displays the mass radius method.

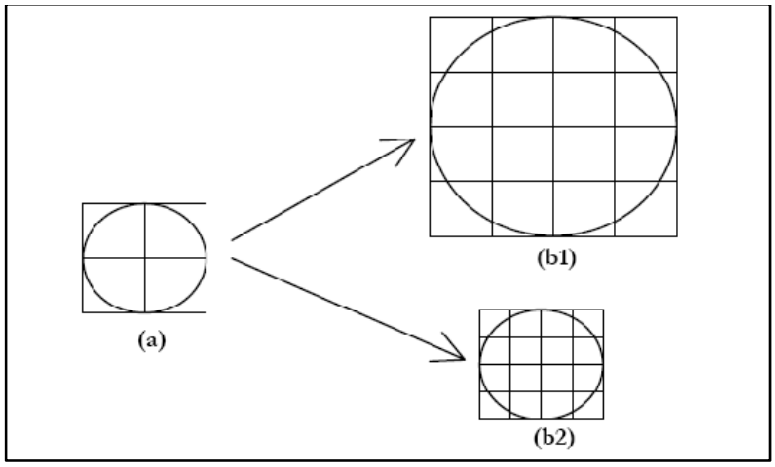

Figure 2: The box dimension. Source: Hastings and Sugihara, 1993

Morency and Chapleau (2003) defined the mass dimension as the 'relationship between the area located within a certain radius and the size of this radius (or box). This is performed for various radiuses as well as from various points of origin. The mass dimension can be estimated from the log-log plot of the area as a function of the radiuses (Lu and Tang 2004). Box counting method provides the fractal geometry of the entire city but the mass radius method can be used to measure the fractal geometry in different sizes of the city. Therefore, mass radius method provides a better spatial understanding about the changes to the fractal geometry by any development or changes adopted for any urban system or subsystem. Mass radius method has a capability to understand the growing phenomenon of the city (Lu and Tang, 2004). By considering those factors, this study uses mass radius method to analyse fractal geometry of the roads and population distribution.

Study Area

The study area (extent = 1964 km^2) is the Kurunegala Township and its surrounding area (25km radius area from town centre), which is served by the city. Kurunegala is the capital of the North Western Province, Sri Lanka. Despite of this administrative boundary, it serves a larger region as a commercial, transport and administrative hub that is located at a highly connected node of several major arteries linking to other regions of the country.

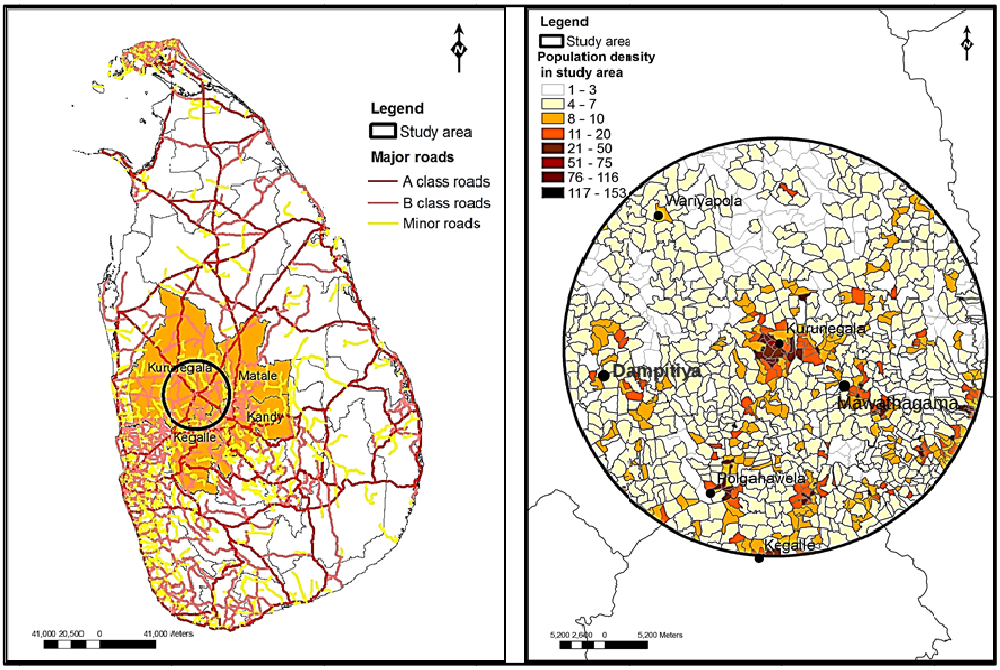

Figure 3: Location of the study area
Source: Prepared based on, 1:50000, Topographic Map, Survey Department Sri Lanka.

Kurunegala is the 1storder city according to the national physical plan-2030 prepared by National Physical Planning Department, Sri Lanka. The city of Kurunegala has been identified as a Mono centric city, which has developed around one single node. Economic and the commercial activities of the city are concentrated in the CBD (T&CP, 2010). The density of activities, buildings, infrastructure and population decreases as you move away from the city centre.For example, the main bus stand of the city is located in the centre of the city, whereas all the commercial activities are also concentrated in the centre of the city around the bus stand and are regularly dispersed.Thevisual appearance of the road pattern exhibits a pattern of equal distribution throughout the study area, though there are some variations. (Figure 4).A higher concentration of roads in the city centre is relatively significant.

The total length of the road network of the study area is about 3090 km. Of which only 637 km from them are motorable roads. This includes 116 km of 'A' class roads, 332 km of 'B' class roads and 188 km of minor roads (1:50000, Topographic Map, Survey Department Sri Lanka, 2001). The strong network of 'A', 'B' and 'C' class roads ensure better accessibility within the regional and local context. Population is highly concentrated in and around the Kurunegala town centre area (about 2-3km from town centre). The highest population density of 435 ppHa (Population per Ha) is recoded in GN divisions that are located near the city centre..Similarly, Polgahawela, Mawathagama and, Wariyapola town areas indicate high population density when compared with other areas.

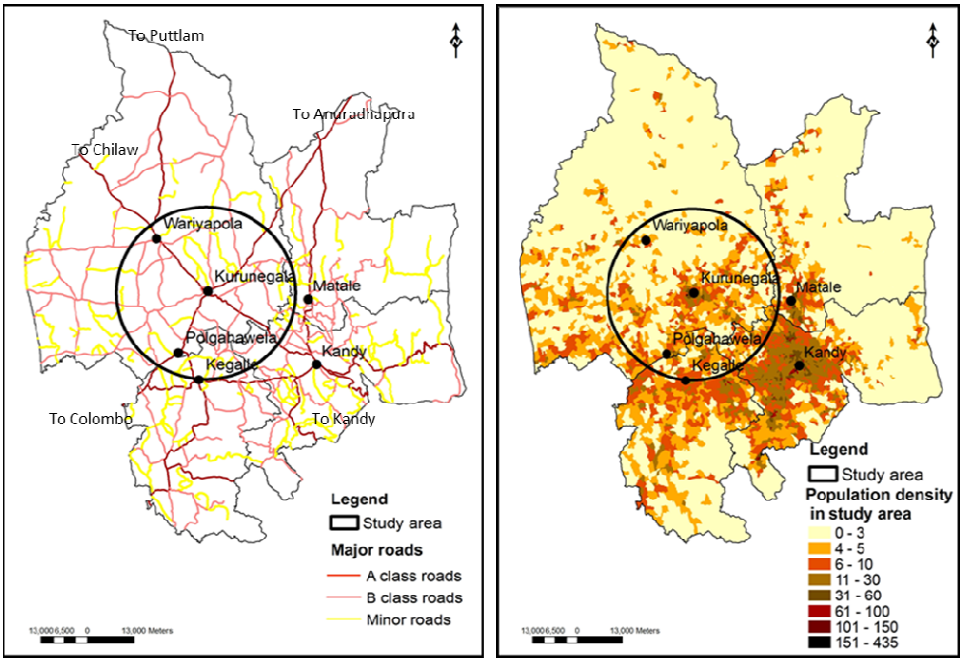

Figure 4: Road pattern and population distribution of the study area
Source: Prepared based on, 1:50000, Topographic Map, Survey Department Sri Lanka & GN level Populations Data-2001, Censuses & Statistic Department, Sri Lanka.

Method

Box counting dimension method was used to calculate the fractal dimension of the road network and population distribution. Of the main two methods in the box counting method for calculating fractal dimension, 'Mass radius' method, which covers more areas by increasing the size of radius, was selected as the appropriate method.

This method calculates the fractal dimension of black & white digitized images of fractals. Mass radius fractal dimension is based on the dependency of black and white pixels on a circle shaped plain, with varying areas. The ratio of changes in the above dependency of different sized radius is the fractal dimension. It assumes that all fractal geographical entities exhibit a dimension relationship as follows.

$$L^{1/1} \alpha S^{1/2} \alpha V^{1/3} \alpha M^{1/D} \ldots\ldots\ldots (1)$$

Where L is the length of geographical entity, S is the area, V is the volume and M is any dimension, and D is the fractal geometry.

1. Preparation of road pattern and population distribution maps

The road network was acquired from the Topographic Map of Sri Lanka-2001 (Survey Department Sri Lanka) as a GIS shape file. The population density was acquired from the census data of 2001 in 'Grama Niladhari' (GN) divisions from Censuses & Statistics Department, Sri Lanka. After transferring the road map and population density map from shape to coverage file in Arc GIS 9.3, the study clipped two maps into different circle areas by increasing the radius of buffer (figure 5&6).

In this research, buffers drawn around the city centre were used(i.e. most connected node by 'A' roads) by increasing the 500m radiuses for each buffer covering entire study area (i.e. up

to 25km).Tang (2003) emphasized increasing 500m distance for each buffer as the best method of calculating fractal dimension in the regional context. But if the geometry is to be calculated at the local scale, it will require having a smaller scale of varying sizes of buffers.

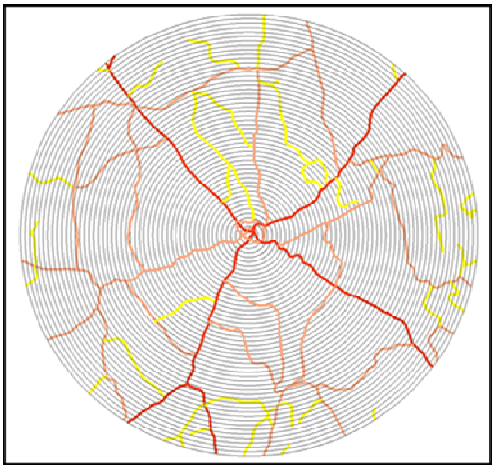

Figure 5: 50 buffers on the Road pattern distribution
Source: Prepared based on, 1:50000, Topographic Map, Survey Department

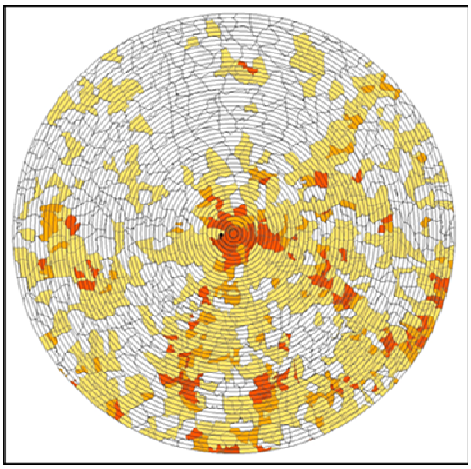

Figure 6: 50 buffers on the population distribution
Source: Prepared based on, 1:50000, Topographic Map, Survey Department

2. Calculating fractal dimension of roads

The study used a modified boxing fractal geometry method to calculate fractal dimension of roads.

Therefore the study used the road map (illustrated above) to calculate lengths of roads in each circle using Arc GIS 9.3.

Then, the following equation isused (developed by Tang, 2003) to calculate the fractal dimension of roads, which is denoted as D(L_i).

$$D(Li) = \frac{Log\left[\frac{L(R_i)}{L(R_{i-1})}\right]}{Log\left(\frac{R_i}{R_{i-1}}\right)} \ldots\ldots\ldots (2)$$

D (Li) = fractal dimension of roads

Ri = radius at scale i
L (Ri) = length of road at scale i
Ri-1 = cell length of scale i-1
L(Ri-1) = the length of road at scale of i-1.

3. Calculating fractal dimension of population distribution

In this step, the following equation (introduced by Batty and Longley, 1991) is used to calculate fractal dimension of population, denoted asD (P), in the study area. Accordingly,R is any given distance from the centre, and the fractal dimension of population distribution D (P) is calculated from following equation:

$$D(P_i) = 2 + \frac{Log\ P(R_i)}{Log(R_i)} \ldots\ldots\ldots (3)$$

D (P_i) = fractal dimension of population distribution at scale i
Ri = radius at scale i
P(R) = population density at scale i

I	Road Length	Cum Road Length	R	Log (R)	Log(LR)	D(Li)	I	Road Length	Cum Road Length	R	Log (R)	Log (LR)	D(Li)
1	8460	8460	0.50	-0.30	3.93		26	53363	1176524	13.00	1.11	6.07	1.1835
2	23216	31676	1.00	0.00	4.50	1.9047	27	54018	1230542	13.50	1.13	6.09	1.1895
3	31256	62932	1.50	0.18	4.80	1.6931	28	58395	1288937	14.00	1.15	6.11	1.2748
4	39295	102227	2.00	0.30	5.01	1.6864	29	60225	1349162	14.50	1.16	6.13	1.3013
5	41670	143897	2.50	0.40	5.16	1.5322	30	60161	1409323	15.00	1.18	6.15	1.2868
6	40415	184312	3.00	0.48	5.27	1.3577	31	62151	1471474	15.50	1.19	6.17	1.3161
7	45969	230281	3.50	0.54	5.36	1.4445	32	60707	1532181	16.00	1.20	6.19	1.2734
8	41700	271981	4.00	0.60	5.43	1.2464	33	54899	1587080	16.50	1.22	6.20	1.1440
9	42366	314347	4.50	0.65	5.50	1.2291	34	54165	1641245	17.00	1.23	6.22	1.1242
10	46497	360844	5.00	0.70	5.56	1.3093	35	58770	1700015	17.50	1.24	6.23	1.2137
11	42649	403493	5.50	0.74	5.61	1.1721	36	61665	1761680	18.00	1.26	6.25	1.2648
12	40653	444146	6.00	0.78	5.65	1.1032	37	61530	1823210	18.50	1.27	6.26	1.2530
13	44783	488929	6.50	0.81	5.69	1.2002	38	62721	1885931	19.00	1.28	6.28	1.2683
14	53803	542732	7.00	0.85	5.73	1.4087	39	62362	1948293	19.50	1.29	6.29	1.2524
15	53770	596502	7.50	0.88	5.78	1.3692	40	62934	2011227	20.00	1.30	6.30	1.2557
16	49998	646500	8.00	0.90	5.81	1.2472	41	62926	2074153	20.50	1.31	6.32	1.2477
17	49192	695692	8.50	0.93	5.84	1.2096	42	66889	2141042	21.00	1.32	6.33	1.3171
18	48450	744142	9.00	0.95	5.87	1.1779	43	66443	2207485	21.50	1.33	6.34	1.2988
19	48380	792522	9.50	0.98	5.90	1.1650	44	66870	2274355	22.00	1.34	6.36	1.2981
20	49917	842439	10.00	1.00	5.93	1.1908	45	67217	2341572	22.50	1.35	6.37	1.2961
21	51851	894290	10.50	1.02	5.95	1.2242	46	66028	2407600	23.00	1.36	6.38	1.2652
22	56794	951084	11.00	1.04	5.98	1.3236	47	66826	2474426	23.50	1.37	6.39	1.2730
23	58633	1009717	11.50	1.06	6.00	1.3458	48	64208	2538634	24.00	1.38	6.40	1.2168
24	58082	1067799	12.00	1.08	6.03	1.3141	49	63774	2602408	24.50	1.39	6.42	1.2033
25	55362	1123161	12.50	1.10	6.05	1.2382	50	65736	2668144	25.00	1.40	6.43	1.2348

Table 1: Result of road fractal analysis. Source: Prepared by Authors

Results and Analysis

1. Road pattern fractal analysis

The above table (table 1) summarizes the results of road fractal analysis. It indicates the road lengths, radius (R), their log values and the fractal dimension D (Li) of roads within the study area.

According to the graph, road lengths increase with the increasing radius. As indicated in the above graph, there is a very high gradient from city centre to 2.5km, high gradient from 2.5km to 7.5km and moderate gradient from 7.5km to boundary of the study area. It indicates that there is a very high concentration of road within the city centre area while that concentration reduces towards the periphery of the study area. This pattern is characteristic a Monocentric city form. Until the end of the city there is a smooth flow that is increasing rather than some fluctuations. It is generally understood that Monocentric cities have the above characteristics of increasing road lengths with the growing city size as roads are concentrated into one single node that then disperse their density outward.

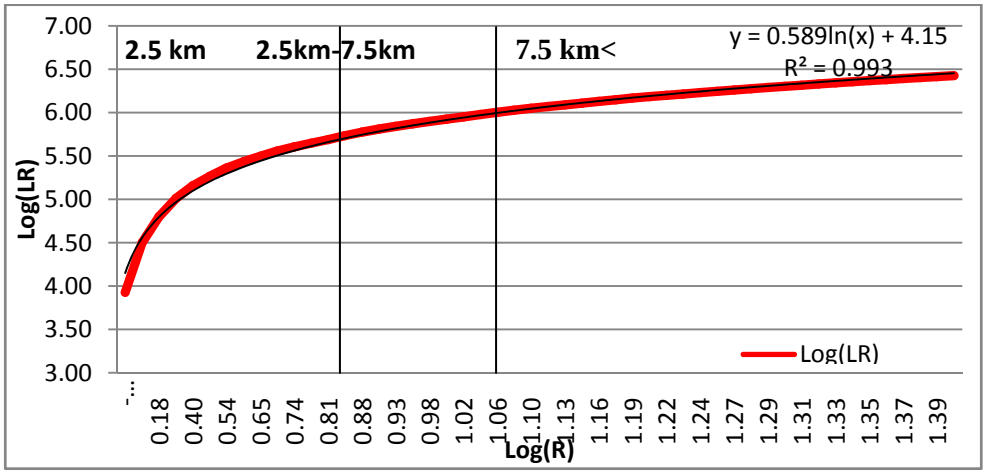

Figure 7: log likelihood ratio curve of roads
Source: Prepared by Authors

But these values of increasing length with city size does not provide an idea as to how the changes in the filled space of city (with roads) may change as new buffers are added to the expanding city limits. Lengths of roads increase when new areas with increasing radius are added. Evaluating this is possible with the fractal dimension of the roads. Figure 6 shows how fractal dimension varies from the growing size of city by 500 m buffers till the boundary.

When considering the gradients of the graph, the Monocentric form of city can be predictable. The centre of the city having higher fractal dimension of roads means that the first few buffers are mostly filled with the road network. When moving away from the city, the dimension is reduced. But still there are some small fluctuations of the dimension that model the uneven distribution of the road network. There are no peaks or troughs of the graph that indicates that the city still servesas the major transport and commercial hub and that there are no emerging centres within the surrounding area.

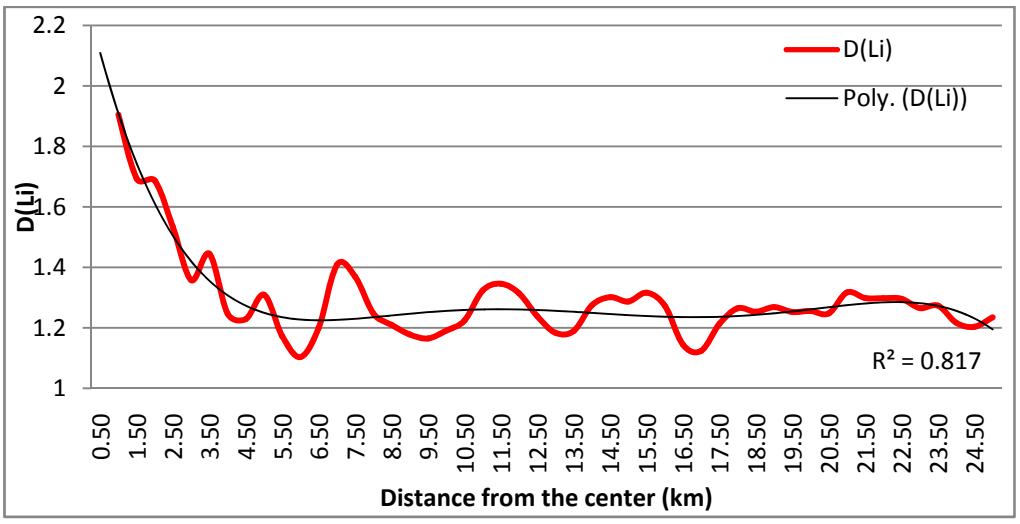

Figure 8: Fractal dimension of the road pattern
Source: Prepared by Authors

As depicted in the histogram, the mean fractal dimension value of the road pattern within the buffers is 1.28. The left skewness (Std. Dev 0.117) indicates that a large number of buffers have low fractal dimension. But the distribution shows that there are more middle level values (the high number of fractal values distributed in the range of 1.2 and 1.4) as well. According to the distribution, only 18% of buffers have fractal dimension values less than 1.2.About 4% of all 50 buffers have higher fractal values (More than 1.6). When the fractal values are getting closer to 2, it means that more land areas are filled up by the road network.

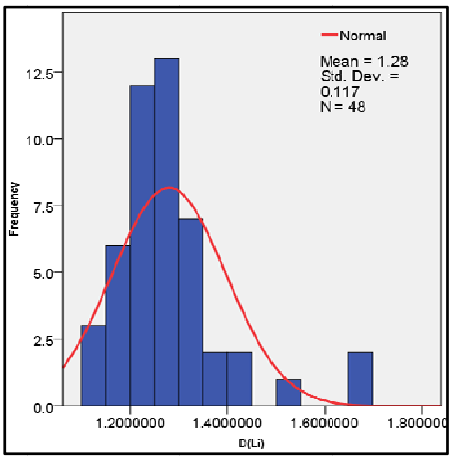

Figure 9: Distribution of fractal dimension of the road pattern. Source: Prepared by Authors

2. Population distribution fractal analysis

The table below summarizes the result of the population distribution fractal analysis. It indicates the population (pop), cumulative population (Cum pop), population density (pop den), radius (R), log value of R and fractal dimension D (Pi) of population density in the study area.

I	pop	Cum pop	pop den	R	Log (R)	D(Pi)	I	pop	Cum pop	pop den	R	Log (R)	D(Pi)
1	2587	2587	32.95	500	2.699		26	281715	3395784	3.68	13000	4.114	2.14
2	10895	13482	35.26	1000	3.000	2.52	27	297460	3693244	3.78	13500	4.130	2.14
3	21721	35203	27.57	1500	3.176	2.45	28	314704	4007948	3.99	14000	4.146	2.14
4	32989	68192	20.50	2000	3.301	2.40	29	332778	4340726	4.04	14500	4.161	2.15
5	43534	111726	14.92	2500	3.398	2.35	30	351331	4692057	4.00	15000	4.176	2.14
6	53464	165190	11.49	3000	3.477	2.30	31	369159	5061216	3.72	15500	4.190	2.14
7	63639	228829	9.97	3500	3.544	2.28	32	386084	5447300	3.42	16000	4.204	2.13
8	72593	301422	7.60	4000	3.602	2.24	33	403463	5850763	3.40	16500	4.217	2.13
9	80831	382253	6.17	4500	3.653	2.22	34	423832	6274595	3.87	17000	4.230	2.14
10	90140	472393	6.24	5000	3.699	2.21	35	446401	6720996	4.16	17500	4.243	2.15
11	99315	571708	5.56	5500	3.740	2.20	36	471979	7192975	4.59	18000	4.255	2.16
12	107983	679691	4.80	6000	3.778	2.18	37	498950	7691925	4.70	18500	4.267	2.16
13	117217	796908	4.70	6500	3.813	2.18	38	525366	8217291	4.48	19000	4.279	2.15
14	128559	925467	5.35	7000	3.845	2.19	39	549715	8767006	4.03	19500	4.290	2.14
15	140615	1066082	5.29	7500	3.875	2.19	40	573559	9340565	3.84	20000	4.301	2.14
16	151667	1217749	4.54	8000	3.903	2.17	41	599284	9939849	4.04	20500	4.312	2.14
17	161721	1379470	3.88	8500	3.929	2.15	42	626645	10566494	4.20	21000	4.322	2.14
18	171546	1551016	3.57	9000	3.954	2.14	43	654657	11221151	4.20	21500	4.332	2.14
19	182164	1733180	3.65	9500	3.978	2.14	44	683496	11904647	4.22	22000	4.342	2.14
20	194022	1927202	3.87	10000	4.000	2.15	45	711310	12615957	3.98	22500	4.352	2.14
21	207600	2134802	4.22	10500	4.021	2.16	46	739473	13355430	3.94	23000	4.362	2.14
22	222200	2357002	4.32	11000	4.041	2.16	47	769230	14124660	4.07	23500	4.371	2.14
23	237726	2594728	4.39	11500	4.061	2.16	48	800813	14925473	4.23	24000	4.380	2.14
24	252352	2847080	3.96	12000	4.079	2.15	49	833201	15758674	4.25	24500	4.389	2.14
25	266989	3114069	3.80	12500	4.097	2.14	50	867446	16626120	4.40	25000	4.398	2.15

Table 2: Result of road fractal analysis
Source: Prepared by Authors

The following Graph (figure 10) indicates Log likelihood value of population distribution against radius of buffers.

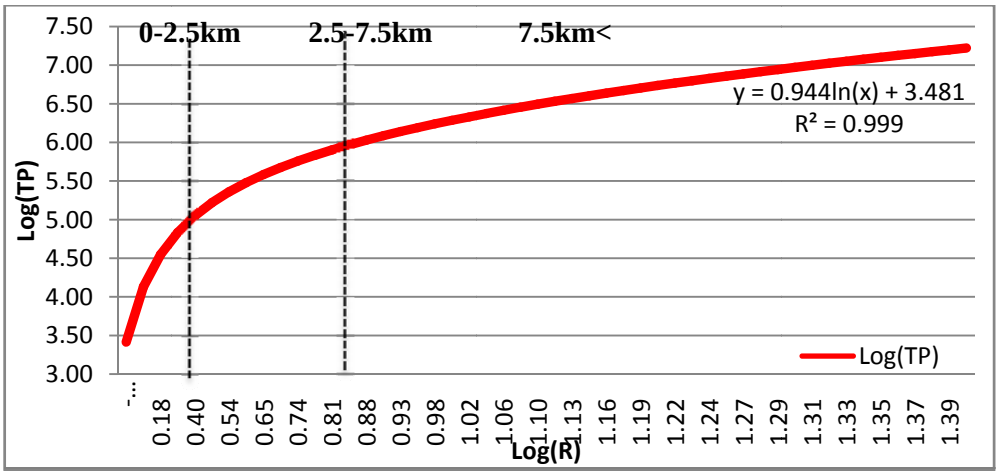

Figure 10: log likelihood ratio curve of population distribution
Source: Prepared by Authors

According to the data,population increases with the radius. As illustrated in figure 11, there is a very high gradient from the city centre to 2.5km away, a high gradient from 2.5km to 7.5km and moderate gradient from 7.5km to boundary of the study area. This indicates that there is a very high population concentration in the city centre area while reducing towards the periphery of the study area. When compared to the log likelihood ratio curve for road lengths, this curve shows a similar gradient of acceleration. (R^2 for road lengths comparison curve is 0.993, whereas $R^2$for population distribution is 0.999). The graph shows that up to 7.5km radius, the gradient of the curve is higher and it is similar to the pattern of the log likelihood curve. This similarity of the pattern explains that the interrelationship between road pattern and the population distribution may be inevitable.

The following Graph (figure 11) whichshows the distribution of fractal geometry values of population distribution D(Pi),provides a better idea as to how population distribution gets dispersed proportionally to the distance from the city centre. The fractal dimension of population distribution is decreasing at a higher rate within the first 4.5 km.

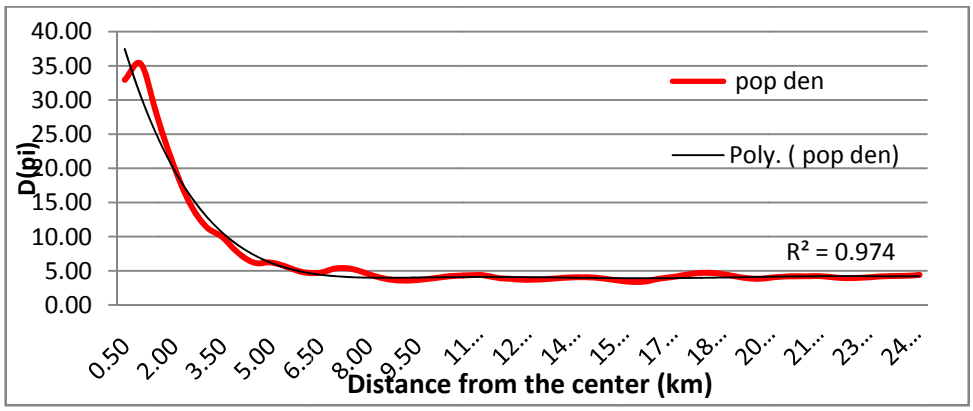

Figure 11: Fractal dimension of the population distribution
Source: Prepared by Authors

As depicted in the histogram (figure 12), the mean fractal dimension of the study area is 2.18. The left skewness (Std. Dev 0.084) indicates that large numbers of buffers have lower fractal dimensions of population distribution. According to the pattern of distribution, more than 80% of buffers have fractal dimensions less than 2.2while very few buffer areas have fractal dimensions more than 2.5 (only 1% out off 50 buffers).

3. Relationship analysis between population distribution fractal dimension and the road pattern fractal dimension

Table 3 presents the results of the fractal dimensions of road and population density in every scale (buffer), computed by equation (2) and equation (3) respectively. In general, the bigger the radius,, the smaller the fractal dimensions of road and population density.

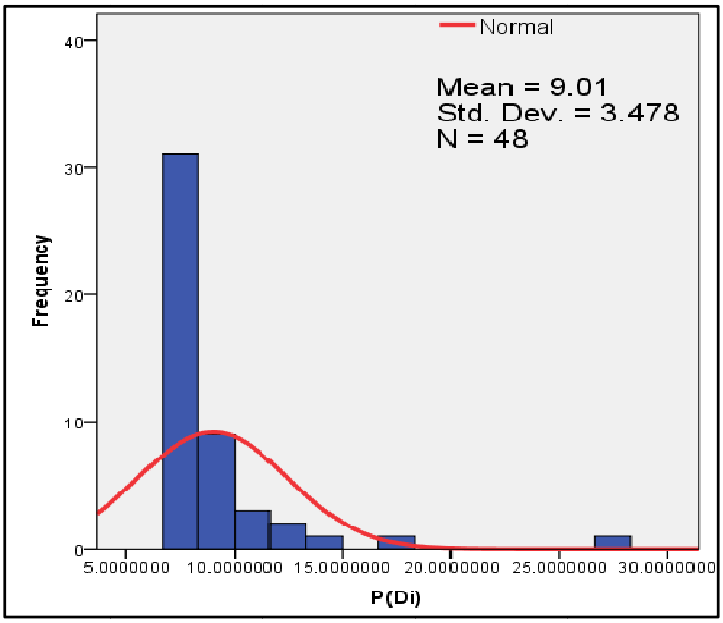

Figure 12: Distribution of fractal dimension of the population distribution

This indicates that the population has transparently spread over the study area. While few areas have a higher level of concentration (i.e. at the city centre), all the buffers, which have fractal dimensions more than 2.2, are located within the first 4.5km from the city centre. This is the nature of a Monocentric city. Monocentric cities have a higher concentration of the population at the centre that disperses towards the periphery.

The range of dimensions of road computed from equation (3) indicates that the dimensions of all roads are less than 2 and ranges from 1.9 to 1.18, which suggests that roads do not fill in the entire two-dimensional space. This trend is especially clear in the dimension of population density, which decreases gradually. We can see that the highest dimension of population density is 2.52 (when R = 1.0 kilometers), which means that people have filled in this centre area greatly. Though the dimensions of population density fall within the range 2.52~2.13.

I	1(0.5)	2(1.0)	3(1.5)	4(2.0)	5(2.5)	6(3.0)	7(3.5)	8(4)
D(Li)		1.90	1.69	1.69	1.53	1.36	1.44	1.25
D(Pi)		2.52	2.45	2.40	2.35	2.30	2.28	2.24
I	9(4.5)	10(5)	11(5.5)	12(6.0)	13(6.5)	14(7.0)	15(7.5)	16(8.0)
D(Li)	1.23	1.31	1.17	1.10	1.20	1.41	1.37	1.25
D(Pi)	2.22	2.21	2.20	2.18	2.18	2.19	2.19	2.17
I	17(8.5)	18(9.0)	19(9.5)	20(10.0)	21(10.5)	22(11.0)	23(11.5)	24(12.0)
D(Li)	1.21	1.18	1.17	1.19	1.22	1.32	1.35	1.31
D(Pi)	2.15	2.14	2.14	2.15	2.16	2.16	2.16	2.15
I	25(12.5)	26(13.0)	27(13.5)	28(14.0)	29(14.5)	30(15.0)	31(15.5)	32(16.0)
D(Li)	1.24	1.18	1.19	1.27	1.30	1.29	1.32	1.27
D(Pi)	2.14	2.14	2.14	2.14	2.15	2.14	2.14	2.13
I	33(16.5)	34(17.0)	35(17.5)	36(18.0)	37(18.5)	38(19.0)	39(19.5)	40(20.0)
D(Li)	1.14	1.12	1.21	1.26	1.25	1.27	1.25	1.26
D(Pi)	2.13	2.14	2.15	2.16	2.16	2.15	2.14	2.14
I	41(20.5)	42(21.0)	43(21.5)	44(22.0)	45(22.5)	46(23.0)	47(23.5)	48(24.0)
D(Li)	1.25	1.32	1.30	1.30	1.30	1.27	1.27	1.22
D(Pi)	2.14	2.14	2.14	2.14	2.14	2.14	2.14	2.14
I	49(24.5)	50(25.0)			Mean	Std. Deviation		N
D(Li)	1.20	1.23			2.1835	.08437		49
D(Pi)	2.14	2.15			1.2927	.14633		

Table 3: Dimensions of road and population density
Source: Prepared by Author

Though a similar pattern of fractal dimensions of road and population distribution can be identified using the above table, the graph below (figure 12) provides a better foundation for the purpose of comparison.

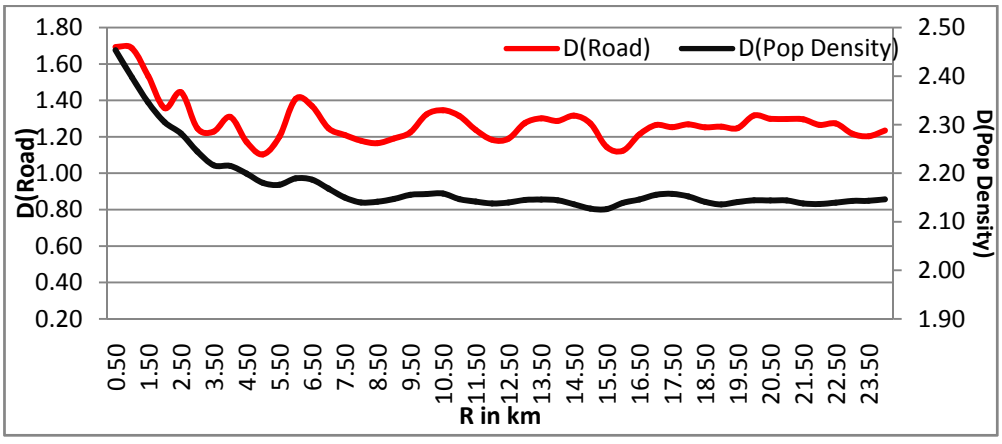

Figure 13: Distribution of fractal dimension of the road pattern and population distribution
Source: Prepared by Author

The curve representing the fractal dimensions for population distribution is smoother than the curve representing the fractal dimension of road pattern. The gradual decrease of fractal dimensions of population can be observed up to 3.5 km which is illustrated by the higher gradient of the graph. The level of higher fractal dimensions for roads can be seen in the first 3, 4 buffers. Road dimensions show variations in different buffers and this indicates that there are emerging potential areas within the city with higher accessibility. As an example there is a higher fractal dimension in the 7th buffer. But the smooth flow of fractal dimensions of population distribution indicates that the very low geographical restrictions on population distribution has caused there to be a more or less equal population distribution.

4. Correlation and regression analysis between population distribution fractal dimension and the road pattern fractal dimension

Correlation and regression analysis between the two curves in figure 13 was carried out to find the relationship between the road pattern and population distribution pattern.

4.1 Results: Correlation analysis

The coefficient correlation value between population distribution fractal dimension and the road pattern fractal dimension is 0.877 (significant at the 0.01 level). The plus value of the correlation indicates that these two variables have a positive relationship. Since the value is much closer to the 1, it says that there is a very strong positive relationship between the two variables. The Reciprocal relationship which was identified earlier between the population distribution fractal dimension and the road pattern fractal dimension can be proven with this coefficient value. When the roads fill more area of the buffer, population fractal dimension of the buffer also tends to increase, and vice versa.

Model	R	R square	Adjusted R Square	Std. Error of the estimates
1	0.875	0.765	0.760	.0414

Table 5: Results Correlation analysis
Source: Prepared by Authors

		D(Pi)
D(Li)	Pearson Correlation	.877**
	Sig. (2-tailed)	.000
	N	50
**. Correlation is significant at the 0.01 level (2-tailed).		

Table 6: Results Regression analysis – Model Summary
Source: Prepared by Authors

4.2 Results: Regression analysis

The regression analysis between population distribution fractal dimension and road pattern fractal dimension provides interesting results.R^2 of the two variables is 0.765. This value illustrates that there is a strong relationship between these two variables. As such there is a 76% possibility of predicting one variable according to the other variable.

Coefficients						
Model		Un standardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.531	.053		28.836	.000
	D(Li)	.505	.041	.875	12.361	.000
a. Dependent Variable: D(Pi)						

Table 7: Results Regression analysis – Coefficients Values
Source: Prepared by Authors

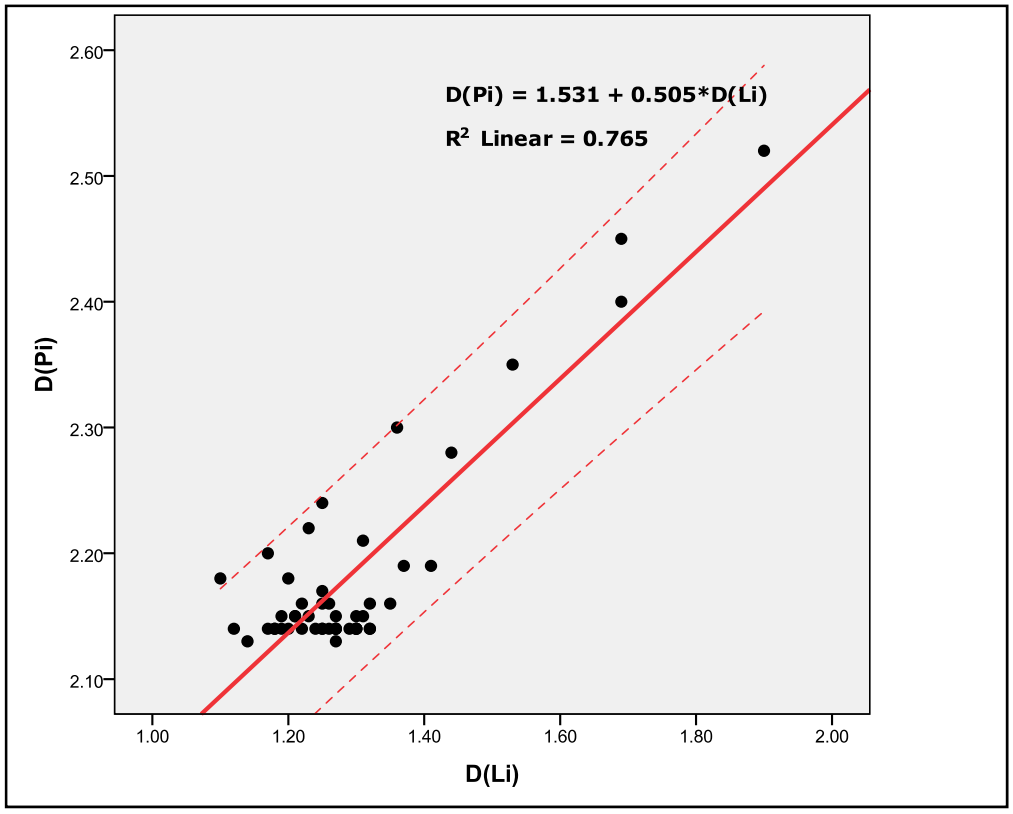

Figure 14: Relationship between fractal dimension of the road pattern and population distribution
Source: Prepared by Authors

Conclusion

As stated at the beginning, what is presented in this paper is only the preliminary findings of the initial stage of a long term project, aimed at exploring the feasibility of 'Fractal Geometry' in modeling the relationship between road network patterns and population distributions. The main finding here is that the areas with higher road fractal dimension were the ones with higher population fractal dimension and vice versa. In other words, there is a non-trivial correlation (correlation coefficient is 0.877 and significant at the 0.01 level) between the road fractal dimension and population fractal dimension and the

strong linear relationship (R^2 = 0.76) between those two variables. There are different types of roads which have different impacts, and major roads have a higher impact on urban population size. For example, highways are more effective than village roads in its effect to increase urban population. However, in this research they are treated as having the same impact instead of classifying them first. Therefore, this generalization may have impacted the overall result to a degree.

The results indicate the competence of fractal dimension analysis as a technique to model the relationship between road and population density. Spatial planners may find a strategic importance in this finding for two directions of interference with the region: the first requires a more passive involvement, where planners can identify and predict the population distribution trends throughout the region in question, and devise suitable policy strategies to enhance the ongoing trends. The second is the active interference, where the whole region can be re-modeled with a few carefully identified strategic projects and steer the population distribution trends in the region towards more desirable directions, deviating from ongoing trends. Further, it will enable transport planners' ability to plan transport networks considering future population distributions. However, it should be noted that in the above scenarios, road the network is only one factor in determining population distribution, yet it is an important aspect of promoting a location for population distribution. The study presented here may have some inbuilt limitations that need to be strengthened with further investigations. Yet, the initial findings shows favourable results to endeavour a wide scale research to analyze the population distribution and road patterns of different regions in Sri Lanka and to indicate situations where planned action is needed. Further, fractal values of the different cities are inbuilt and those values must be studied differently to identify the relationship between fractuality of roads and population in those different cities. Studies on the changes of fractal values in different years may provide a better understanding of how the fractuality of population and road pattern have changed according to the each other over time.

Finally it can be concluded that fractal analysis is a suitable method to read the patterns of Transport Network and Population Distribution and it will be a useful tool for spatial and transport planning application in the Sri Lankan context.

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An Agent Based Simulation for Home Interior Designing

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Abstract

Interior design is the art of making a space both comfortable and aesthetically pleasing; this is achieved mainly by applying interior design principles. Human involvements in the field of interior design do not produce a perfect design and do not apply all relevant techniques in the field of interior design. Furthermore, designing interior space by getting the service of an interior designer consumes a considerable amount of time and money. This agent based simulation solution for the interior designing process, using agent technology can help to address the highlighted issues. There are several agents for different elements in the interior spaces in this technology, such as a chair agent, a table agent, a light agent, a fan agent etc. According to architectural principles, these agents will consist of different properties. By considering the individual properties, these agents adjust the required elements in the proper order using interior design techniques. The Final output is obtained by communicating between different agents. By implementing this kind of agent base interior designing system, normal clients as well as interior designers can be facilitated, as agent technology has both power and control.

Introduction

Interior design is a profession that combines multiple aspects, such as functionality, the enhancement of quality of life, culture of occupants as well as aesthetic attractiveness [4]. The interior design process follows a systematic, ordered method which includes research, analysis and the integration of knowledge into the creative process; whereby the needs and resources of the client are used to produce an interior space which fulfils the goal of maximum efficiency and aesthetic quality. The popularity and importance of interior design has increased because of the increasing awareness of the roles played by interior designers. Interior designers plan and organize the design and decoration of interior spaces to produce creative and technical solutions that are applied within a structure to achieve a perfect interior environment. Interior design solutions are based on environmental aspects, human psychology, architecture, product design, and traditional decoration. An interior designer is responsible for the interior design, decoration, and functionality of a client's space, whether the space is commercial, industrial, or residential. Interior designers work closely with architects and clients to determine the structure of a space, the needs of the occupants, and the style that best suits the client to get the maximum efficiency from the space.

An interior designer has to consider all the required principles and techniques when carrying out a suitable design for an interior space. In this field, most interior designers choose a speciality to focus on, as an individual is incapable of handling the vast variety of design problems that arise. Furthermore, professional best practices of using a wide range of different skills in the design process is frequently not adhered to. Obtaining the assistance of an interior designer requires a considerable amount of money, whilst finding the right interior

designer who creates something beautiful and functional according to ones perspectives can be a real challenge. However when one attempts to design without professional assistance, by referring to design books and other material, problems arise due to the lack of experience in design and the lack of awareness on design principles in the interior designing field.

It is recognized that computer simulation, especially agent-based simulation, is valuable for studying complex systems. Computer simulation in general and agent-based simulation in particular, is a primary research tool of complexity theory [7]. Several agent-based simulation applications have been developed in many domains ([5], [9]).Despite this growing interest in applying computer simulation to study complex systems, there are only a few simulation studies that have been done in order to understand and model various configurations of computer supported work ([3], [6]).
Using this agent-based technology system can help efficiently plan the interior design of a building during the design phase. After deciding on the size of the place and the furniture that is going to be used, agents will decide the way in which the interior design should be handled. For each different aspect there will be multiple agents that will communicate with each other in order to determine the final placement of objects and final selection of colours to be used. In this simulation, interior design principles related to each object will be the properties of each agent that are considered when placing objects in a space.

Current State of Interior Design

There are currently only a few interior designing/decorating systems and even fewer computerized designing systems related to interior design implemented in the world; of these, few use proper interior design principles for the purpose of design.

A. *Manual Interior Designing and Software Aided Manual Interior Designing*

The extensive use of computer design systems in commercial interior design is fairly new in the field. People still seek the help of professionally qualified interior designers to design their home/office/trade centres in the most aesthetically pleasing manner. This is done in accordance with architectural principles that are not known to everyone. However, nowadays newspapers and websites help to consult regular people with regards to interior design [8].

Software such as AutoCAD, with its robust modelling capabilities enables commercial interior designers and architects to shape and visualize their ideas unlike ever before. According to AutoDESK, the redesigned interface of AutoCAD uses a single, easy-to-learn environment for creating both solids and surfaces. Designers can even create solid objects that have faces defined by complex surfaces. Applying materials to a model is a simple task requiring one to simply drag materials from a predefined library onto any solid face or surface defined in their model.

Computerized interior design is a major technological advancement for designers as it has helped to speed up the design process. Computers have helped to reduce delays and cut the time that designers have to work on a project by half and also allowed for the electronic transfer of files. A project that could have taken several weeks now can be done within a couple of days by software such as AutoCAD. But designing is essentially a human act and as such any human involvement can lead to native errors unlike a fully automated system.

B. *Computerized Interior Designing Expert System.*

This technology is a computerized expert system [1] that allows home owners to enter their interior design requirements and select interior design treatments according to his/her design requirements. Through this technology, groupings of compatible interior design treatments are provided for the home owner to use in decorating their home. Another objective of this invention is to provide an expert interior design system which has the ability to validate selected interior design treatments, to ensure that the final interior design plan is integrated, consistent, aesthetically pleasing, and compatible with the homeowner's design wishes. In doing so this technology aims to reduce or eliminate the time and expense associated with employing a professional interior designer.

The above objectives are accomplished by the present computerized expert system. In order to provide home owners with selected interior design treatments in accordance with their preferences, the following are required;

- A computer processor
- A computer readable medium in electronic communication with the processor,
- A database in electronic communication with the processor which contains data to represent individual interior design treatments selectable by selection criteria
- An input device to communicate with the processor for inputting a homeowner's design requirements,
- An output device to communicate with the processor to provide an output to the homeowner.

This system process works by running a set of computer readable instructions embodied within the computer readable medium that enables the processor to receive the design requirements from the input device and select a set of interior design treatments by using the selection criteria in accordance with the design requirements, and producing an output set to the homeowner. As a result of this process the homeowner is provided the available interior design treatments according to the homeowner's design requirements. Fig.1 shows this approach using a flow diagram.

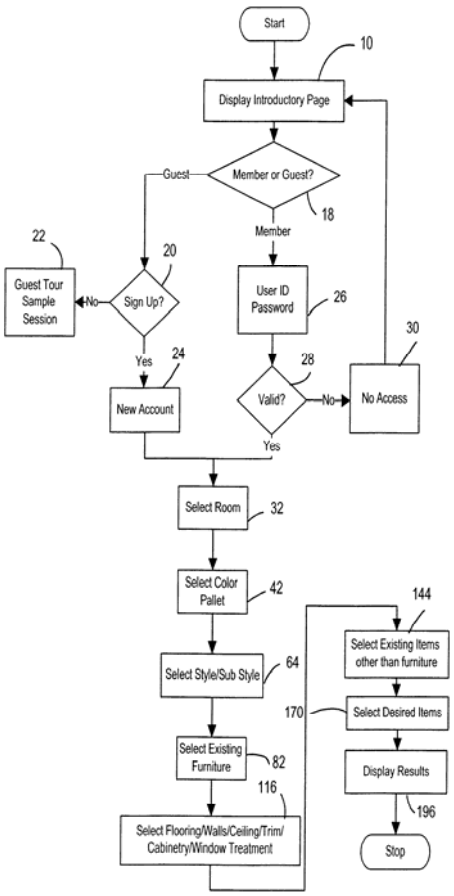

Fig. 1: Interior Designing Expert System

However like many other such expert systems, this computerized interior designing expert system also suffers a common issue, in its inability to adapt to changing environments, unless the knowledge base is changed.

Technology Behind Interior Design Simulation

Any Successful invention is backed by successful technologies that make the invention an effective one. So this section describes in comprehensive detail, the technological adaptation of the Agent methodology for interior designing simulation to deliver efficient and pleasing interior space.

A. Agent Technology

Agent Technology, especially the Multi Agent Technology plays a vital role in Interior Design as it provides a better solution for complex environments, as emphasized in the Pregogine's complexity science. In simpler terms an agent is a software program that works for the user proactively and recedes to the background once the job is done. Agent behaviour cause for effective resource consumption and can possess some human capabilities, such as intelligence, autonomy, reactivity, and pro-activity. Further the agent has to use reasoning to achieve its goals and build interactions with the environment to learn from the environment. Agents have sensors to perceive its environment and actuators to act on it as shown in Fig 2. The reasoning process takes place with this interaction. This kind of emerging intelligence is required to solve complex problems [2].

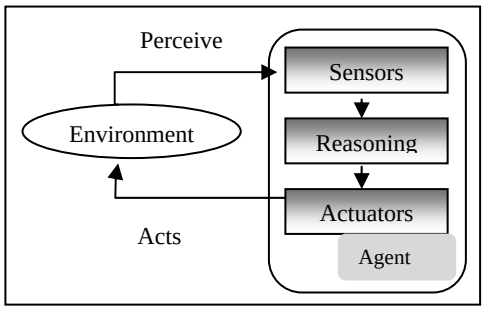

Fig. 2: Agents interaction with environment through actuators and sensors

The interior design process is a complex system where different entities are interconnected and behaviours of each entity are uncertain. In this context interaction among interior components can create novel designs. As changing the location of one entity affects another entity and a small disturbance may cause global change. This is also one of the features that can be seen in complex systems, which is known as the butterfly effect. Through this technology, interior components should autonomously adjust to suite with their new situation to create an effective design. Therefore the interior designing process should reflect this feature of self organization or adoption. This interior designing process is not at equilibrium, and one cannot expect the system to be stable until all the entities are correctly placed. So entities co-evolve with the environment and adopt with the situation to suite with the environment. As this process of interior designing reflects almost all the features of a complex system, this can be considered as a complex system.

In other fields, technology has a certain kind of power and control over humans. But with an agent like AI technologies both power and control are found within the technology, so as to minimize the errors that are likely to occur by human involvement. Furthermore agent technology suggests the problem solving strategy which could be used by sending messages to the appropriate entities, rather than applying algorithms. In this case, each agent which models the tables, chairs and other interior components is placed appropriately through communication. From the agent view point intelligence is an emergent field due to these interactions. As agent technology can work in an ubiquitous and interconnected environment by showing intelligence, accepting delegated commands and working together with humans to model interior spaces, it is the ideal solution to model these kind of complex systems. This can be a better

alternative to using an expert system which uses a static knowledge base.

B. Ontology

Any *sys*tem requires domain knowledge or task related knowledge to perform the relevant tasks, especially in the agent based system. Ontology plays the key role in representing knowledge and typically carries knowledge in terms of a set of concepts within a domain and the relationships between those concepts for agents to work. Ontology can be defined in a variety of ways either as an XML file, database or simply a text file. In the case of interior design domain, agents should be provided with the domain knowledge to carry out the necessary placement of components. All the required knowledge is presented using ontology within the JADEX toolkit which was used to develop the system.

The Design

This agent based interior design simulation design according to MAS architecture that is illustrated in Fig 3, shows the four components that are interconnected. Request agent is the one that supplies inputs to the system. Then the resource agent gives the output and most importantly the message agent mediates the communication between other agents. Furthermore input and output of the system communicate through the message agent.

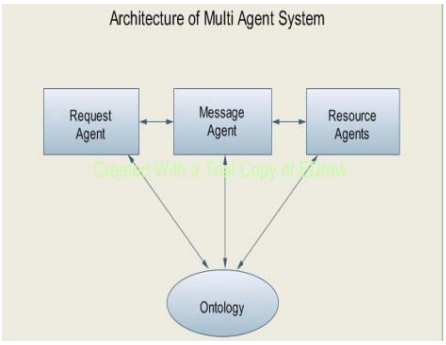

Fig 3: Top level MAS Architecture

For design and implementation simplicity, the overall system has been designed as a composition of a set of modules which can be implemented independently. Basically, on the top level view there are three core modules namely: the bathroom interior designing modules, bed room interior designing module and the dining room interior designing module.

A. Bathroom Interior designing Module

In the bathroom designing simulation, when the user inputs the size of the interior space that will be used for the bathroom, the fittings required, the preferred colours from the colour collection, the technology determines the most suitable places for the selected bathroom fittings according to architectural principles and the size selected by user. It also provides an output using interior design principles by considering the user's taste, and selecting the matching colours for the preferred colour collection. A typical MAS architecture for the bathroom designing module is illustrated below in the Fig 4.

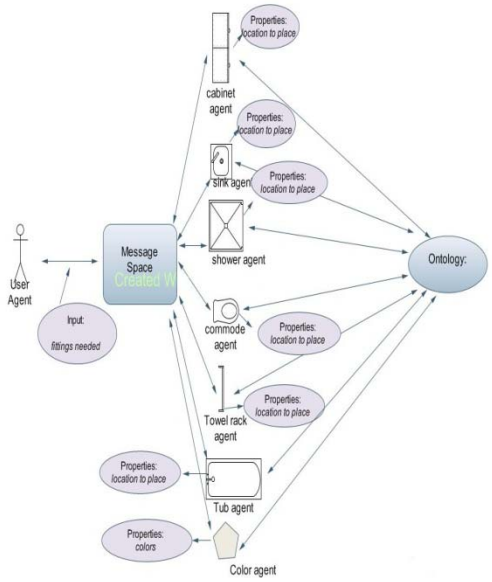

Fig 4: Bathroom designing architecture diagram

C. Bedroom Interior Designing Module

In the bedroom designing simulation when the user inputs the size of the bedroom; the appliances needed for the bedroom, the user type (adult or child) and type of theme preferred, the bedroom instruments (appliance) are placed in the most suitable place, according to architectural principles and the selected size. By considering the user's taste, as well as interior design principles, thematic concepts can be chosen from the given list.

This design process is shown in Fig 5 below.

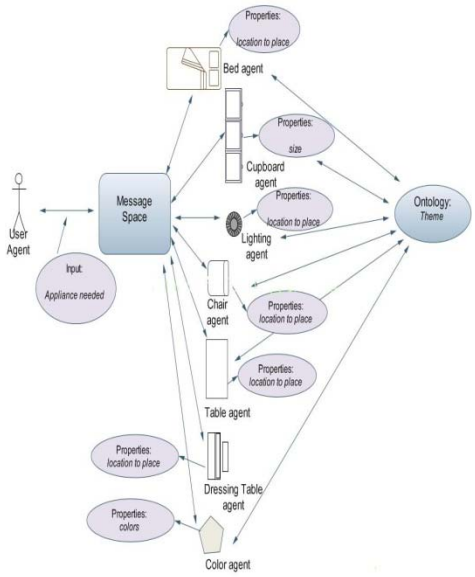

Fig 5: Bedroom designing architecture diagram

D. Dining Room Interior Designing Module

In the dining room designing simulation when the user inputs the size of the dining room, type of the dining room (i.e. whether it with a kitchen or only dining room), the interior components and theme preferred, the dining room instruments are placed in the most suitable places according to architectural principles and the selected size.

By considering the user's taste as well as interior design principles, thematic concepts can be chosen from given list. A typical MAS architecture for the dining room designing module is illustrated in the Fig 6.

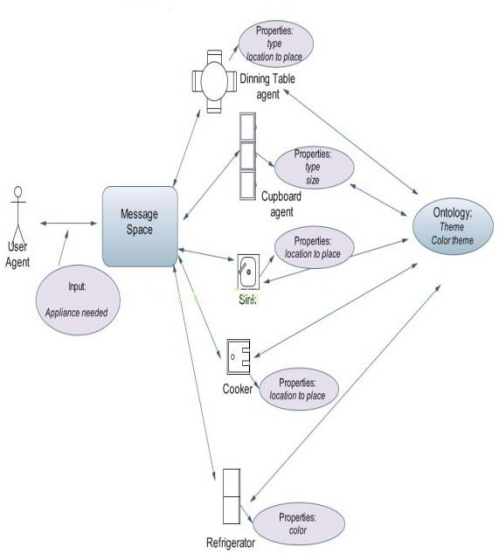

Fig 6: Dinning room designing architecture diagram

Implementation

Since the system mainly comprises of bathroom designing module, bedroom designing modules and dining room designing modules, implementation is carried out separately to achieve an increased level of flexibility and manageability. The typical agent working process is illustrated in Fig 7.

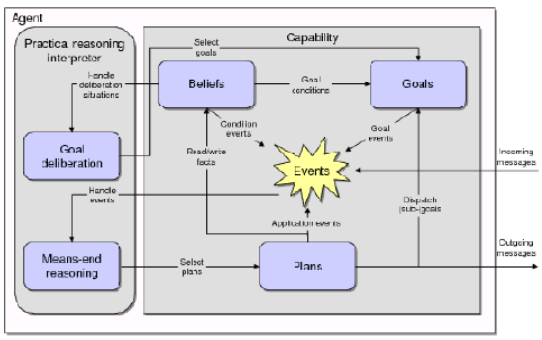

Fig 7: BDI agent working process

There are four major java classes to handle each module. They are; GoPlan.java, CheckingPlan.java, PickupPlan.java and TakePlan.java. Agents were defined using xml file which are integrated with java classes and are able to place the interior component in the correct place by being sensitive to the environment. The Algorithm used to integrate the above classes to agent behaviour so as to achieve the message passing phase is illustrated in Fig 8.

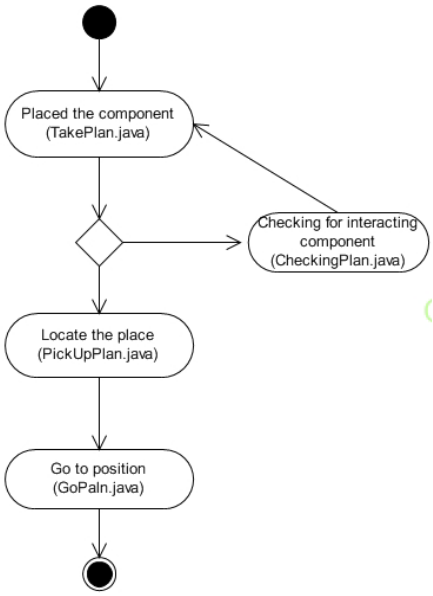

Fig 8: Message passing process

Evaluation

Any system's success or failure is identified through a proper evaluation mechanism. Therefore a systematic evaluation plan was carried out for Agent Based Interior Designing Simulation to gain a successful outcome. Since implementation followed a modular approach, initially unit testing along with functionality testing were conducted to test each module. In each individual module, including the bathroom designing module, the bedroom designing module, and the dining room designing module were tested for the expected functionality. After ensuring the proper functionality of each individual component, integration testing was carried out to check how well the modules were functioning after the integration. At the final level, a full system testing plan was designed using users who were looking to improve their interior space and users who have domain knowledge in the field of interior design.

Conclusion

Interior Design is a subject that applies to almost every type of building, including homes, hotels, corporate spaces, schools, hospitals, shopping malls, restaurants, and theatres. Complete interior design can be divided into sub sections such as bathroom designing, bedroom designing, dining room designing, living rooms etc. For this work, people need to get the service of an interior designer to have an accurate design. But obtaining the services of an interior designer generally tends to double the cost of the building/home. Furthermore, the existing systems for interior design are not fully capable to handle the issues at hand. So there is a clear need for an automated interior designing system to handle this matter and to help interior designers to do their work with maximum efficiency. By using agent technology, this system can plan the interior design phase of a building in an efficient manner. After deciding the size and other needed inputs for the design, agents will decide the way in which the interior design should be handled. Different multiple agents represent the interior components and final placement of objects that will be decided through communication between them. Interior design principles related to each object will be the properties of each agent which is used in deciding the placement. As such agent concepts such as sensitivity to environmental components, communication and negotiation address the interior designing

process comprehensively which create a complex system. Ultimately the implemented agent based interior designing simulation achieved its target successfully.

Acknowledgment

We would like to express our gratitude to all those who gave us the support to proceed with a valuable project idea. We are deeply indebted to Prof. A.S.Karunananda, Professor attached to the Department of Computational Mathematics of the Faculty of Information Technology, University of Moratuwa who proposed this research idea and encouraged to go ahead with the project with his help, guidance, knowledge, stimulating suggestions. We would also like to acknowledge the contribution of Ms. Gayanthi Mallawarachchi who was a student of faculty of architecture for providing the domain expertise.

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Indoor Comfort Implications of Urban Microclimate: Case study of Office Buildings in Colombo

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Abstract

The equatorial tropics are experiencing an explosive urban growth. With intensified urbanisation comes a rapid increase in atmospheric carbon, dwindling resources and concerns over energy security. In this context the need to achieve thermal comfort by the adoption of passive strategies assumes a great significance.

There is clear evidence to the link between indoor thermal comfort and the urban microclimate. This study is a research initiative that aims at exploring the effects of the urban microclimate on the indoor thermal comfort level. The focus is on office environments along Galle Road, Colombo.

The research method initially establishes a representative typology of office buildings along Galle Road, Colombo. The computer simulation tool ENVI-met is used to model the existing urban microclimate and the strategies adopted for its improvement. The simulations establish the base external climatic parameters that effect the indoor environments.The indoor thermal comfort is simulated using DEROB-LTH. The simulated results are presented as comparative 'Thermal Heat Index' values.

Keywords – Thermal Comfort, Urban Microclimate, Tropics, Energy Use in Buildings

Introduction

The background climate of Colombo, a city affected by the 'Urban Heat Island' phenomenon, presents a barely-tolerable condition. Urbanisation and the ensuing local climate changes are making the achievement of thermal comfort by passive means, increasingly difficult. This is especially problematic in the urban tropics, which are doubly disadvantaged on account of the already oppressive heat being made worse by the deteriorating urban climate and the lack of financial resources and political will to re-direct urban growth towards a more favourable outcome. The worsening microclimate casts doubt on the efficacy of tropical design ethos of open buildings with fuzzy demarcation between the inside and the out (Emmanuel, 2009).

In this context the study is a research initiative to establish the adaptive and mitigatory ability of the urban fabric as key to managing the deteriorating trend of the microclimate in the growing tropical settings of Colombo, Sri Lanka and with it create a situation where passive building strategies can be made

effective in keeping the indoors thermally comfortable.

2. Background

Urbanisation has consequences not only on local warming but also on regional and perhaps global warming. The rapid development of tropical megacities poses a special problem in terms of managing such local warming from reaching the regional/global scale. However they also present an opportunity in that the increasing urban growth and associated infrastructure development could be used as a first line of defence against the vagaries of climate change. Such action remains within the urban planning and design domain and the phenomenon of UHI provides both a focal point as well as a political/policy opportunity to cities to contribute to the issue of adaptation to climate change. (Emmanuel et al, 2011)

In order to realise such a planning approach, the following need to be carried out (Mills, 2006):

1. The needs of designer (e.g. existing built forms and individual building needs),
2. A range of outdoor urban spaces,
3. The links between indoor and outdoor air,
4. Outdoor levels of comfort,
5. Case-studies that link design decisions to measurable impacts

Objective	Impacts	Limits		
		Buildings	Building groups	Settlement
Indoor comfort	Buildings	Location Materials Design (e.g. shape, orientation, etc.)	Access to sunlight and wind Air quality	Building codes
Outdoor comfort and health	Building Groups	Local climate change Emissions Materials/surfaces Building dimensions – flow interference & shadow areas	Building placement Outdoor landscaping, materials and surfaces Street dimensions & orientation	Guidelines on: Densities; Heights; Land uses; and Green-spaces
Energy use Air quality Protection from extremes	Settlement	Energy efficiency Air quality Urban climate effect	Mode and intensity of traffic flows Energy efficiency Air quality Urban climate effect	Zoning Overall extent and shape Transport Policy

Figure 1 : A summary of the tools are shown as gray diagonal highlights. These tools are to be employed at the building, building group and settlement scales to achieve climatic objectives at those scales. The application of tools at each scale has a climate impact, shown below the diagonal cells, and places limits on decisions made at other scales, shown above the diagonal cells. (Source - Mills, 2006)

As shown in Fig 01 above, the widespread incorporation of the tenets of sustainability into planning offers an opportunity for including climate/weather issues into urban design on a routine basis. The global concern for climate change and resource use provides a mandate for the development of a coherent and broad-based applied urban climatology, which has not existed previously. In particular, it encourages research that is guided by the needs of planners/designers. (Mills, 2004)

Urban climate change mitigation in the warm humid tropics

Emmanuel (2005) presents amelioration strategies for the warm humid tropics in three main categories (based on a review of previous UHI studies from 1966-2005);

1. Increase vegetation cover
2. Increase thermal reflectivity (albedo) of urban surfaces, particularly roofs
3. Manipulate urban geometry.

The other significant mitigation strategy at local and mesoscale is ventilation enhancement. An analysis of a typical case of equatorial thermal comfort as cited in Emmanuel (2010) states, "barely tolerable conditions may be had only with excessive wind movement (> 0.6m/s).

The achievement of such wind movements by passive means (especially in the indoors) is nearly impossible. Since temperatures and relative humidities are high, dehumidification is also necessary. This will involve the use of energy: no passive dehumidification technology applicable at a 'whole-house' scale exists at present". In consideration of the above, the current study focuses on vegetation cover, albedo, and shade by manipulating the urban geometry as the main strategies.

1. Increase vegetation cover

The importance of urban greenery to human comfort at street level is long recognised. (Bowler et al, 2010). The effect of increased vegetation cover on street level air temperature is deemed not as significant as that of its effect on outdoor thermal comfort. Spangenberg et al., (2009) explored this by incorporating street trees in urban canyons in Sao, Paulo, Brazil. Here it was found that the effect on air temperature was limited, although there was significant cooling of the street surface and the mean radiant temperature at pedestrian height.

2. Increase thermal reflectivity (albedo) of urban surfaces, particularly roofs

In the typically low wind speeds prevalent in tropical cities, the effect of facade materials and their colours assume greater significance. Priyadarshani et al., (2008) found that low albedo facade materials in Singapore led to a temperature increase of up to 2.5°C at the middle of a narrow canyon. Emmanuel and Fernando (2007a) found that high albedo could make sunlit urban street canyons up to 1.2°C cooler in Colombo, Sri Lanka.

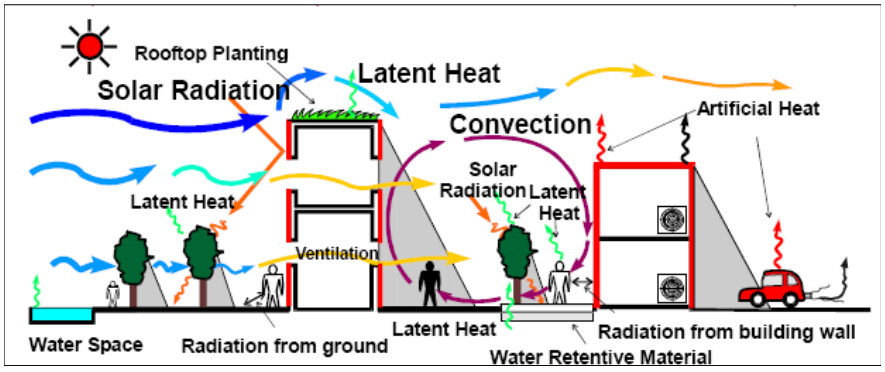

Fig 02 - Typical microscale UHI causes and amelioration options. The canyon on the right demonstrates the negatives while the canyon the left is an example of the positive measures that could help the indoors and outdoors. Source – http://www.ibec.or.jp

However, it is important to keep in mind that albedo enhancement strategies are more likely to show improvements in air temperatures than thermal comfort (Emmanuel et al, 2007b).

3. Manipulate urban geometry

The primary design strategy to manipulate urban geometry is to enhance the shading potential of the urban mass. It may be noted that sun control of individual buildings in the tropics where the sun is closer to the azimuth, is relatively easy. It is therefore necessary to enhance the comfort potentials of the urban outdoors in the tropics where considerable living occurs. (Emmanuel, 2010)

Evidence from the warm, humid tropics as well as from cities with warm, humid summer conditions indicate that shade (either caused by buildings or trees) to be the single most important design parameter in determining local warming/cooling as the radiative flux from direct sunlight has a strong influence on the heat balance of the body (Taylor and Guthrie, 2008). Emmanuel and Johansson (2006) showed that shading can be the main strategy for lowering air and radiant temperatures in the warm, humid city of Colombo, Sri Lanka, using a more compact urban form with deeper street canyons, covered walkways and shade trees.

Linking the 'outdoors' to the 'indoors'

Colombo's UHI is well documented. (Emmanuel and Johansson, 2006. Emmanuel and Fernando, 2007. Emmanuel, Roseland and Johansson, 2007). These studies encompass the effects of the nocturnal as well as the daytime UHI characteristics. The mitigation and adaptive strategies that are discussed mainly focus on UHI amelioration and making the urban outdoors thermally comfortable for pedestrians.

Although, outdoor thermal comfort cannot be ignored, it is well established according heat transfer theories, that indoor temperature significantly depends on outdoor temperature. Therefore, the exploration of the link between the urban microclimate and indoor thermal comfort is key, to provide for buildings that adopt passive strategies for thermal comfort and thus, reduced energy use.

Emmanuel (2010) quantifies the thermal comfort consequences of design choices at both the settlement and building levels. The study for a proposed housing estate in the central lowlands of Sri Lanka, showed that substantial improvement in indoor thermal comfort is possible, but also established that efforts to do so needs start at a neighbourhood scale.(i.e. outside the building). He states "Indeed, the manipulation of settlement geometry, street orientation and external factors such as street trees are key to achieving thermal comfort in the equatorial tropics"

This research is focussed upon an area that has yet to be explored for the specific urban context of Colombo, Sri Lanka. It looks at high energy consuming (especially for creating thermal comfort) office buildings along Galle Road, Colombo, where bulk of the building type is seen. It is deemed that knowledge gained on how best to address 'indoor thermal comfort' of a crucial building type, in the most critical part of Colombo, is important in its contribution to establishing a basis for a more holistic approach to designing for the future of the city, in both the urban and building level .

The Method

The research is approached in a step-wise manner, such that the results of each step are used to drive the next. The research method initially establishes a representative typology of office

buildings along Galle Road, Colombo. The computer simulation tool ENVI-met is used to model the existing urban microclimate and the strategies adopted for its improvement. The simulations establish the base external climatic parameters that effect the indoor environments. The existing parameters as well as those of the simulated cases are then modelled for indoor thermal comfort using DEROB-LTH (Dynamic Energy Response of Buildings). The simulated results are presented as comparative 'Thermal Heat Index' values.

The method of using ENVI-met to simulate the urban outdoors and mitigation strategies were adopted in Emmanuel and Fernando (2007a) and Emmanuel, Roseland and Johansson (2007b) for Colombo and in Emmanuel (2010) for Anuradhapura in Sri Lanka. Emmanuel et al (2007b) also validated the simulation software for the warm humid climate of Colombo. The method of simulating indoor thermal comfort using DEROB-LTH with parameters from simulated microclimates using ENVI-met was adopted in Emmanuel 2010, where it was used to simulate the best way to layout a 1500 unit housing scheme(Anuradhapura, 8°20'N,80°25'E) in terms of both outdoor and indoor thermal comfort.

Site Selection

The main focus of the research is Colombo, located at 6°54'N, 79°52'E on Sri Lanka's West coast. The main transport axis in the city, Galle Road, runs N–S some 200 m parallel to the coast and is bordered by an almost continuous skyline of medium-rise commercial and office buildings along much of its length within the city.
Colombo is fast changing in terms of land use patterns and building morphology. This factor is further highlighted in the Sri Lanka Urban Development Authority, "Zoning Plan 2020 for City of Colombo", which zones the Galle Road environs for increased growth. Most of the recently developed office buildings adopt large façades of glass or aluminium cladding and thus use air-conditioning for indoor thermal comfort.

Urban Canyons on Galle Road

Fig 3 highlights the typical canyon geometry along Galle Road. The most predominant of which is seen as a canyon with a Height to Width (H:W) ratio of 0.75 to 1.0.

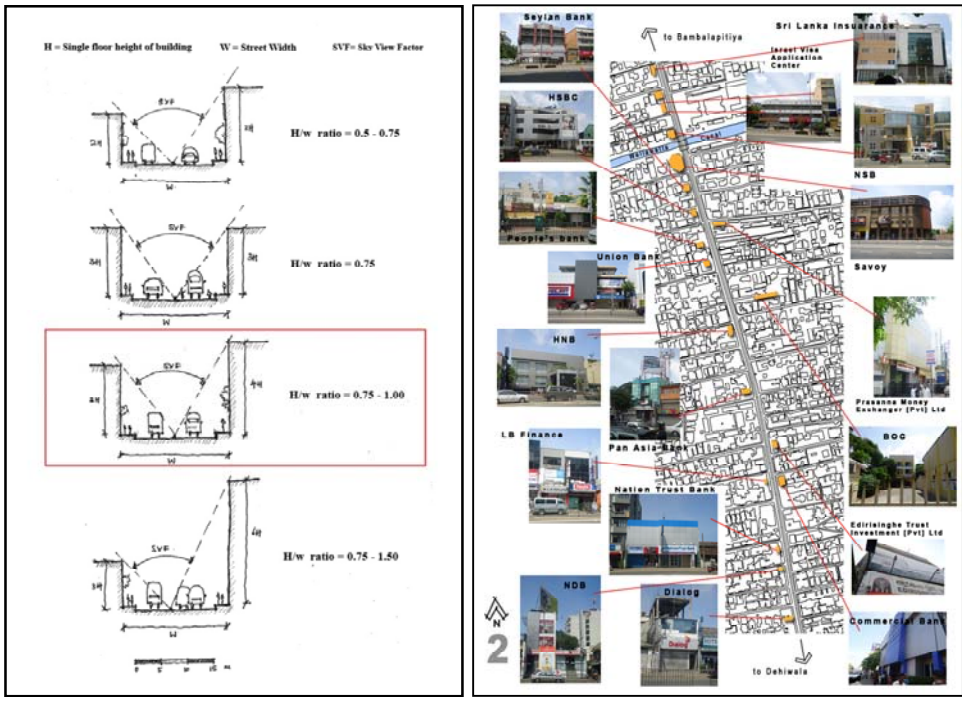

Fig 03 - Typical canyon geometry along Galle Road and survey of office buildings

Climate conditions

Colombo is a lowland region with a typically hot humid climate that is affected by the seasonal wind reversal of the Asiatic monsoon. The monsoon blows from the SW from late May to late September and the NE from late November to mid February. Air temperature and humidity are high throughout the year. Wind speeds are low, especially during the Inter-monsoon periods of March to April and October to November. The annual rainfall is 2300 mm, with 2 seasonal peaks. Solar radiation is intense under clear sky conditions. However, there is a high probability of cloud development, especially during the afternoon. The mean daily sunshine duration varies between 5 hrs in June and 9 hrs in February. [Based on data from Colombo city station, 1970–2004(Department of Meteorology, Sri Lanka)] (as cited in Emmanuel and Johansson, 2006)

Representative typology of office buildings on Galle Road

The research method initially adopts an in-depth survey of office buildings along Galle Road to build a representative typology.

The parameters adopted for classification are facade orientation, materials of the building envelope, window to wall ratio, number of floors, H:W ratio of the street canyon, plot coverage, dimensions of the building footprint, external floor materials and A/C usage.

Table 01 shows the typical office building parameters. The main difference highlighted is the extent

of the plinth and therefore the shape of the building. The buildings East or West siting along Galle Road is also highlighted.

Table 01 - Representative Typology of Office Buildings

Parameter			Typical value
Typical storey height		-	4
Typical floor to floor height		-	4m
Typical building height to street width ratio		-	1
Typical window to surface area ratio		-	¾ [75%]
Typical window material		-	Tempered glass
Typical wall material		-	Brick , Cement mortar , Cement Plaster, Aluminium Cladding
Typical roof material		-	Concrete [slab, roof terraces]
Typical paving material		-	Concrete paving
Air conditioning usage		-	Fully air conditioned office floors are frequent
Building Shape (Plinth Area)	Type A	-	less than 100 m^2 (10x10)
	Type B	-	100 – 200 m^2(10x20)
	Type C	-	200 – 300 m^2(10x30)
	Type D	-	More than 400 m^2(20x20)

Simulation of existing and modified Urban Microclimate

The computer simulation tool ENVI-met is used to model the existing urban microclimate and the strategies adopted for its improvement. ENVI-met developed by Michael Bruse (University of Bochum, Bochum, Germany) reproduces the major processes in the atmosphere that affect the microclimate, including the simulation of wind flows, turbulence, radiation fluxes, temperature and humidity, on a well-founded physical basis (www.envi-met.com). The simulations establish the base external parameters that affect the indoor environments.

Case 01 – Morphology (High density case)
High density case 1**[HD1] –** H:W ratio from 1.0 to 1.5
High density case 2**[HD2]** – H:W ratio from 1.0 to 3.0

Case 02 - Thermal Reflectance (High Albedo case)
Albedo case 1**[R1] -** walls and roof Albedo from 0.6 to 0.8
Albedo case 2**[R2] -** roof Albedo from 0.6 to 0.8

Case 03 - Vegetation Cover (Green case)
Green case 1**[G1] -**15m high, light shaded trees @ 6m distance on both sides of Galle road
Green case 2**[G2]-**10m high, very dense leafless base trees @ 6m distance on either side of Galle road

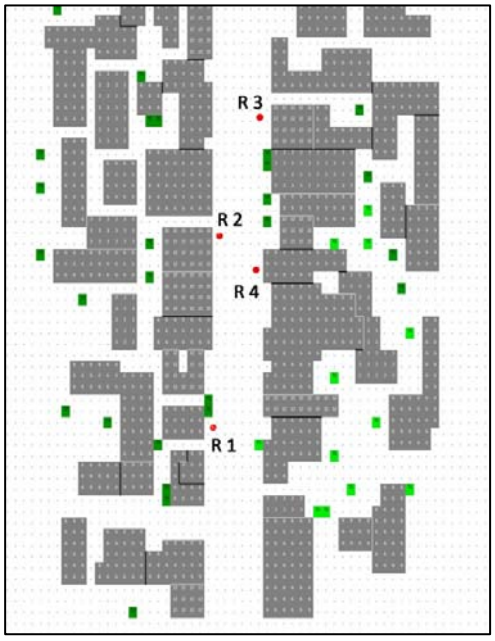

Fig 04 - ENVI-met model example (Mt Lavinia) showing simplified morphology

Results

The simulation results in Table 2 show the mean radiant temperature difference with that of the base (existing) case. The greatest effect of the strategies adopted is seen in the two High density (HD) cases. Minimal or no variations are seen in the high Albedo (R) and Green cases (G) for all building types considered. The Green cases show an increase in the MRT.

Table 02: Relationship between microclimate modifications and building type – Outdoor Mean Radiant Temperature Difference

Outdoor Mean Radiant Temperature Difference (°C) - Day						
	Microclimatic modifications					
Type	HD1	HD2	R1	R2	G1	G2
A - East	3.07	4.66	0.03	0.01	-0.03	-0.32
A - West	3.24	4.62	0.03	0.01	-0.01	-0.09
B - East	1.99	3.99	0.04	0.02	-0.1	0.43
B - West	1.12	3.13	0.04	0.02	-0.08	-0.27
C - East	1.87	3.5	0.02	0.01	-0.15	-0.27
C - West	1.96	4.01	0.02	0.01	-0.01	0.04
D - East	1.67	3.7	0.03	0.01	-0.13	-0.19
D - West	2.67	4.67	0.02	0.01	0.12	-0.06

Simulation of existing and modified Indoor Thermal Comfort

The indoor thermal comfort is modelled using DEROB-LTH. DEROB-LTH, which is an acronym for Dynamic Energy Response of Buildings, is an MS Windows based flexible simulation tool for thermal model design. The calculations are influenced by climatic factors such as outdoor temperature, solar radiation and the sky temperature. Properties for the indoor climate of the building are calculated based on the simulated results derived by the ENVI-met simulations.

The indoor thermal comfort is presented using the "Thermal Heat Index' (THI) developed by E C Thom in 1959. The Thermal heat Index is a parameter, which is used to account for the Thermal comfort effects of air Temperature and Humidity.

The Results

The simulation results in Table 3 show, the greatest effect of the strategies adopted are seen in the two High density (HD) cases. Minimal or no variations are seen in the high Albedo (R) and Green (G) cases for all building types considered.

High Albedo case 2 (R2) sees a slight increase in the THI level, in the building types A and B. Therefore it is deemed less comfortable than the existing indoor condition.

- Buildings of Type C and Type D on the East side of the street are more positively affected than those on the West side of the street.

Case 02: Thermal Reflectance (High Albedo case)

- An increase in Thermal Reflectivity has a minimal or no effect on indoor thermal comfort.
- An increase in the Albedo of both wall and roof (R1) has a more positive effect than increased Albedo of the roof only (R2)

Indoor 'Thermal Heat Index Difference (°C) – Day (2:30pm)						
	Microclimatic modifications					
Type	HD1	HD2	R1	R2	G1	G2
A - East	6.65	10.45	0.54	-0.14	0.68	0.68
A - West	7.32	10.45	0.54	0	0.54	0.41
B - East	5.02	8.95	0.41	-0.27	0.41	0.27
B - West	5.4	10.45	0.41	-0.14	0.41	0.27
C - East	4.85	9.15	0.41	0.41	0	0
C - West	3.26	5.8	0.41	0.54	0.27	0.27
D - East	7.12	11.3	0	0.14	0	0
D - West	4.61	7.19	0.54	0.54	0.54	0.54

Table 03: Relationship between microclimate modifications and building type –Indoor Thermal Comfort ('Thermal Heat Index' Difference)

Analysis

Results and analysis of the simulations establish that;

Case 01: Morphology (High density case)

- Modified Urban Morphology has a positive effect on indoor thermal comfort.
- An increased H:W ratio (3.0) seen in case HD2 has a more positive effect on Indoor Thermal Comfort than case HD1 (H:W = 1.5)
- Buildings of Type A and Type B on the West side of the street are more positively affected than those on the East side of the street.
- Buildings of Type A and Type B see a slight reduction of indoor thermal comfort when the wall Albedo is increased (R2)

Case 03: Vegetation Cover (Green case)

- Modified Vegetation Cover has a minimal or no effect on indoor thermal comfort.
- Height of the trees adopted (G1 and G2) have similar effect. Thus no change is seen between cases except in Type A situated on the West side of the street and Type B on both sides of the street, where case G1 with 15m light shaded trees yield better results.

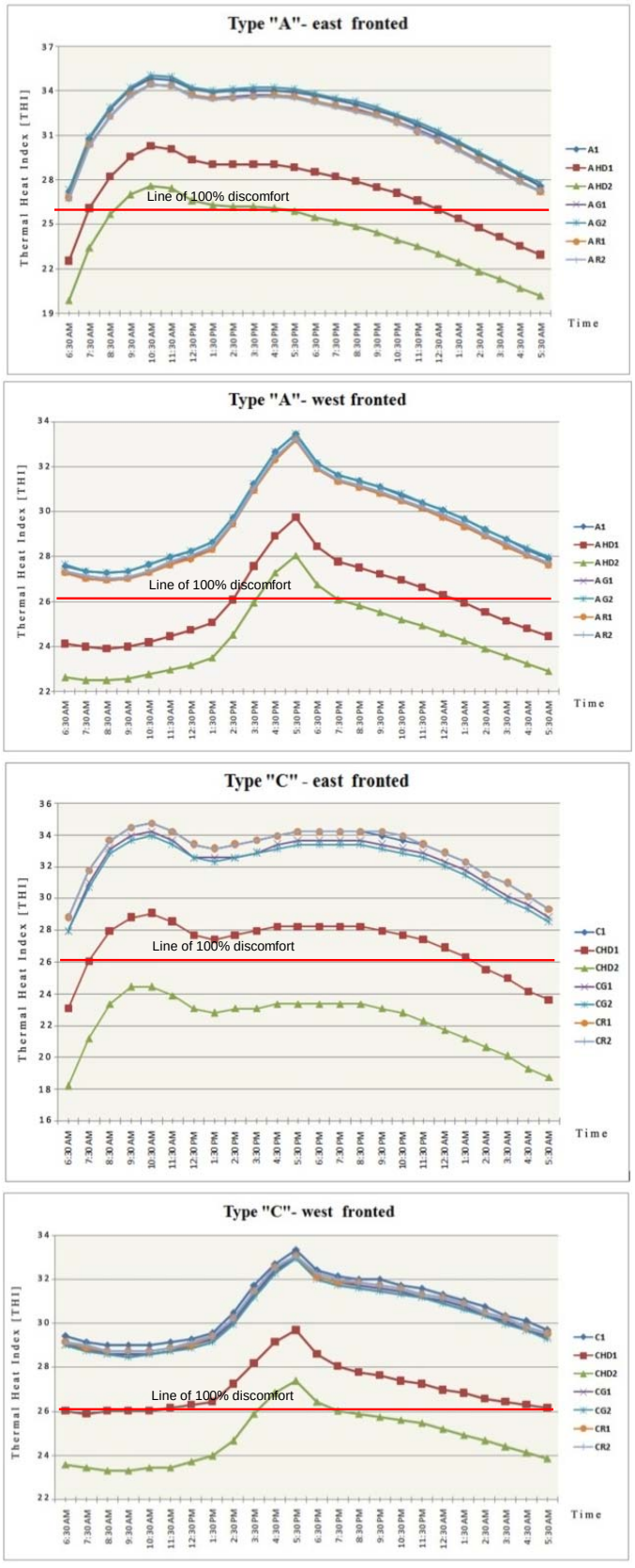

Fig 05 – THI Difference in Type A and Type C

Conclusion

The analysis showed that, where there was a clear improvement in the microclimate as in Case 01 (High Density case), the indoor thermal comfort also saw a comparative improvement. The improvement of the microclimate is attributed to the increased 'shade' created by the taller buildings along North-South oriented Galle Road.

The High Albedo (Case 02) and the Vegetation Cover (Case 03) adaptation options did not show a significant effect on the microclimate along Galle Road. Thus, the effect on the indoor thermal comfort was also minimal.

As shown in Fig 05; the high density cases allowed the indoor thermal comfort parameter to fall within the comfortable range for most of the building types considered. This will allow a significant saving on energy used in the currently air conditioned office buildings along Galle Road, Colombo.

The study explored the effects of the urban microclimate on the indoor thermal comfort level. The focus was on office environments along Galle Road, Colombo. The results clearly show the link between indoor thermal comfort and the potential of the urban microclimate to positively contribute to a more holistic solution.

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Literature Review on Lean Implementation Cases in the Construction Process

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Abstract

Lean construction is a concept still new to many in the construction industry around the world. All construction activities can be divided into two; conversion activities which produce tangibles and flow activities which bind such conversion activities during the delivery process of the output. Although all activities expend cost and consume time, Lean Principles states that only conversion activities add value and these should be made more efficient, whereas non value-adding flow activities should be reduced or eliminated. By eliminating wasteful non value-adding activities, processes can become 'lean' which provide 'more with less' resources.

Research into these lean principles in construction has found that considerable waste lies in flow activities of the construction process. However, construction contractors are mainly aware of the waste associated with material usage during the construction process and are ignorant on wastes associated with flow activities. Previous research has found major causes and types of wastes in flow activities and also that they significantly hinder performance and efficiency in the Sri Lankan construction industry. Hence, it is high time that the Sri Lankan construction industry start considering lean construction to improve its overall performance. However, the Sri Lankan construction industry lacks an implementation framework to implement lean principles into construction processes. The research study, on which this paper is based on, ultimately aims to develop such an implementation framework through an action research study for Sri Lankan construction contractors.

Other countries such as the United Kingdom, United States of America, and Singapore have reaped sustainable benefits through proper implementation of lean construction. Extant literature offers several case studies on such lean construction implementations. Hence, this paper offers a critique on these case studies, as an initial step to develop an implementation framework for Sri Lanka. Accordingly, few case studies are critically compared with their construction settings. The findings reveal several similarities in the lean implementation in different settings and deviations are also identified. The paper finally, identifies the most commonly applied lean techniques for implementing lean principles in construction processes and its benefits. It is hoped that the key literature findings arising from this stage, will ultimately assist to develop a conceptual implementation framework using lean principles for the construction process.

Key words: Lean Implementation, Construction Process, Review of case studies

1.0 Introduction

1.1 Lean Principles

Lean production was developed by Toyota led by Engineer Ohno who was dedicated to eliminate waste (Howell, 1999). The term 'lean' was coined by the research team working on international auto production to reflect both the waste reduction nature of the Toyota production system and to contrast it with craft and mass forms of production (Womack et al., 1991). Waste is defined by the performance criteria for the production system. Failure to meet the unique requirements of a client is waste. Moving towards zero waste shifts the improvement focus from the activity to the delivery system. (Howell, 1999). Similarly, Koskela (2004) determined that lean production is 'lean' because it uses less of everything when compared with mass production**.** Howell and Ballard (1998) redefined the goals of lean thinking as performance against three dimensions of perfection: i) a unique custom product, ii) delivered instantly, with iii) nothing in stores. This is an ideal that maximizes value and minimizes waste.

1.2 Lean Construction

Lean construction is a concept still new to many in the construction industries around the world (Senaratna and Wijesiri, 2008). All construction activities can be divided into two; conversion activities which produce tangibles and flow activities which bind such conversion activities during the delivery process of the output. Although all activities expend cost and consume time, Lean Principles state that only conversion activities add value and these should be made efficient, whereas non value adding flow activities should be reduced or eliminated (Koskale,1993). Research into these lean principles in construction has revealed that considerable waste lies in flow processes of construction. By eliminating waste activities, processes can become 'lean' which provide 'more with less' resources (Womack and Jones, 2003).

1.3 Background of the Research

Recent findings (Senaratne and Wijesiri, 2008; Senaratne & Nissanka, 2009) have revealed some of the frequent flow activities that generate waste and their causes in the Sri Lankan Construction Industry. Traditional thinking in most Construction organisations focuses on conversion activities and tend to *ignore flow and value considerations*. Waste is generally associated with waste of material in the construction process, while activities such as inspection, delays, transportation of materials and others are *not recognized* as non value-adding flow activities *that may lead to waste.* Common wastages include; waste due to wait periods, defects, waste due to design errors, transport/ handling time, activity delays, waste due to operations, excessive space / stock, and rework. The causes of wastes include; late information, environmental causes, poor management control, poor planning, poor quality of resources, shortage of resources, defective information, and unclear information. The majority of flow wastes and their causes are identified as controllable.

These flow wastes are recognized as a major weakness, which hinder the performance and efficiency of the Sri Lankan construction industry (Senaratne and Wijesiri 2008). Previous studies (Senaratne and Wijesiri (2008), Senaratne and Nissanka (2009) conclude that the domestic construction industry workforce is ignorant of these flow activities that create waste and hinder construction

performance. Through an opinion survey of the construction workforce, Senaratne and Wijesiri (2008) establish that lean construction is suitable and acceptable in the Sri Lankan context. This research aims to develop an implementation framework through an action research study of the Sri Lankan construction industry and achieve long-term, sustainable benefits by adopting lean construction.

Extant literature offers several case studies on such lean construction implementations. Hence, this paper offers a critique on these case studies, as an initial step to develop an implementation framework for Sri Lanka. Accordingly, a few case studies are critically compared with their construction settings. The findings reveal several similarities in the lean implementation in different settings as well as deviations that are also identified. Finally, the paper identifies the most commonly applied lean techniques for implementing lean principles in the construction process and its benefits. It is hoped that the key literature findings that arise from this stage, will ultimately assist to develop a conceptual implementation framework using lean principles for the construction process.

1.4 Lean Techniques

Egan (1998) revealed that Lean Construction presents a coherent synthesis of the most effective techniques for eliminating waste and delivering significant sustained improvements. The philosophy of lean is an umbrella that covers a multitude of tools and techniques commonly used within the industry (Salem et al, 2005). Several lean techniques were developed for the manufacturing industry by many authors, and Table 1.1 summarizes some of the lean techniques that relate to the construction industry. This paper will not describe all the techniques mentioned in Table1.1 in detail as the focus is on analysing lean implementation cases. However, more details on the given techniques could be found in Thilakarathna & Senaratne (2012).

Table 1.1: Lean Construction Techniques

Lean Techniques	**Definition**
Last Planner (LP)	Last Planner system is a technique that shapes workflow and addresses project variability in construction. LP has been created to maximize reliability of the work /material / information flow to minimize waste in time / money in project processes and to maximize customer value (Ballard, 2006).
Just In Time	JIT manufacturing has the capacity, when properly adapted to the organisation, to strengthen the organisation's competitiveness in the marketplace substantially by reducing wastes and improving product quality and efficiency of production. (Cheng and Podolsky, 1993)
3D Models	3D modelling is the process of developing a mathematical representation of any three-dimensional surface of object via specialized software. The model can also be physically created. The use of 3D models for improving constructability has typically included model based design and coordination by combining multiple models into one and running clash detection (Staub-French and Khanzode, 2003)

Lean Techniques	Definition
Increased Visualization	The increased visualization lean tool is about communicating key information effectively to the workforce through posting various signs and labels around the construction site. Workers can remember elements such as workflow, performance targets, and specific required actions if they visualize them (Moser and Santos 2003).
Value stream mapping	A value stream map is a comprehensive model of the project that reveals issues hidden in current approaches (Howell and Ballard, 1998). Value stream maps can be identified as Process Flow Charts that identify what action releases work to the next operation
Stopping the line	Stopping the line in manufacturing prevents the release of defective work downstream. Planning at the assignment level is the place to "stop the line" in construction to assure a reliable flow of work and no defective assignments are released downstream (Howell and Ballard, 1998)
Reverse Phase Scheduling (RPS)	RPS is a pull technique is used to develop a schedule that works backwards from the completion date by team planning (Ballard and Howell 2003). Phase scheduling is the link between work structuring and production control, and the purpose of the phase schedule is to produce a plan for the integration and coordination of various specialists' operations.
Huddle Meetings	Two-way communication is the key of the daily huddle meeting process in order to achieve employee involvement. As part of the improvement cycle, a brief daily start-up meeting was conducted where team members quickly give the status of what they had been working on since the previous day's meeting, especially if an issue might prevent the completion of an assignment (Schwaber, 1995).
Make it flow	Product components should be in constant motion, that is without stopping. In construction, this may mean repackaging work so that parts of the project can proceed without completion of others (Howell and Ballard, 1998)
Kaizen	Kaizen is a system of continuous improvement in quality, technology, processes, company culture, productivity, safety and leadership. Kaizen implicates cost reduction and zero defects in the final product
Five S	Five S is a set of techniques providing a standard approach to housekeeping within lean (Kobayashi 1989; Hirano 1998) visual work place: a place for everything and everything in its place. It has five levels of housekeeping that can help in eliminating wasteful resources
Fail Safe Quality	Shingo (1986) introduced Poka-yoke devices as new elements that prevent defective parts from flowing through the process. Fail safe for quality relies on the generation of ideas that alert for potential defects. This approach is opposed to the traditional concept of quality control, in which only a sample size is inspected.
Off site manufacturing (OSM) Prefabrication	OSM is largely seen as offering the ability to produce high-volume, high-quality products based on the efficiencies of general manufacturing principles common to many industries (Cooperative Research Centre for Construction Innovation, 2007). Manufacturing and assembling process, whereby, construction components are made at a location different from the place of final assembly, under specialized facilities with different materials. May lead to better control of the inherent complexity within the construction process

Lean Techniques	Definition
Target Value Design	TVD is a management practice that seeks to make customer constraints drivers of design for the sake of value delivery (Ballard, 2011). TVD is a method that assures customers get what they need (where it is valued by customers) and also a method for continuous improvement and waste reduction

2. Lean Implementation

2.1 Lean Project Delivery in Phases

Ballard (2000a) divides the lean Project Delivery System into four interconnected phases; Project Definition, Lean Design, Lean Supply, and Lean Assembly. Addressing sustainable issues such as economic, social, and environmental values as the requirement of an owner, Lean may act from the project definition to the construction phase.

Project Definition: Defining value and waste is critical and value management in lean production is an attempt to maximize value and eliminate waste (Bae and Kim, 2007). Ballard (2011) revealed that cost, time, location and other constraints are conditions that must be met in order to deliver value to customers. Target Value Design is a management practice that seeks to make customer constraints drivers of design for the sake of value delivery. According to Zimina et al (2012), target costing stands for a range of techniques and methods as part of traditional cost management, such as contract and cost management and target cost contract. It includes several phases: client brief, procurement advice and budget; cost planning and control of the design stage.

Lean Design: The building design process involves thousands of decisions, sometimes over a period of years, with numerous interdependencies, under a highly uncertain environment (Tzortzopoulos and Formoso,1999). Moreover, it is a very difficult process to manage and usually lacks effective planning and control to minimize the effects of complexity and uncertainty. Therefore, Huovila et al (1997) proposed a conceptual frame work for managing the design process in which three different views of this process are considered; a) design as a conversion of inputs into outputs; b) design as a flow of materials and information; and c) design as value generating process for the clients. Hence, recent researchers (Bae and Kim, 2007; Formoso et al, 1998; Tzortzopoulos and Formoso,1999) discussed the application of some lean principles to design management.

Lean Supply: Pasquire and Connolly (2002) revealed that Lean production has made significant improvements within the manufacturing sector and there is a simple argument that increasing the amount of factory based manufacturing of building, their components, sections and elements would form one logical method for incorporating lean production into construction project delivery. Lean techniques such as Just in time (JIT), off site manufacturing (OSM) reduce damages and materials. Moreover, these methods may reduce the various sources of extra inventory. Further, Pasquire and Connolly (2002) concluded that lean manufacturing has a direct application in construction through the pre-assembly of building

components and considerable benefits are available as a result of off-site manufacturing.

Lean assembly: Lean supply is the phase beginning with the first delivery of resources to the site and ending with project turnover (Salem et al, 2006). Moreover, it is particularly important to general contractors in the construction implementation stage. Further Salem et al (2006) expressed that there are approaches to Lean Assembly and these are flow variability, process variability, transparency, and continuous improvement.

Having identified the different phases in lean construction and related lean techniques that can be developed in lean construction, this paper summarizes different lean implementation cases implemented in different parts of the world with their main findings.

2.2 Lean Implementation Examples in Different Phases in a Construction Project

Over the last ten years an increasing number of companies have implemented lean construction practices in an attempt to improve the performance in construction projects. Most companies and researches have reported satisfactory results from their implementation (Alarcon et al, 2005). However, there is still a need to provide more extensive analysis of the empirical evidence available, to assess the impact of the implementation of lean construction. Extant literature offers several case studies on such lean construction implementations, and details of the research studies are summarized in Table 2.1.

Table 2.1: Lean Implementation cases

Name of the Study	Scope of the study	Research Methodology	Lean Technique applied	Main Findings
Project Definition and Lean Design				
Target Value Design: using collaboration and a lean approach to reduce construction cost ***Zimina,D., Ballard, G., Pasquire, C.,2012***	To find out how to cure the shortcomings of mainstream costs and contract management approach that result in regular cost over runs and client dissatisfaction	Action Research carried out on 12 construction projects in USA with a number of clients and construction industry companies	Target Value Design	Systematic application of target value design leads to significant improvement of project performances. The final cost of each project was on average 15% less than market cost. It was noticed that the positive effects of lean principles and methods on project management become more obvious as project complexity and the corresponding level of risk increase.
Sustainable Value on Construction project and Application of lean construction Methods ***Bae,J.W., and Kim, Y.W., 2007***	To examine how current lean construction tools and methods impact the construction and operation of sustainable facilities	Literature Synthesis	Target Costing, Just-in-time Prefabrication, Value Stream Mapping kaizen	**Economic perspective**; possible upfront cost reduction, resource saving, operating cost reduction, and high performance capability **Social perspective**; work place safety, occupant health, community wellbeing, loyalty among stakeholders, and external image improvement **Environmental Perspective**; reduce resource depletion, pollution prevention by eliminating wastes, and resource preservation

Name of the Study	Scope of the study	Research Methodology	Lean Technique applied	Main Findings
Considerations on Application of Lean Construction Principles to Design Management ***Tzortzopoulos, P. and Formoso, T. (1999)***	To analyse on the application of some lean construction principles to design management	Two Case Studies developed in Brazil with the development of a model for managing the design process for a small-sized house building company	Modelling the process using Flow Charts and Input-output chart	There are some gaps in the knowledge concerning the application of the theory in design. The development and implementation of models for managing the design process in practice is an important source of reflection and as such a discussion approach should be carried out in the future.
Lean Supply				
Leaner construction through off-site manufacturing ***Christine L Pasquire****, C. L.,* ***and Connolly, G.E.,*** *2002*	To examine the integration of lean production into the pre-assembly of building components	Case studies supported with multidisciplinary workshops managed by an industrial steering group with the support of major construction, consultants and client organizations	Off-site Manufacturing. Kaizen Kaizen Formula One Just-In-Time	Lean manufacturing has a direct application in construction through the pre-assembly of building components and considerable benefits; *reduction of on-site labour, welfare cost, health & safety risk, coordination interface, just in time delivery, reduce opportunities for waste, improved cost certainty, zero defects* as a result of off-site manufacturing
Lean Production, value chain and sustainability in precast concrete factory –a case study in Singapore ***Peng, W. And Pheng, S. 2010***	To identify the contribution of the lean concept to achieve sustainability in Precast Concrete Factories. By using appropriate lean principles, the precast concrete industry can move closer towards sustainability	Quantitative assessment of each non-value adding activity and qualitative assessment of activities that cannot be quantitative though semi-structured interviews of 17 pre-casters	Lean Production philosophy Value Chain	Lean Production philosophy can provide a lean benchmark for construction materials. It offers relative measurements of the sustainability factors for construction materials based on the best operations that can be achieved for long term comparison. Lean Production philosophy has practical contributions to sustainable development. By eliminating non-vale activities pre-casters can achieve more environmentally friendly construction materials

Name of the Study	Scope of the study	Research Methodology	Lean Technique applied	Main Findings
Lean Assembly				
Site Implementation and Assessment of Lean Construction Techniques ***Salem.O., Solomon.J, Genaidy,A. and. Luegring, M. 2005***	To test the effectiveness of some lean construction tools that can be applied in medium size construction firms	Direct observations, interviews, questionnaires and documentary analysis through the lean implementation measurements standards and performance criteria.	Last planner, Increased Visualization, Daily Huddle Meetings, First run studies, the 5S process, Fail safe for Quality.	Last Planner, Increased Visualization, Daily Huddle Meetings and First Run Studies achieved more effective outcomes whereas, 5S and Fail Safe for Quality did not meet the expectations of the tool champion and the research team. Last Planner is ready to be implemented where Visualization, daily huddle meetings, First Run Studies and 5S process are to be implemented with some modifications. Fail safe for quality to be re-examined.
Assessing the impact of implementation lean construction ***Alarcon,L. F, Diethelm, S., Rojo, O., and Caldero, R., 2005***	To analyze some of the main impacts and lessons learned from the Lean Implementation.	Data obtained from the authors own experience and case studies found in the Lean Construction Literature ***(Koskela 2000, Ballard 2000, Bernardes 2001)***	Last Planner System (LPS)	The poor use of information generated during the implementation of Last Planner System was identified as the main barrier for a more complete implementation. Early in the project, the research team had attempted to introduce Work Plan, a computer system developed by Choo (Choo et al 1999) for Last Planner System implementation. However, the companies did not feel comfortable using this system
Last planner and Integrated Project Delivery ***Cho, S, and Ballard, G., 2011***	To figure out the relationship between Integrated Project Delivery, Last Planner and Project Performance	Survey of 'Lean' projects known to adopt Last Planner	Last Planner System (LPS)	There is a significant correlation between the implementation of Last Planner and project performance; the sum of cost and schedule reduction percentage. If a project implements Last Planner more, it achieves project performance better than those employing Last Planner

Overall, the above findings reveal that lean techniques used in the manufacturing industry can be adapted in the construction industry in different phases of construction. Moreover, many researchers such as Salem et al, 2005, Ballard (2011) and Singleton and Hamzeh(2011) concluded that in construction projects where more lean techniques are applied, project performance and effectiveness are high. This paper will select lean implementation cases in lean assembly phase for a detailed review. Lean

assembly phase is found to be more relevant when compared to other phases, considering the ultimate aim of the this research is to develop a lean implementation framework for the construction processes for Sri Lankan construction contractors.

3. Lean Assembly Implementation

Lean Assembly is particularly important to general contractors who develop human and technical structure for construction activity (Salem et al (2006). Previous studies such as Senartna and Wijesiri (2008), Ekanayake and Senartne (2010) conclude that the domestic construction industry workforce is ignorant of the flow activities that create waste and hinder construction performance. Hence, it is vital to develop an implementation framework in the context of Lean Assembly for the Sri Lankan Construction Industry. The aim of this study is to develop such an implementation framework through an action research study for Sri Lankan construction contractors and achieve long-term sustainable benefits by becoming lean. As such it is important to critically evaluate the above three studies carried out in the phase of Lean Assembly in Table 2.1. The next section of this paper will discuss the similarities and deviations of the lean implementation of the above three studies and finally a summary will be given in Table 3.1.

3.1 Evaluation of Lean Assembly Implementation Cases

Case A: Site Implementation and Assessment of Lean Construction Techniques O. Salem, J. Solomon, A. Genaidy, and M. Luegring Lean Construction Journal 2005

The aim of this study was to test the effectiveness of some lean construction tools; Last Planner, Increased visualization, Daily huddle meetings, First run studies, the 5S process, Fail safe for quality that can be applied in medium size construction firms. Data was collected through direct observations, interviews, questionnaires and documentary analysis. The effectiveness of lean construction was evaluated through the lean implementation measurements standards and performance criteria.

The study focused on the first phase of a four-floor university garage project. This garage was a cast-in-place reinforced concrete structure which is to be built on top of the garage. This is a five story building that consists of a steel frame and reinforced masonry walls designed for retail shops and dormitories. The size of the garage is about 133,500 sq.ft. Participants in the lean construction implementation study were limited to the general contractor, the formwork subcontractor and the rebar subcontractor.

The findings revealed that Last Planner, Increased visualization, Daily huddle meetings and First run studies achieved more effective outcomes than 5S and Fail Safe for Quality, which did not meet the expectations of the tool champion and the research team. Further, the study disclosed that Lean construction is not widely implemented in US construction industry yet, as Lean concepts are relatively unfamiliar. For both General Contractor staff and sub contractors this project was the first opportunity to use lean techniques for operational purposes. Moreover, the findings divulged that initially in this project, changing mind sets and behaviour with lean thinking became a challenge, and this had a great impact on the 5S process implementation. The

unfamiliarity with or misunderstanding of lean concepts and implementation were the greatest barriers at the beginning of the project.
To eliminate this barrier, the general contractor had offered training classes, provided recognition to promote behavioural change, encouraged employee involvement and rewarded real improvement. As a result, the work force showed a tremendous amount of learning and improvement with regards to lean thinking and implementation. The findings suggest further training will be a key aspect of implementation and success of the Last Planner on the construction site. The staff and workers will need to be trained to use this tool effectively. This training may result in an increased burden in the early stages of implementation but over the long term it will serve to increase the efficiency of construction companies and more than make up for the initial investment in training.

The authors had also found that the lean manufacturing tools can be modified for specific use in construction projects and successfully implemented. The commitment of the top management for implementation of these tools may prove to be the most important factor for the successful implementation of these tools. The authors observed a complete attitude shift among project participants for this project; initially, the project manager questioned the applicability of these lean tools at the site, however, by the end of the project, everyone on site participated in the implementation of these tools. The workers enjoyed being a part of a structured planning and decision making process.

Finally the study concluded that Last Planner is ready to be implemented whereas Visualization, Daily Huddle Meetings, First Run Studies and 5S process are to be implemented with some modifications, and Fail safe for quality should be re-examined.

Case B: Assessing the Impact of Implementation Lean Construction
Luis F. Alarcon, Sven Diethelm, Oscar Rojo and Rodrigo Calderon
Proceedings IGLC, July 2005, Sydney, Australia

The aim of this study was to analyze some of the main impacts and lessons learned from the implementation. This study discusses difficulties and barriers for implementation, productivity improvements, variability reduction and effectiveness of implementation strategies. The study declares that the production Management Centre (GEPUC) from the Catholic University of Chile, promotes long term research and implementation alliances among companies to pursue common goals. The companies undertake their improvement programs working as a group. This allows collaborative sharing of problems and solutions to the individual process improvement. Some of the important activities developed under this scheme are; periodic meeting, Workshops, Preliminary Sessions and Site visits by the researchers. More details can be found in these methodological aspects in Alarcon et al 2002a and 2002b)

Data was obtained from the authors own experience and case studies found in the Lean Construction Literature (Koskela 2000, Ballard 2000, Bernardes 2001). A data base of 77 Chilean projects from 12 companies was used to analyze the impact of the introduction of the Last Planner System on different aspects of project performance. The project sample included: 39 low rise building projects, 15 high rise building projects, 11 heavy industrial projects, 12 light industrial

constructions. Data was collected during the research process carried out to develop implementation strategies for Lean Construction and to measure the impacts of those strategies. The analysis considered implementation of projects over three years.

Projects were classified in to two groups according to the level of implementation of the Last Planner System. The first group consisted of 10 projects with a basic level of implementation with an emphasis on the Weekly Work Plan, and only informal look-ahead planning. The second group included 6 projects that had formal look-ahead planning processes and one case of formal workable backlog and learning processes.

The findings revealed that the poor use of information generated during the implementation of Last Planner System was identified as the main barrier for a more complete implementation. Early in the project, the research team had attempted to introduce Work Plan, a computer system developed by Choo for Last Planner System implementation (Choo et al 1999). However, the companies did not feel comfortable using this system. Therefore, the research team had to develop a prototype computer system named "Plan Control", working closely with the companies and maintaining a continuous interaction with them during the system design. One of the main impacts of this tool was a more completed implementation of the LPS in projects that used" Plan Control". These resulted in higher PPC performance for those projects that used IT support compared with projects without IT support.

This study explored the benefits in implementing Last Planner System; this included working in a collaborative approach, with different training actions, sharing experiences and information among companies. This system produced a number of benefits, such as the development of skills for implementation, development of healthy competition among companies that are working together, and fast learning from successes and failures. Further, participating companies have realized that things are possible because there is always a project that can be done and that they can learn how to do it better the next time. Some implementation barriers were also identified in this study with regard to the implementation of LPS. These barriers include; a) Time: Lack of time for implementing new practices in the projects, b) Lack of training c) lack of organizational elements to respond to LPS, d) Lack of Self Criticism and limited the capacity to learn from errors, e) Low understanding of the concepts (production unit, work flow, screening, shielding, and pulling in LPS), f) Inadequate administration of the necessary information to generate a learning cycle and to take corrective action, g) Weak communication and transparency among participants, and h)Lack of integration of Client, Subcontractors and suppliers.

Finally this study recommended that Last Planner System is an effective tool to improve reliability of planning in projects and IT tools can support a more complete and standard implementation of the LPS in projects.

Case C: Last Planner and Integrated Project Delivery
Seongkyun Cho and Glenn Ballard
Lean Construction Journal 2011

The aim of this study was to figure out the relationship between Integrated Project Delivery (IPD), Last Planner (LP), and project performance. Three research questions were designed; i)

Does the use of Last Planner improve project performance? ii) Does Integrated Project Delivery show different project performance? iii) Do IPD projects use LP? Only Research question 1 is considered for this discussion since the other two do not directly relate with lean implementation.

The research methodology was adopted as survey of 'Lean' projects known to adopt LP, including IPD projects, to determine the correlation between LP implementation and project performance. Three hypotheses were assumed for this study, the first hypothesis being, "*if a project implements last Planner more, it achieves better project performance better than those employing LP less". Th*is hypothesis was considered for this evaluation since the other two hypotheses were only related to the research question II and III. This study identified the independent variable of the hypothesis as the degree of implementation of Last Planer (LP). To measure this concept, the authors have developed indicators to be scored based on the following elements.

i. *Pulling Production*: each worker investigates the readiness of the next workers before execution of tasks (Tommelein, 1998)
ii. *Lookahead process*: each front line supervisor removes constraints such as prerequisite work, contractual approvals, sequential inappropriateness, insufficient resource, inadequate duration, funding problems and problems found in first run study before execution of its tasks. Constraints tasks are not eligible for inclusion on daily or weekly work plans (Ballard, 2000).
iii. *Learning from breakdowns*: failures to complete planned tasks are analyzed to root causes and actions are taken to prevent reoccurrence (Ballard, 2000).
iv. *Phase scheduling*: every handoff in a phase should be defined by collaboration of all relevant specialists in the phase before the handoff is produced (Ballard et al, 2003).
v. *Distributed Control*: work is planned in greater detail as you get closer to execution, and planning is done collaboratively by those who are to do the work (Ballard et al, 2003).

The above five indicators were transformed into survey questions and answer type with scoring rules were established. The sum of scores of the survey questions is the total degree of Last Planner implementation of a project. Moreover, in this study, the dependent variable, project performance was identified and the measure of the project performance was; sum of the cost reduction ration (actual cost under final approved budget) + duration reduction ratio (%) (actual duration relative to final approved schedule). Data was analyzed in the regression model and presented as a scattered plotting and a linear regression line.

Findings revealed that there is a significant correlation between the implementation of Last Planner (LP) and project performance and the authors successfully supported the hypothesis "*if a project implements last Planner more, it achieves better project performance better than those employing LP less"*

3.2 Comparison of above three cases

Three studies conducted for implementing lean techniques in the Lean Assembly phase were summarized as Case A, Case B, and Case C and Table 3.1 presents the comparison of these three studies evaluating their similarities and deviations.

Table 3.1 : Comparison of lean Assembly Cases

Criteria	**Case A**	**Case B**	**Case C**
Phase of construction	Lean Assembly	Lean Assembly	Lean Assembly
Main Lean Technique applied	Last Planner System	Last Planner System	Last Planner System
Lean Implementation	Last Planner is ready to be implemented	Last Planner System is an effective tool to improve reliability of planning in projects	Last Planner achieves better project performance
Observations			
Attitude shift in the project participants	changing mind sets and behaviour with lean thinking became a challenge initially	development of skills for implementation	Not observed
Use of Information generated	Not observed	poor use of information generated during the implementation	Not observed
Time Factor	Not observed	Lack of time for implementing new practices in the projects	Not observed
communication and transparency	Not observed	Weak communication and transparency among participants	Not observed
integration	Not observed	Lack of integration of Client, Subcontractors and suppliers.	Not observed
Understanding of Lean concepts	Lean concepts are relatively unfamiliar	Low understanding of the concepts	Not observed
Requirement of Training	Training will be a key aspect and the staff and workers will need to be trained	Lack of training	Not observed
Behavioural Change	Changing mind sets and behaviour with lean thinking became a challenge initially	Not observed	Not observed
The commitment of the top management	The commitment of the top management for implementation of these tools may prove to be the most important factor in successful implementation	lack of organizational elements to respond to LPS	Not observed

The Last Planner lean technique is commonly applied in all cases and it was identified as an effective lean technique in construction processes. Findings revealed further that, changing mind sets, low understanding of the concepts and behaviour with lean thinking are the challenges faced in implementing lean technique and as such training will be a key aspect to overcome most of these barriers.

4.0 Conclusions and Way Forward

This paper reports on the literature review of Lean Implementation cases in the construction process in order to develop a lean implementation framework through an action research study for Sri Lankan construction contractors. Initial discussions in this paper was on Lean Principles, Lean Construction and Lean Techniques that can be applied in the construction projects identifying different phases such as Project Definition, Lean Design, Lean Supply and Lean Assembly. Lean Techniques especially applied in Lean Assembly were also disclosed in order to develop a framework for the Sri Lankan Construction Industry. Lean Implementation cases, obtained from a literature review, were first identified with their main observations. Subsequently, three studies that relate to lean assembly phase were critically evaluated to identify their similarities and deviations in implementing lean techniques in the construction process.

Preliminary literature review into lean construction implementation was carried out (Thilakarathna and Senaratne, 2012) to explore the lean techniques and their applications with benefits and barriers. Following which, this paper presented the lean implementation cases through literature survey to identify the most commonly applied lean techniques and their implications in the construction process in different project settings. The next objective of the research was to explore the current status of implementation of Lean techniques within construction projects in Sri Lanka through a preliminary survey by interviewing C1 contractors in Sri Lanka. Following this survey results, a conceptual framework would be developed which is expected to be tested through an action research phase.

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Use of Mathematical Modelling for Planning Municipal Solid Waste Collection

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Abstract

When people hear the term "Solid waste management" they immediately think of recycling. But it is not the aspect that requires the greatest expenditure, or has the greatest impact on the urban environment and public health. It is the "collection" of municipal solid waste that has a significant impact on both municipal expenditure and public health.

The decisions pertaining to solid waste collection and transportation are basically based on the perception and experience of drivers and other minor staff working at the municipalities. The optimum utilization of available resources within the municipalities for day to day collection of waste is essential as it makes the biggest demand on the Municipal budget.

Therefore the main objective of this research is to develop a mathematical model as a tool for decision making in municipal solid waste collection. This research has utilized two mathematical models known as "Network Analysis" and "Transportation problem method" to achieve the aforementioned objective.

The case study of this research is based on the proposed project of implementing three Integrated Resource Recovery Centres (IRRC) in the Matale Municipal Council (MC) to manage the solid waste by means of producing compost and recycling. By applying the two mathematical models, the research has shown the possibility of reducing the daily solid waste collection cost within the Matale MC Area.

Keywords: Solid Waste Collection, Network Analysis, Transportation Problem Method

1.0. Introduction

Cost analyzed by Ludwig and Black (1968) reveal that 85% of the solid waste system cost is due to collection, and only 15% to disposal. Therefore there is an increasing demand for greater efficiency, so as to minimize the solid waste collection costs, while providing an adequate and regular service to all of the target area.

This research is based on a proposed project of establishing three Integrated Resource Recovery Centres (IRRCs) at Matale Municipal Council (MC) for the purpose of Municipal Solid Waste (MSW) Management. IRRC is the place where the collected solid waste is further managed to produce compost and recycled. Therefore applying mathematical models to solid waste collection can lead to a significant saving in the overall cost, once the project is implemented. The collection system proposed through this research is based on solid waste collection points, road network, location of Integrated Resources Recovery Centres (IRRCs), capacity of the tractors and the population in the area under study.

First, the theoretical and methodological aspect of Municipal Solid Waste Collection, mathematical models and several past case studies of

application of mathematical models in planning municipal solid waste collection, were reviewed. Thereafter two mathematical models were introduced and applied for Matale MC Area to plan activities pertaining to solid waste collection in a cost effective manner.

2.0 Case Study

The case study of this research is based on the proposed project of implementing three Integrated Resource Recovery Centres (IRRC) in Matale Municipal Council (MC), to manage the solid waste by means of producing compost and recycling. The Matale MC Area, generates 21 tons of waste from its residential and non-residential establishments daily. At present, there are four major waste management partners in the city i.e. Matale Municipal Council (17 tons per day), Matale Enrich Compost (MEC) Pvt. Ltd (01 ton per day), Informal Sector collectors (02 ton per day) and individual households (01 ton per day). However, the Matale Municipality dumps 17 tons of waste into an open land fill daily, which has created serious environmental and social issues to the entire Matala City. By contrast, MEC Pvt. Ltd. manages 1 ton of waste daily, in an Integrated Resource Recovery Centre (IRRC), through composting and processing & selling recyclables. In this context, the Matale Municipality has identified IRRC as a suitable option to manage all the generated waste in its municipal council area through Cleaner Development Mechanisms (CDMs) and Private Public Partnership engagement. This will include capacity improvement of existing two IRRCs up to 15 tons per day (Dola Road IRRC – 5 tons, MC Road IRRC – 10 tons) and building up a new IRRC (Parawaththa IRRC) with 03 tons per day capacity with a Resources Centre.
The above improvement will enable Matale Municipal Council to manage 18 tons of waste daily under the Resource Recovery in Matale city project, which would be sufficient to handle the waste collection, transportation and disposal of the city for the next decade.

3.0 Problem Statement

Most of the time in Sri Lanka, solid waste collection is handled by the public sector especially through Municipal or Urban Councils, rather than through the private sector. Compared to the private sector, decisions taken by the public sector is more vague and difficult to express formally as most of the decisions are political and social in nature. As they do not seek to minimize the cost of operation subject to explicit constraints, it is hard to measure the effectiveness of such decisions. In this circumstance, this research is focusing on applying mathematical models as a tool for decision making in solid waste collection, in order to achieve the desired level of service at minimum cost.

Currently the Matale MC collects solid waste by means of tractors, compactors and handcarts that go from house to house. People use handcarts to collect solid waste from houses which are located adjacent to narrow roads, as solid waste collection vehicles cannot travel. The solid waste collecting route is decided by the drivers based on their perception and experience.

According to the data shown in Table 1, Matale MC annually incurs nearly 90% of its solid waste management expenditure on collection and transportation of solid waste. Currently, solid waste is collected from three out of thirteen the wards that belong to Matale MC Area as shown in Table 3.

Table 1: Municipal annual budget on solid waste management

Stage	Annual Expenditure Breakdown (in Rupees)					
	2008	**%**	**2009**	**%**	**2010**	**%**
Collection	8,872,066	53	14,936,860	50	15,338,815	50
Transport	5,979,436	36	12,715,314	42	13,057,486	42
Recycling	70,852	0	63,312	0	65,016	0
Disposal	951,937	6	1,526,528	5	1,567,608	5
Miscellaneous	872,769	5	679,782	2	698,075	2
Total Expenditure	**16,747,061**		**29,921,797**		**30,727,000**	

Source: Feasibility Study on Resource Recovery Options for Matale MC Area, 2010

Table 2 shows the cost structure for make 1 kg of compost at the feasible break-even point. Accordingly to produce 1 kg of compost, nearly 18% is incurred for fuel cost on collection of solid waste.

Table 2: Cost structure at feasible break-even point

Expenses	Electricity (Rs.)	Water Charges (Rs.)	Telephone charges (Rs.)	Salaries & Allowances (Rs.)	Others (Rs.)	Fuel Cost (Rs.)	Office Expenses (Rs.)	**Total Expenses (Rs.)**
Avg. Cost (Rs) per collect, transport and make 1kg compost	0.17	2.00	0.41	8.85	1.17	3.00	1.17	**16.77**

Source: Business plan for Resource recovery in Matale city project 2011 – 2015

Hence, applying mathematical models to solid waste collection, where there is a possibility to reduce the overall expenditure in solid waste collection in a meaningful way, is critical.

4.0 Objectives

The objectives of this research are to identify the most cost effective plan to collect solid waste by;

- Finding the best locations to collect solid waste generated in each zone
- Finding the shortest route from solid waste collection location to IRR center
- Finding the optimum allocation of solid waste to IRR centers considering the supply of the solid waste collection location and demand of the IRR center.

5.0. Literature Review

5.1.Solid Waste Management

There has been a rapid increase in the volume of MSW, due to continuous economic growth, urbanization and industrialization. It is becoming a burning problem for national and local governments to ensure effective and sustainable waste management. It is estimated that in 2006 the total amount

of MSW generated globally reached 2.02 billion tones. This problem is aggravated in Sri Lanka as well, due to the absence of a proper solid waste management system in the country.

Solid Waste Management (SWM) is an integral part of the urban environment, and planning of the urban infrastructure in a way that ensures a safe and healthy human environment while considering the promotion of sustainable economic growth. The main aim of SWM system is to ensure human health and safety, as well as to be environmentally effective, economically affordable and socially acceptable. Municipal solid waste management (MSWM) is a complex task which depends as much upon organization and cooperation between households, communities, private enterprises and municipal authorities as it does upon the selection and application of appropriate technical solutions for waste collection, transfer, recycling and disposal (Schubeler, 1996). Municipal solid waste management (MSWM) encompasses planning, engineering, organization, administration, financial and legal aspects of activities associated with generation, storage, collection, transfer and transport, processing and disposal of municipal solid wastes (household garbage and rubbish, street sweepings, construction debris, sanitation residues etc.) in an environmentally compatible manner adopting principles of economy, aesthetics, energy and conservation (Tchobanoglous et al, 1993). This study will focus on the planning aspect of activities associated with waste collection and transportation in a cost effective manner.

5.2.Waste Collection & Transportation

Waste collection is the act of picking up wastes from homes, businesses, institutions, commercial and industrial plants and other locations and loading waste into a collection vehicle and hauling them to a facility for further processing or transfer to a disposal site (Technical Guidelines on Solid Waste Management in Sri Lanka, Central Environmental Authority).Waste collection depends on the amount of waste generated in each area. Shaida, M.N.(2011)has identified that waste generation differs from place to place to a great extent, since its production and composition are influenced by the consumption pattern, climate, season, cultural practice, population density, lifestyle of the people, technological development, etc.

Korner, et. al.(2009) has identified significant criteria which should be encompassed with municipal solid waste transportation. Some of these criteria include, heavily travelled roads should not be served or used during rush hours, collection paths should not overlap and the availability of fully covered collection of vehicles during transportation.

Klundert, A. and Anschutz, J.(1999) have shown suitable criteria which should be taken in to account when planning for a solid waste collection mechanism, they include:

- Using any one of the methods, or combination of several methods on house to house collection, communal bin collection and curbside collection of municipal solid wastes
- The availability, notification and well functioning waste collection schedule
- That if there is any evidence of infectious waste or hazardous waste that it not be accepted into the normal waste collection vehicles
- Adequate collection frequency
- Evidence of daily collection in public places

- Evidence of regular clearance of public streets and drainage removal of building debris and tree cuttings
- Evidence that bins or containers wherever they are placed, are cleaned when they start overflowing

5.3. Factors that Affect Solid Waste Collection

Ghiani,G., Guerriero,F. Improta, G. and Musmannod, R. (2005) pointed out several factors that need to be considered when selecting a location for waste collection points. They are:

- *Proximity*: Locate as close as possible to where solid waste is being generated to minimize waste handling and reduce transport cost. Furthermore, locate away from water supply (Suggested minimum 500 feet)
- *Access*: Should have adequate width with minimum traffic congestion.
- *Geology / Hydrogeology*: Avoid areas with earth quakes, flood, landslides, faulty, underlying mines, sinkholes and solution cavities.
- *Soils*: Should have natural clay liner or clay available for liner and final cover material available.
- *Ground Water*: No contact with ground water. Base of fill must be above high ground water table.
- *Air*: Locate to minimize fugitive emissions and odour impacts.
- *Noise* : Minimize truck traffic and equipment operation noise
- *Land Use* : Avoid populated areas and areas of conflicting land use such as parks and scenic areas
- *Cultural resources* : Avoid areas of unique archaeological historical and paleontogical interest
- *Legal / Regulatory*: Consider local requirements for permits.
- *Public / Potential*: Gain local acceptance from elected officials and local interest groups.

5.4. Applications of Mathematical Model for Solid Waste Collection

The available literature indicate that many methods and algorithms have been used for planning municipal solid waste collection by applying mathematical models. Maniezzo,V. (2004), Amponsah ,S. KandSalhi,S. (2004) have modeled the optimization problem of urban waste collection and transport as various versions of the Arc Routing Problem.

Nevertheless, the particular problem has been also modeled by Ghiani, G., Guerriero, F., Improta, G, and Musmannod, R. (2005) as a Vehicle Routing Problem (VRP), in which a set of waste trucks have to serve a set of waste bins minimizing the cost function by applying minimal spanning tree.

Sahoo, S. Kim and Kim, B.I. (2005).and Donati, A.V., Montemanni, Casagrande,. Rizzoli, A.E and Gambardella L.M. (2003) have applied a mathematical model considering the characteristics of the vehicles and the Dijkstra's Algorithm for Municipal Solid Waste Collection and Routing Optimization 225 constraints determine the various types of VRPs.

Hsieh and Ho, (1993), Lund and Tchobanoglous, (1994) have applied the transportation problem model and LPM for optimizing sitting and routing aspects of solid waste collection networks. However, uncertainty frequently plays an important role in handling solid waste management problems. The random character of solid waste generation, the estimation errors in parameter values, and the vagueness in planning objectives and constraints, are possible sources of uncertainty.

Koo et al.(1991) applied a mathematical model for the

hypothetical solid waste management problem in Canada, and for an integrated solid waste management system in Taiwan. Katkar.A.A. (2012) has developed a methodology based on Floyd's Algorithm and LPM for effectively solving the network analysis in the field of solid waste routing system in large cities.

Past practices emphasize the application of mathematical models such as Network Analysis which are based on Dijkstra's Algorithms. However, the Transportation Problem Method is more suitable to cope with non-linear optimization problems, such as deciding on efficient routing for solid waste collection and transport.

5.5 Network Analysis

A network consists of a set of nodes (vertices) and a set of arcs (edges). Each node represents a location and each arc represents the connection (road link) between two different locations. There are three types of network analysis techniques:

(a) Shortest-path model
(b) Minimum spanning tree
(c) Maximal flow model

The objective of this research is to reduce the overall solid waste collection cost. This can be achieved by finding the shortest path between solid waste collection locations and the IRR centres. To achieve this, "Shortest Path model"; one of the models which comes under the Network Analysis technique was applied.

Several methods are there to find the shortest path to a particular node from any of the other nodes in a road network. They are;

(a) Systematic method
(b) Dijkstra's Algorithm
(c) Floyd's Algorithm

In this research, Dijkstra's Algorithm was applied to find the shortest path between solid waste collection locations to IRR centres.

5.5.1Dijkstra's Algorithm

Dijkstra's algorithm was discovered by the Dutch computer scientist Edsger Dijkstra in 1956 and published in 1959. It is a graph search algorithm that solves the single-source shortest path problem for a graph with non-negative edge path costs, producing a shortest path tree. It turns out that one can find the shortest paths from a given source to all points in a graph at the same time; hence this problem is sometimes called the single-source shortest paths problem.

To find a shortest path from starting location ***s*** to destination location ***d***, Dijkstra's algorithm maintains a set of junctions, ***S***, whose final shortest path from ***s*** has already been computed. The algorithm repeatedly finds a junction in the set of junctions that has the minimum shortest-path estimate, adds it to the set of junctions ***S***, and updates the shortest-path estimates of all neighbours of this junction that are not in ***S***. The algorithm continues until the destination junction is added to ***S***.

5.6 Transportation Problem Method

"Transportation Problem Method" was applied to find the optimum allocation of solid waste from solid waste collection locations to IRR centres considering the supply and demand.

"Transportation Problem Method" is a special kind of linear programming problem in which goods are transported from a set of sources, to a set off destinations, subject to the supply and demand of the source and destination respectively, such that the total cost of transportation is minimized.

Let, m be the number of sources
n be the number of destinations
a_i be the supply at source i
b_j be the demand at destination j
c_{ij} be the cost of transportation per unit from source i to destination j
X_{ij} be the number of units to be transported from the source i to the destination j

The linear programming model for the transportation problem is presented as:

$$Minimize\ Z = \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij} X_{ij}$$

Subject to,

$$\sum_{i=1}^{m} X_{ij} = a_i \qquad for\ i = 1, 2, \ldots n$$

$$\sum_{i=1} X_{ij} = b_j \qquad for\ i = 1, 2, \ldots m$$

$$X_{ij} \geq 0 \qquad for\ all\ i\ and\ j$$

5.6.1 Types of Transportation Problem

The transportation problem can be classified into "balanced transportation problem" and "unbalanced transportation problem". If the sum of the supplies of all the sources is equal to the sum of the demands of all the destinations then the problem is termed as "balanced transportation problem". This may be represented by the relation:

$$\sum_{i=1}^{m} a_i = \sum_{j=1}^{n} b_j$$

If the sum of the supplies of all the sources is not equal to the sum of the demands of all the destinations, then the problem is termed as "unbalanced transportation problem". That means, for any unbalanced transportation problem, we have

$$\sum_{i=1}^{m} a_i \neq \sum_{j=1}^{n} b_j$$

In this research the problem was considered as a "balanced transportation problem".

5.6.2 Methods to Solve Transportation Problem

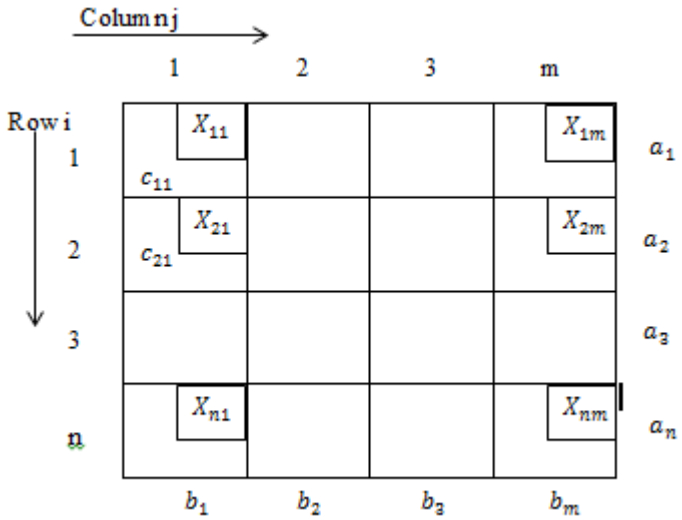
The solution procedures for the transportation problem consist of two phases:

(a) Finding the initial basic feasible solution.
There are three types of techniques to find the initial basic feasible solution. The solution using these techniques may not be optimal.
   (i) Least cost cell method
   (ii) Northwest corner cell method
   (iii) Vogel's approximation method (VAM)/ penalty method

This research has used Northwest corner cell method to find the initial basic feasible solution. The steps of the Northwest Corner cell method are explained below:

Consider a transportation problem with 'm' number of supply points and 'n' number of demand points. Each unit produced at supply point i and transported to demand point j incurs a

variable cost of c_{ij}. The relevant data can be formulated in a transportation tableau as given below:



- Begin in the upper left (or northwest) corner of the transportation table.
- Set X_{11} as large as possible. Clearly X_{11}= min {a_1, b_1}.
- If X_{11}= a_1, cross out row 1 of the transportation tableau. Also set b_1= b_1-a_1.
- If X_{11}= b_1, cross out the column 1 of the transportation table. Also set a_1= a_1-b_1.
- If X_{11}= a_1 = b_1, cross out either row 1 or column 1 (but NOT both).
- If you cross out row 1, set b_1= 0.
- If you cross out column 1, set a_1= 0.
- Continue applying this procedure to the most northwest corner cell in the tableau that does not lie in a crossed-out row or column. Eventually, it will come to a point where there is only one cell that can be assigned a value.
- Assign this cell a value equal to its row or column demand, and cross out both the cell's row and column.

(b) Optimization of the initial basic feasible solution

U-V method is the most commonly used method to optimize the initial basic feasible solution obtained from one of the above methods.

The steps of the U-V method are explained below:

- Use the initial basic feasible solution obtained from the Northwest corner cell method.
- Use the fact that u_1= 0 and u_i+ v_j= c_{ij} for all basic variables to find [$u_1u_2 \ldots u_m v_1 v_2 \ldots v_n$] for the current basic feasible solution.
- If u_i+ v_j-c_{ij}≤0for all non-basic variables, then the current basic feasible solution is optimal. If this is not the case, then we enter the variable with the most positive u_i+ v_j – c_{ij} into the basis using the pivoting procedure. This yields a new basic feasible solution.
- Using the new basic feasible solution, return to steps 2 and 3.
- If u_i+ v_j-c_{ij}≥0for all non-basic variables, then the current basic feasible solution is optimal. Otherwise, enter the variable with the most negative u_i+ v_j-c_{ij} into the basis using the pivoting procedure. This yields a new basic feasible solution.

6.0 Analysis & Results

6.1 Finding the Optimum Locations to Collect Solid Waste Generated in Each Zone

Under the above project, the MC area has been divided into seven zones (Figure 1) and it has been proposed to assign one tractor, one driver and two labourers for each zone to collect solid waste from house to house in handcarts and then to transport the collected waste to IRR centres by tractor. The seven zones were demarcated based on the ward boundary of the MC area. Table 3 shows the wards that come under each waste collection zone.

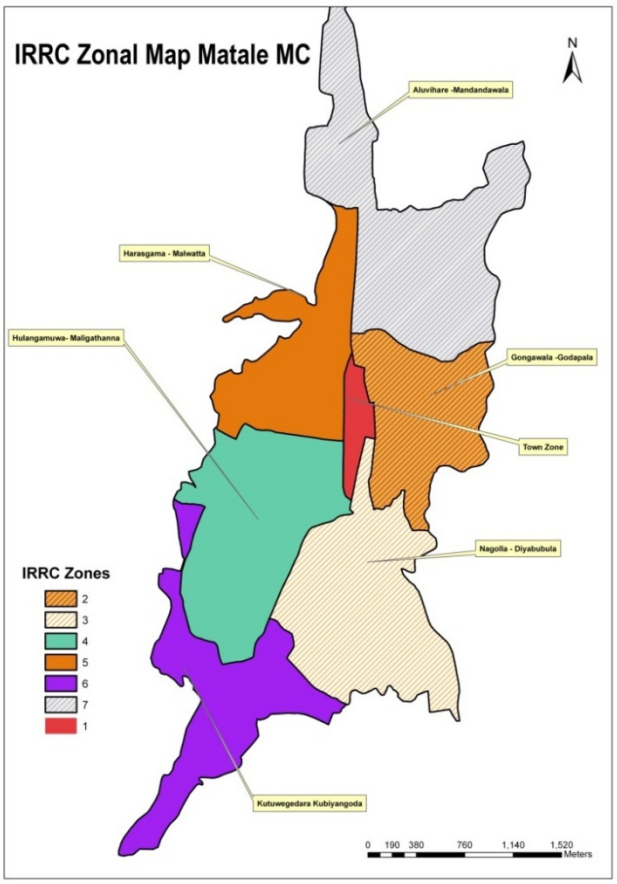


Figure 1: Solid waste collection zones of IRR Project
Source: SEVANATHA Urban Resource Centre

Table 3: Wards come under each waste collection zone

Waste Collection Zone	Wards
Zone 1	Town
Zone 2	Godapola, Gongawala
Zone 3	Diyabubula, Nagolla
Zone 4	Maligathenna, Hulangamuwa
Zone 5	Malwatta, Harasgama
Zone 6	Kumbiyangoda, Kotuwegedara
Zone 7	Mandandawela, Aluvihare

The first objective of this research is to identify suitable waste collection locations of each zone by considering the criteria identified through the literature review. The Model Builder tool in Arc GIS, was applied to spot the suitable waste collection points which fulfil the requirements such as: shortest distance from transfer stations (IRRCs), high accessibility from all houses in the zone, suitable geological condition, soil and hydrological condition, compatibility with surrounding land use activities and minimum required service area. Figure 2 shows the waste collection locations identified in this manner.

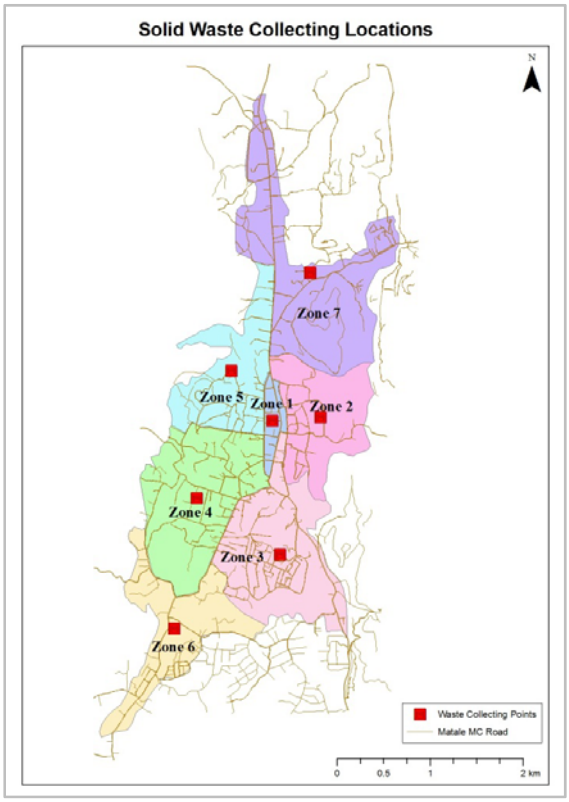


Figure 2: Optimum locations SW collection *Source*: Compiled by the Authors

Five waste collecting bins, each with a capacity of 500 kg are located in the above identified waste collection locations of all seven zones, in order to separate waste into bio-degradable and non-bio-degradable materials. The recommended colour codes for waste collection bins are Green for Organic Waste, Blue for Paper, Red for Glass Bottles, Brown for Metals / Coconut shells and Orange for Plastic & Polythene. Each zone will have two labourers to collect and transport waste from house to house to the waste collection location using hand carts each with a capacity of 250kg, on a daily basis. Then, using tractors the collected waste at each waste collection location will be transported to IRR centre. This mechanism will facilitate a reduction in transport cost by a considerable level. It is hoped that this cost will be reduced further by finding the shortest route for the distribution of collected solid waste from each zone to IRR centre.

6.2 Optimizing the Routing of Municipal Solid Waste Collection

The second objective of this research is to optimize the routing process of solid waste collection by minimizing the total collection distances travelled by vehicles.

The optimum routing of Municipal solid waste collection can be examined under two aspects:

1. Optimum routing for collection of solid waste from house to house
2. Optimum routing for transportation of collected solid waste from zone to IRR center

Under this study, the scope of route optimization was restricted to find the optimum route for distribution of collected solid waste from zone to IRR centre by tractors. Therefore the waste collection location was considered as the origin point and the IRR centre was considered as the destination point.

The following assumptions were considered in applying the network analysis for optimizing the routing of Municipal Solid Waste Collection.

(a) On a given day, the first trip starts from the IRR Center and ends up at the IRR Center as well.

(b) The cost of transportation is totally based on the cost of fuel of travelled distances.

(c) The traffic condition and the physical condition of the road were considered as uniform.

(d) The slope of the MC area does not significantly influence fuel consumption or wastage. As shown in Figure 3, the slope of the Matale MC area is comparatively low when compared to its surrounding area. Hence it was considered that the slope does not significantly influence fuel consumption or wastage.

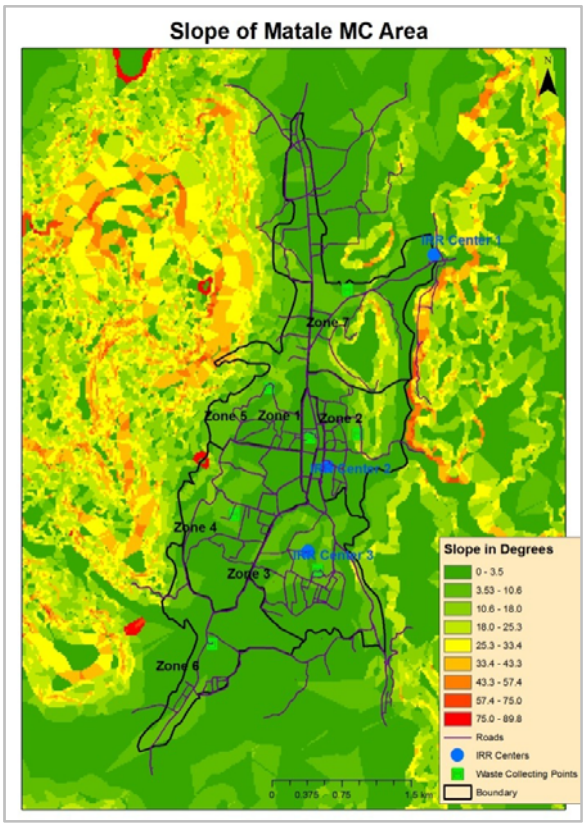


Figure 3: Slope of Matale MC Area *Source*: Compiled by the Authors

To find the shortest path between the solid waste collection points and the IRR center, Dijkstra's Algorithm was applied. Network Analysis Route tool in the ArcGIS software, which was developed based on the Dijkstra's Algorithm, was used to find the shortest path between the waste collection locations and the IRR centre. For this study, only the routes in which the solid waste collecting tractors could travel were considered. Figure 4 shows the shortest routes identified from each waste collection location to each IRR centre and Table 4 shows the shortest distance, in kilometres, between each location and IRR centre.

Table 4: Shortest Distance obtained from the Dijkstra's Algorithm

Shortest Distance from waste collecting zone to IRR Centre (in km)($\boldsymbol{d_{ij}}$)			
Waste Collection location	Centre 1	Centre 2	Centre 3
1	2.839	0.534	1.876
2	3.190	0.774	2.289
3	4.581	1.602	0.882
4	4.225	1.546	1.497
5	3.170	1.457	2.667
6	5.539	2.863	1.839
7	1.213	2.254	3.600

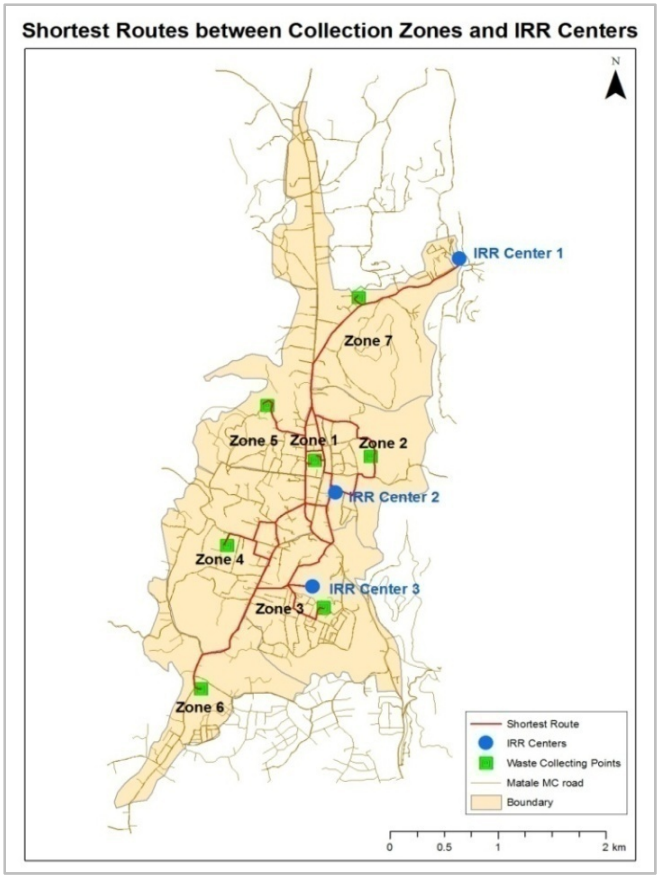


Figure 4: Shortest path between collection zones and IRR Centres
Source: Compiled by the Authors

6.3 Optimizing the Allocation of Collected Solid Waste to IRR Centres

Under the IRR project, several catchment areas were identified based on the location of the MC wards in order to collect the required amount of solid waste to IRR centres as shown Figure 5. But such catchment areas were decided on without considering the solid waste transportation cost, demand of the IRR centres and the supply of each catchment area.

As shown in Figure 6, at some IRR centres, demand is greater than the supply and at some other IRR centres demand is less than the supply. Therefore it is essential to plan an optimum strategy to allocate the collected solid waste among IRR plants considering the transportation cost, supply of solid waste collection points and demand of IRR centres. Therefore to achieve the third objective of finding the optimum allocation of solid waste from waste collection locations to IRR centres, the Transportation Problem method was applied.

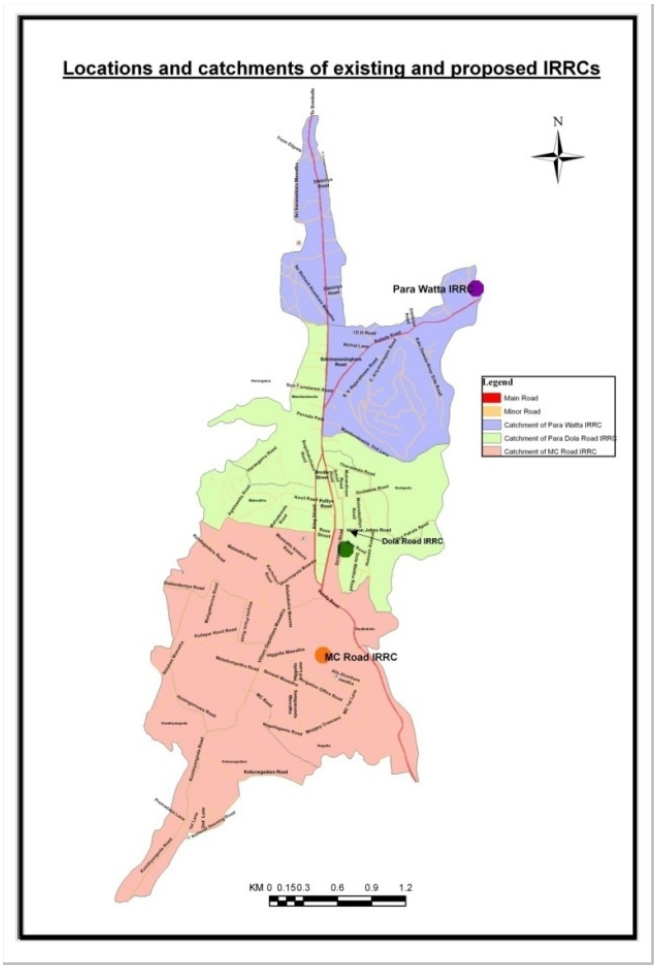


Figure 5: Locations and catchments of existing & proposed IRRCs
Source: SEVANATHA Urban Resource Centre

The following assumptions were considered when applying the Transportation problem method:

(a) Under Transportation costs only fuel costs were considered

(b) The research has obtained the relevant data and information from the feasibility study carried out by the SEVANATHA Urban Resource Center for the Matale MC area in 2010. Therefore when calculating the fuel cost, the authors have used the fuel prices in year 2010. Hence, 1 ton 1km fuel cost for solid waste transportation was considered as Rs. 180.

(c) The assignment of solid waste was considered as a "Balanced Transportation Problem"

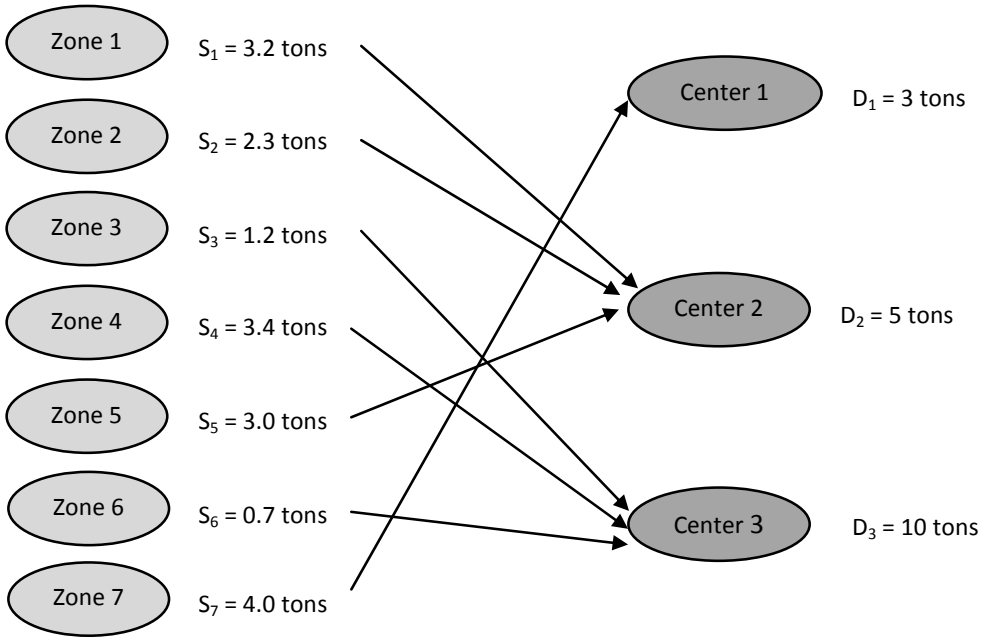


Figure 6: Proposed solid waste distribution plan under the IRR Project

To calculate the c_{ij} values, first, the cost of transportation of 1 ton of solid waste (c_{ij}) from solid waste collection zone to IRR center was calculated.

$$c_{ij} = d_{ij} \times w$$

Where,

c_{ij} = the cost of transportation per unit from source i to destination j
d_{ij} = shortest distance between source i to destination j
w = Fuel cost of transporting1 ton of solid waste for 1km distance (Rs. 180)

Table 5: One ton daily transportation cost - c_{ij}

One ton daily transportation cost (in Rupees)(c_{ij})			
Waste Collection Location	Centre 1	Centre 2	Centre 3
1	511	96	338
2	574	139	412
3	825	288	159
4	761	278	269
5	571	262	480
6	997	515	331
7	218	406	648

Thereafter, the initial basic feasible solution was obtained by using the Northwest corner cell method. Table 6 shows the initial solution obtained from the Northwest corner cell method.

Table 6: Initial Basic Feasible solution of the Northwest corner cell method

Zone	**Plant 1**	**Plant 2**	**Plant 3**	**Supply**
1	511 3.0	96 0.2	338	**3.2**
2	574	139 2.3	412	**2.3**
3	825	288 1.2	159	**1.2**
4	761	278 1.2	269 2.3	**3.4**
5	571	262	480 3.0	**3.0**
6	997	515	331 0.7	**0.7**
7	218	406	648 4.0	**4.0**
Demand	**3.0**	**4.9**	**9.9**	

The initial basic feasible solution obtained from the Northwest corner cell method was optimized using the U-V method.

Table 7: Optimum solution of the U-V Method

Zone	Center 1	Center 2	Center 3	Supply
1	511	1.6 96	1.6 338	**3.2**
2	574	2.3 139	412	**2.3**
3	825	288	1.2 159	**1.2**
4	761	278	3.4 269	**3.4**
5	571	262	3.0 480	**3.0**
6	997	515	0.7 331	**0.7**
7	3.0 218	1.0 406	648	**4.0**
Demand	**3.0**	**4.9**	**9.9**	

According the U-V method, the total daily solid waste collection cost is:
= Rs. (96×1.6) + (338×1.6) + (139×2.3)+(159×1.2) + (269×3.4)+(480×3)+(331×0.7)
+ (218×3) + (406×1)
= Rs. 4851

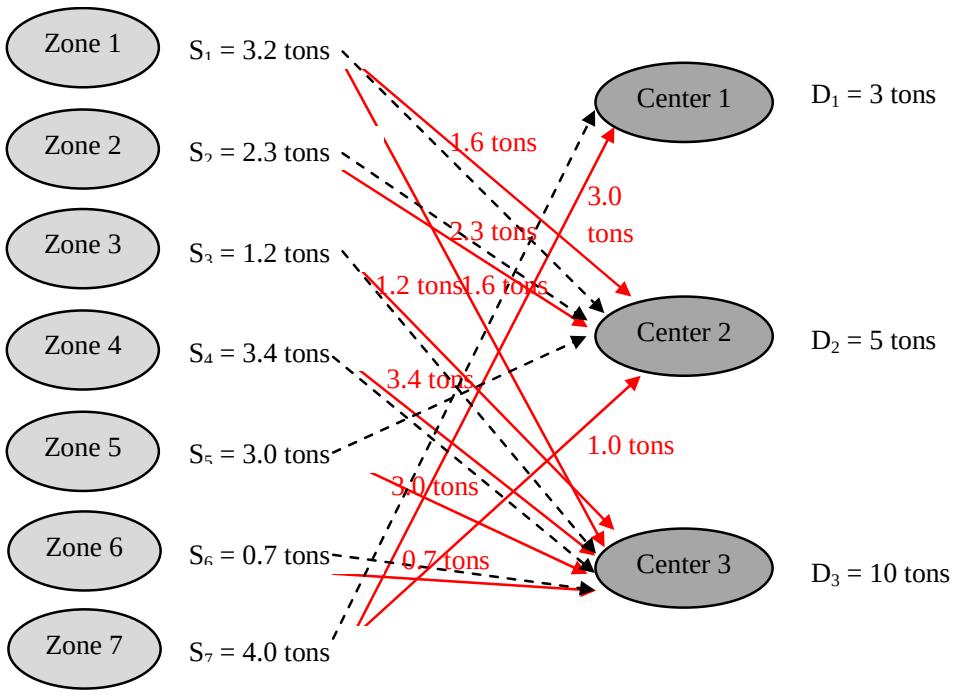


Figure 7: Solid waste distribution plan obtained from the Mathematical Model

Expected daily solid waste collection under the project = 18 tons
Percentage of bio-degradable waste = 85%
Quantity of daily bio-degradable waste = 15.3tons

The compost is produced in the IRR plant with an input/output ratio of 15%.

Hence, expected daily compost production = 15.3 ×15% tons
= 2295 kg
Solid waste collection cost for produce 2295kg of compost = Rs. 4851
Solid waste collection cost for produce 1kg of compost = Rs. 4851 / 2295
= Rs. 2.10

Therefore, by applying mathematical models in solid waste collection, there is a possibility to reduce the fuel cost incurred in producing 1kg of compost, by up to Rs. 2.10. Daily fuel cost to produce 2295 kg of compost, before and after applying the mathematical models, are Rs. 6885 and Rs. 4819.50 respectively. Hence there is a possibility to save Rs. 2065.50 per day with the new solid waste collection plan developed from mathematical models.

7.0 Conclusion

There are more nonlinear relationship among the variables, which are encompassed with the activities of solid waste collection, transportation and disposal. This study emphasized that application of Network analysis which is based on Dijkstra's Algorithms and Transportation Problem method which are more suitable to cope with such non-linear optimization problem on deciding on the most efficient routing for solid waste collection and transport in the Matale MC Area.

The collection process has been improved through the application of Network Analysis and Transportation Problem Model, which minimizes the total distance travelled by the collection vehicles and improves the assignment of required solid waste quantity to IRR centres. This proposed mechanism of using mathematical models for planning solid waste collection and transport activities, in this case study will save up to Rs.2065.50 per day.

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Evolution of Female Costume in Sinhala Tradition

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Abstract

According to the Oxford English dictionary the meaning of costume denotes 'the distinctive style of coiffure, jewellery, and apparel of a period, country, class or a group'. Costumes are considered as things that are laid on the human body for beauty, aesthetics and function. Body shape or figure is believed to be the cumulative result of a woman's skeletal structure and distribution of muscle on the body. The female figure in many cultures has been worshipped as the symbol of fertility and prosperity. The female form is considered as more attractive than its male counterpart. In general female figures are narrower at the waist than at the bust and hip area, and accentuated with long hair that falls along the back.

This study intends to identify deeper meanings in costumes that were practiced in local traditions, by mapping out the visible connections between costumes/dress and the social, material, and philosophical aspects of female dress. The research problem is the examination of the principles that have evolved in the history of Sinhalese female costume. In the world of costume design today, it is important to always look back to tradition, for creative inspiration in design. This has been the main objective of the research paper. A wide range of costumes, from the royalty to the commoners can be identified in the Sinhalese culture. This wide range of costumes has evolved to make the female figure a focal point for design and creativity. The traditions of costumes have been subjected to external changes from outside influences. The concepts behind dress design that have evolved from local traditions need to be brought in to focus. For instance, the ancient temple paintings of Sri Lanka depict the life style of a bygone era and in these paintings we come across stories illustrated with people at different events in their various costume and ornament. As such, it is possible to derive the social significance, philosophy of life, customs and beliefs, and design aesthetics of the era from these paintings. Much of the information has been collected by visiting ancient temples in Kandyan region and Southern coastal areas. Line drawings were then prepared from the scanned photographs. The dresses of the royals, variations of the costumes of the commoner, Kandyan villagers costume, costume according to Robert Knox, the occupations related to costumes, costumes of the dancers, costume and its western and Indian influences are some of the sections that will be discussed in this study.

Key words - female, costume, tradition, Sri Lanka, design, evolution

Evidence from Literary and Epigraphic Sources

Direct and indirect literary sources include the chronicles (Mahavamsa & Chulavamsa) and the written dissertations, books and silpa texts. The Mahavamsa, (Geiger W, 1953) the ancient chronicle of the Sinhalese (5th century A.D) and the Chulavamsa (Geiger W, 1953) give some idea of the dress and ornaments worn by the Sinhalese in ancient and medieval times. The Mahavamsa states that the Yakkhini woman Kuveni was first seen by the Aryan prince Vijaya from Bengal, seated under a tree spinning cotton. This event is believed to have taken

place sometime during 5th - 6th century B.C. This indicates that some knowledge and skills in cloth making had existed in the island as early as the 6th century B.C. From this it is only natural to suppose that the ancients, whether Aryans or the aboriginals, clad themselves in some form of garment. The costumes/dress were subjected to change according to the Sinhalese caste system. As for womens' attire Martin Wickramasinghe (1935) basing his contentions on the Pali work Dhammapadatthakatha (5th century A.C) has shown that ancient Sinhalese women did not cover the upper part of their bodies.

Garments for the upper body became popular amongst the Sinhalese nobility by the 17th century as noted by Robert Knox, in his monumental work, Historical Relation of Ceylon (1681) says of the attire worn by Kandyan ladies: Govi women were distinguished by the wearing of their cloth, which they wore to their heels with one end of the garment flung over the shoulders carelessly covering the upper part of the body.

As for the low caste women, he says that they would go naked from the waist upwards and their clothes did not hang down much below their knees. Knox also states that when going outdoors Kandyan women wore a short frock with sleeves, made of fine white calico wrought with blue and red thread with designs of flowers and branches, to cover their bodies.
Wickramasinghe states that middle class women only wore a cloth around their hips when at home, and also used another cloth to cover their shoulders whenever they went outdoors. As for the upper classes, the Sigiri frescos (5th century AC), depict the aristocratic women as being bare breasted, though heavily bejeweled, while their lower class female attendants are depicted with a breast band. As noted by Wickramasinghe, women of the Chandala/ rodhi caste covered their upper bodies even if those of the noble birth did not do so. It appears that in ancient times exposing a woman's breasts was considered, a mark of respect and high birth and that covering them was a sign of inferiority and low birth, in later times however, the very opposite was true. As noted by Coomaraswamy (1956), in Mediaeval Sinhalese art the dress of women of high caste consisted of 'hettaya'(jacket) with 'mante' (mantle) like that of a man, and a cloth (helaya) around the loins arranged in various ways. Alternatively the end of the cloth (ohoriya) was thrown over the shoulders similar to that of Tamil fashion. He states that 'ohoriya' is a fashion of Tamil origin.

The intention of this study is to identify the characteristics of female costumes belonging to three time periods of history, namely; Anuradhapura & Polonnaruwa, Mediaeval /Kandyan period and Southern Colonial times. An effort is made in this study to understand the evolution of womens' costumes in a way that can be traced from the above mentioned time periods of history.

Eastern and Western Approach to Female Costumes

In the development of the great civilizations of the world, people understood the techniques of dignifying the human form with cloth, arranging it in many methods, in different lengths for different uses and functions. Generally the wrapping style of cloth as costume was considered more dignified than the cut and sewn dresses. Womens' costumes are subjected to local culture, religion and climate. Looking into the developments of western costume one can identify the cut and sewn dresses to be of European origin, whereas particularly in the hot, humid climates the human form was

left exposed with a minimum of clothing to suit the climatic conditions. Traditionally in Indian costumes, the upper body was covered with jewellery and lower body was covered with the lower garment. Many of the draping styles have evolved from the Indian traditions, most significantly the costume identified as the 'sari' for women. The costume when worn, of which falls around the ankle, and elevates the female form in a dignified manner. In eastern culture, the dress represents much more than fashion or aesthetics; it signifies beliefs that become part and parcel of life.

Female Costume in Sri Lankan Tradition

Evidence on early period developments of female costumes can be gathered from literary and epigraphic sources. Similar to the Indian tradition, early period (Anuradhapura & Polonnaruwa) female costumes had a garment for the lower part of the body, with jewellery adorning the upper part of the body. This had been the practice till colonial influences came into existence. Female costumes varied with regard to occupations, rituals, events of life, social classes etc. A gradual evolution can be traced from the Anuradhapura and Polonnaruwa periods to the Kandyan and Colonial times in history.

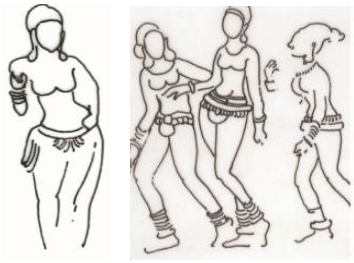
Expression of Female Costume in Anuradhapura and Polonnaruwa Sculpture

The earliest sculpture from the 2nd century A.D, a wooden sculpture believed to represent a 'yakkini' figure indicates a hip ornament as shown in the figure below.

Yakkinifigure
2nd -3rd century A.D
Source –Schroeder 1990

The sophisticated classical lines of the sculpture as illustrated below depict the simplicity and graceful draping of early period costumes. The ancient sculpture indicates the accentuation of the chest and hip area of the female form.

Female sculpture from Abayagiriya, Anuradhapura



Sculpture from Jethavana archaeology museum, Anuradhapura
Source –Schroeder 1990

Nikawakanda
Source - Schroeder 1990

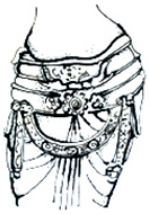
The Sigiriya damsels, representatives of the 5th century aristocratic women are shown to be adorned with elaborate head dresses, large ear rings, arm bracelets and a plethora of necklaces and bangles. Some of these ornaments are uniquely found only in the Sigiriya paintings and sculpture. The perfect form of the female figure is depicted with high breasts and narrow hips. The dignified formation of the female form, denoted with classical lines, was continued in the Sinhalese tradition from the early Anuradhapura period. The upper areas of the female form, that include the neck, shoulders and the breast are adorned with ornaments, including; a tightly fitted choker ornament to the hanging pendants that rest on the mid plane of the chest, accompanied by the fitted armlets on either side of the arms. Various expressive details from elaborate Sinhalese literature work (such as writings on the mirror wall) can be taken as examples on the beauty of the Sigiriya royal women in dress and ornament. For instance, the breast is compared to a couple of swans, and the stately arms to the well formed trunk of an elephant. A number of necklaces adorn the neck area at different levels, this is a common occurrence in female ornament: Primarily the shoulders, upper arms and chest were adorned with necklaces and armlets. This is very well expressed, in the Sigiriya jewellery.

Sigiriya paintings & sculpture
Source - Chutiwongs 1990

Sigiriya paintings & sculpture
Source - Chutiwongs 1990

Sculptural examples taken from local traditions indicate different forms and expressions of the female figure. A particularly spectacular example of female sculpture in the Sinhalese tradition is the seated figure of the goddess 'Tara' (7th-8th century Anuradhapura). This sculpture indicates the supremacy that is achieved by classical expressions in Sinhalese ornament and detail. The tall gem studded headgear identified as the 'Jatamukuta' emphasises the head, as the only decorative ornament adorning the female figure.

Sculpture of Tara. Late Anuradhapura period, 7th -8th century. Source National museum Colombo



Hip ornament detail from Polonnaruwa sculpture

Gaja Laksmi at Vahalkada pillar. Archaeology museum Ampara. Source Schroeder 1990

Kubera figure from Anuradhapura Source - Schroeder 1990

As attested by literary evidence, from ancient times to around the 16th century till the arrival of the Portuguese, the lower garment of men and women folk of all classes were worn similar to the modern day 'dhoti'of North India. This was worn from the waist down to below the knees. However unlike the Indian 'dhoti', the ancient Sinhalese garments appear to have been worn as neatly arranged horizontal folds. This was especially apparent among the upper classes. Another important ornament worn by upper class women was the 'minimevla' or 'manimekala' which is a gem studded girdle that was worn at the hip level. This is indicated in sculptures that date back as far as the Anuradhapura and Polonnaruwa period. These ornaments were considered as a mark of wealth and status of the wearer. Further references to these ornaments are made in the 15th century in literary sources such as the 'Hansa Sandeshaya'.

Womens Dress of the Kandyan Period

It is observed that the Aryan influences that was the spring of art and civilization in the early periods in Sri Lanka, were evidently overtaken by the South Indian traditions during the Kandyan period. The Madurai influence on the arts and crafts of Kandy, particularly during mediaeval times was clearly evident. The matrimonial alliances made with South Indian royalty particularly, brought with it a great influence to the costume and jewellery of the Kandyan period. Another example of the royal queen's dress, the 'mottakkiliya' which is used to cover the body from head to toe, is evidently of South Indian origin. However this practice was not continued into the latter periods of the era.

The Kandyan King and the queen: Painting of a wooden panel, source - Kandy museum

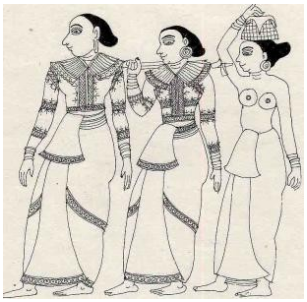
Royal family:
Sources - Dambulla temple paintings

The way in which the lower garment is draped differs according to various styles. In the Kandyan draping styles the folds are taken in front, and tucked at the hip level.

Variations of Kandyan womens' costumes
Source Gangaramaya temple paintings, Kandy

In colder climates higher up in the hill country, people were in the habit of wearing a mantle/ 'mante'(Large collar), as indicated by the Kandyan temple paintings and sculpture. This was evidently an influence from the Portuguese costume.

According to Wickramasinghe, during the Kandyan times (16th -18th centuries) it was the practice amongst respectable women to cover their upper bodies, while women of the low castes and the 'Rodi' were prohibited from doing so. Furthermore, upper caste women wore their lower garment to the ankles.



Noble women and female servant of the Kandyan period. Source-Madawala temple paintings

Robert Knox (1681), as quoted from Medieval Sinhalese Art, (page 35) gives a description of the dress and ornament of Kandyan ladies, which is as follows: on their arms silver bracelets, and their fingers and toes full of silver rings, about their necks, necklaces of beads or silver, curiously wrought and engraven, gilded with gold, hanging down so low as their breasts. In their ears hang ornaments made of silver set with stones, neatly engraven and gilded. Their ears they bore when they are young, and roll up coconut leaves and put into holes to stretch them out, by which means they grow so wide that they stand like round circles on each side of their faces, which they account a great ornament, but in my judgement a great deformity, they being well featured women.

Kandyan lady according to Robert Knox

The above mentioned description indicates the details of jewellery worn by the Kandyan ladies and their extreme fondness for jewellery in costume during the Kandyan period.

European Influences

In response to the cold climates of the European region, rather than the folded costumes prevalent in Asia, Europeans gave emphasis to cut and fitted dresses on the human form, which also comprised of hats, gloves, stocking and shoes. One can observe that quite differently to the Eastern concept of dress and ornament, where emphasis was given to the fulfilment of spiritual factors, in the Western traditions costume was considered as a changing style that moved with time, material and the attitudes of the people.

The history of Colonial occupation that originated in the Southern Coastal regions of the island with the arrival of the Portuguese in A.D 1506, opened up Western cultural and religious influences in the coastal region of Sri Lanka. According to Coomaraswamy the Portuguese and Dutch influence in the low country (16th and 17th centuries), on art, costumes and manners was marked with extremes. It shows that the influence of the Portuguese was not limited to the aristocracy, but its impact was rapid and widespread throughout society.

Queen and the noble women
Source - Suriyagoda18th century

The temple paintings of Suriyagoda indicate the costume of the queen and noble women. The long sleeved jacket, tight fitting upper garment and hair styles show European influences. Certain features like 'mante'(collar) in the ladies' costumes can be identified as a prominent feature in Western style.

Low Country Traditions of Female Costumes

The costume and ornament of Western origin bear evidence to the changing patterns that occurred in Sinhalese traditions. Furthermore the merging of Western and Eastern concepts resulted in hybrid formations. There is a clear revolution that took place from Anuradhapura and Polonnaruwa to the Kandyan era and then to the Southern Colonial times. These traditions are subjected to an indigenous process, marked with material, life style, and technological skill. Lace and such upper garments as 'arichchi' and 'borichchi', comprising of puff- sleeved bodices or blouses, mainly worn in low country areas, were very popular among the Sinhalese women. In certain instances the skirt or 'saya' of the Portuguese replaced the 'redda' or the lower garment and the 'jacket' took place of the 'hattaya'. Techniques such as 'beeralu' became an artistic craft of cloth making, in the low country, which was introduced by the Portuguese.

Drawing of J.L.K Van Dort 1861
Source – National Archives, Colombo

Source – Karagampitiya temple paintings

Variation of Lower Garment Details

The daily life events depicted in temple paintings indicate the various occupations women engaged in, including house hold chores etc. In most instances various draping patterns are shown as they were understood by the artists of these paintings. As indicated in the diagrams, there are vegetable sellers, and women attending to their daily chores, wearing the simple 'redda' as the lower garment. In the low country traditions 'redda' is simply tucked in at the loins of the female figure.

Women attending the daily chores. Source- Kotte raja maha vihara

Another important feature is the ornamental shawl or 'satakaya' (Wickramasinghe 1935) that is worn on the upper body. In certain instances it is carelessly thrown over at the shoulders, neatly worn crisscrossed at the chest or partly covering the head.

Source - Kataluva temple paintings

Source - Telwatte temple paintings

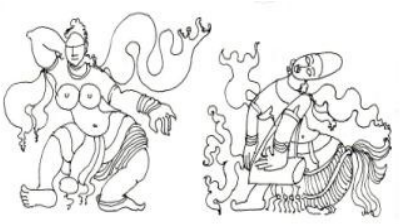
Womens Costumes in Dance, Rituals and Pageantry

Sinhalese dance traditions have a conspicuous place in Sri Lankan cultural heritage, which has formed through the life pattern, beliefs and customs of the Sinhalese. The dance costumes and

accessories is an important aspect of the overall expression of the dance. In the past, it seems that women had taken an active role in these traditional dances. As such alongside with the different dance postures, a picturesque variety of costumes have developed for women. Traditional dance belong to a number of categories that can be identified as classical dances, folk dances, dance plays, ritual dances, royal court dances and dances for amusement, recreation and processions. The distinctive attributes of these dances can be marked in the development of the Sri Lankan dance tradition from ancient times by tracing the sources of stone friezes, sculpture, wood carvings, temple paintings, literary sources, figures carved in low relief in ivory combs, metallic images and so forth.

Temple Dances

Temple or 'devala' dance have evolved with the influence of 'Indian temple dances' and is a ritual of 'performing before the gods'. In the Sri Lankan context, the 'devala dancers' were identified as 'nalaganan', with the earliest archaeological inscriptions depicting the influence of 'Bharatha natya' in the temple dance forms. Among the many stone sculptures, the frieze of a female dancer and a drummer from the Polonnaruwa Vishnu Devalaya is illustrated in the figure given below. The dance costume is designed in such a way that it allows for the vigorous movements of the dancer and vibrates with the swinging and swaying actions of dance. Dance costumes would comprise of turbans, body ornaments and flowing robes that would hug the contures of the body.



Stone friezes from Polonnaruwa.
Source – National museum Colombo

Musicians and dancers from the stone friezes of Yapahuva

The wood carvings of 'Gadaladeniya' and 'Embekke' show a remarkable wealth and precision in the costume details. They are well proportioned figures with expressive faces, appropriate jewellery, attractive drapery with graceful frills and folds at the centre and on the sides allowing for the free movement of the dancers. The costume with its intricate details is a pleasing ensemble; from the elaborate hairdo to the disposition of the frills and folds. The significant feature in the 'nalagana' is the shawl the dancer sports over her shoulders, the ends of which spread like a fan on either side. It is believed that the shawl has a particular reference to the goddess 'pattini', who in the legendary stories has her birth in the 'shawl'. Thus the shawl has a ritual sacredness in the cult

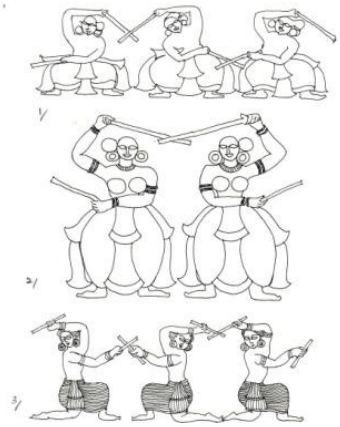
of the goddess 'Pattini'.

Female dancers costume from Ambakke & Panavitiya

Female dancers costume from Ambakke & Panavitiya

Folk Dances

Many folk dances have evolved for the amusement and recreation of village folk. These dances are oriented purely towards amusement purposes, and sometimes towards magical or ritualistic aspects of village life. Along with historical developments, the most popular folk dances are, the 'kalagedi', 'leekeli' and 'raban dance'. They are followed by the 'goyam kapima' and 'kulu natuma' dances that were latter developments. A significant factor of their costume is the distinctive, spectacular appeal created by village life.



1/2 - examples from Polonnaruwa
3 - from Ambekke

Kalagedi Dance

This is a popular dance play for maidens throughout all provinces in the country. This charming dance is performed by group of young girls carrying pots. The pot is used as an important element in the dance; it is passed around from hand to hand, and very dexterously projected up and down. The distinctive charm of the play is highlighted by the simple village costume of the cloth and jacket.

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Folk Dances from the 'Kotte Period'

Carvings from the Ivory casket made by King Bhuvanekabahu as a present to the Portuguese King, Don Juan III, (1521-1551) depict female dancers in folk dance postures. The use of natural leaves and flowers with the fitted bodice and lower garment are characteristic features of the Kotte period dances. Elaborate head gear is a marked feature of all folk dances. There is no jacket covering the upper part of the body however in some instances there is a tight bodice worn at the breast. In some dances the end of the lower garment is taken by hand in the dance movements.

Folk dance costumes from Kotte period
Source – Schroeder 1990

Dance Troop from Mulkirigala

The dancers and musicians from Mulkirigala indicate Western influences in their costume and ornament. The female musicians wear lower garments as the 'redda' leaving the upper part of the body bare. The shawl is used to partly cover the head in a careless manner. The hair is set as tight bun carefully placed with hair pins. As such it can be concluded that the dancers costume is of Western style.

A group of musicians from Karagampitiya
(19th century)

A group of female musicians from Karagampitiya are represented wearing a Western style 'saya'and 'jacket' and partly covering the head with a shawl.

Art & Design of Female Costume

The art and design of female costumes consists of the way in which the costume is composed, its colour composition and detailing. The examples can be derived from Sigiriya, Kandyan temple paintings and the low country temple paintings. The costumes of the Sigiriya damsels indicate the elaborate headgear, jewellery and the lower garment. The headgear consists of a cloth pedestal on which the head gear rests; natural flowers and leaves, gems, and other structural elements such as coils are incorporated into the headgear. The colourful stripped clothes were worn as lower garments. The thin borders with white cloth and delicate embroidery indicate the practices during the Kandyan era. The Kandyan female costume consisted of mantle, jacket and the lower garment. Female costume of the low country consisted of the jacket and cloth, with elaborate textile designs on the lower garment. The subtle colour range of the low country textiles is a marked feature in low country costume design.

Textile patterns of the fabrics from Southern temple paintings source -Telwatte temple paintings

Conclusion

Costume had become an inseparable part of the human existence, fulfilling a higher purpose that man found necessary. The trends and styles were evidently set in vogue by the upper classes and the royalty which then trickled down to other social strata. The practices appear to have been in vogue at certain times which would have been influenced by the prevailing aristocratic styles. There exists a variety of female costumes from different social backgrounds, ranging from the royalty to the commoner. The female body, because of its characteristic form became the vessel from which a variety of costumes spanning into different eras of history came to be. A wide range of costumes have evolved through various geographical, political, social, religious, economical, and cultural motivating factors. Local costumes were influenced by other cultures and sartorial practices were carefully absorbed in to local customs and norms. As a result, these processes have created a unique identity to local trends of the female costumes. In certain instances what was accepted from other cultures remained part and parcel of the local practice while the rest were rejected.

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Identification of Traditional Surface Decoration Techniques in Earthenware Products of Sri Lanka

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Abstract

Clay is a natural, earth made resource, which goes back to the pre history of man, with its infancy as a useful material in the past. Clay was identified as a material to produce culinary utensils and objects. When fired, clay gets hard enough to make durable objects and it adds a value to the product. At the beginning, designs were in primary stage and the only purpose was to fulfil the requirements and functional value, but later on people considered about the aesthetical pleasing value. People came up with decorative effects to enhance the beauty and functionality of the product. Outer appearance or surface decoration gives more value and the first impression about the product. According to the above considerations surface appearance could be identified as an important aspect of a ceramic product.

At the beginning, different decorative methods were used to enhance their ideas throughout the ceramic body. They were decorated with social stories and creative designs; it was an explanation media for the society. Pottery is a horizon of the cultural empire and solid item which explains the past. Decoration is the aspect that makes a piece of art more than the utilitarian communicating to the user and contributing to the total appearance. Evolution and variety of decoration methods in Sri Lanka cannot be omitted because it has a great history than contemporary situation. Pinching, Engobing, Engraving, Stamping, Springing, Painting could be identified as traditional decoration methods. They add an aesthetical appearance and a value, giving a meaning and a life to a ceramic product.

Studying the surface decoration methods of ceramic ware is a vast area. This research focuses only on the identification of various traditional decorative techniques in low temperature earthenware products in Sri Lanka.

Present products have less design qualities compared to traditional clay objects. Even though the consumer expects a design value, the manufacturer pays a less consideration on the aesthetical value of the product; it is a main problem in the current clay ware industry. Because of that people try to use other alternative products to fulfil their needs. But if it has a good design quality they would like to use earthenware products for their day to day needs.

The information and data collected using the following methods will be analyzed under several key sections of the research. Primary data will be collected from the primary source by using structured questionnaires and field visit. The questionnaires will be given to people live in urban areas (Colombo & Kandy). The questionnaires mainly focus on the surface decoration methods in present clay vessels. Secondary data will be collected from the previous and existing earthenware vessels, from the books, research journals, research articles, archaeological excavations etc.

This research will be an investigation to identify traditional decorative techniques in earthenware products and it will be helpful to re design earthenware clay vessels with aesthetical pleasing and re-establish the creative tradition in the earthenware industry in Sri Lanka.

Key words: Clay, Earthenware, Firing, Surface, Pinching, Engobing, Engraving, Stamping, Springing

Introduction

Water, fire, air, earth and space are the basic natural elements in the planet. Ceramic is a natural material formed with the combination of above mentioned elements. Earth means clay, which is flexible when mixed with water, and gets hardened by the effect of air and that shape will be made permanent by the effect of fire and also product volume will be created as a result of the way of handling the space. These are the basic steps of making clay ware objects. Sentence (2004) explained about the use of four types of basic elements for clay product manufacturing; "We are enthralled by the magic of a craft that involves all four of the elements: earth mixed with water cooked in a fire and coloured by the presence or absence of air. It feels as though, while molding the clay to our will, we could almost breathe life in to it" (p.9). At the beginning, designs were in primary stage and the only purpose was to fulfill the requirements. But later people considered about functional and aesthetical values of the product. Decorations help to enhance the beauty. It is no argument, outer appearance or surface decoration gives more value and first impression about the product. Surface decorations can be identified as the main decoration method in a ceramic product. At the beginning different methods were used to enhance their ideas through the ceramic body. It is like a canvas for the painter. In past people used social stories to decorate the ceramic body, which was an explanation media to the society. They used different kinds of decoration techniques, pigments and colouring agents for grateful works.

Although clay was a simple and a basic material, it was developed in various ways. At present several types of ceramic varieties exist in Sri Lanka. According to the firing temperature and body composition it can be categorized in to five different types. These are Terracotta ware, Earthenware, Stone ware, Porcelain and Bone China (Thakashima, 2004). This categorization is different from country to county and will be changed in accordance with body composition and firing temperature of clay products. From this classification; earthenware can be described as low temperature (red/brown colour) and high temperature body (red/brown and gray).

By considering the product functionality and the usage of ceramic product, it can also be divided in to three main categories. According to (Coomaraswamy, 1979), three main types of product variations can be identified in Sri Lanka. They are Domestic ware, Ritual ware and Architectural ware. In addition, toys and ornamental ware are produced in Sri Lanka presently. Earthenware clay is an ideal material to manufacture domestic products. According to the above classification, domestic products are frequently used in each and every house in Sri Lanka and cooking pots play a huge role among the domestic products. Most domestic products are made from low temperature earthenware clay. The domestic usage products can be classified in to three main parts with a view of product functionality. Rice (1987) explains three varieties of Domestic products; "Storage products, Processing products, and Transferring products" (p.207).

It is a known fact that most of the people in ancient Sri Lanka used clay pots as their kitchen utensils, because clay is a recyclable and eco-friendly material. Earthenware (low temperature) products are easily recyclable, as it is fired under low temperature atmosphere. It is very important to note that, during the process of earthenware manufacturing

the environment is not affected by any harmful effect. Materials like aluminum and the processes of aluminum casting release several types of dreadful things to the environment. (Mudalige,2010) said "They are turned out using an eco-friendly production processes (drain casting) in comparison to the aluminum casting processes that generates high heat and chemical fumes which adversely affect the working environment". It is believed that the clay is a suitable and environment receptive material.

In a fast moving world, life has become more competitive and busy. Therefore people are compelled to change their traditions in order to face new challenges in life. Hence they tend to use alternative products which are made from other materials such as Nonstick, Aluminum, Stain-less steel, and Enamel etc. Although these products made the life easy and comfortable with the passage of time people understood these alternative products have certain disadvantages. It has now been found the materials like Nonstick, Aluminum, Stain-less steel, and Enamel would cause fatal diseases like cancer and kidney ailments, it they are used for a prolonged period. (Mudalige, 2010) explained about the disadvantage of the pots made out with other material as; "Traditional cookware found in Sri Lanka such as those made with aluminum, stainless steel and non-stick have been reported to cause health disorders in continuous use". Due to the urbanization, the kitchen arrangement also has changed. In Most of the houses, there is a place called pantry which is used for both cooking and dinning. There are houses which have both the pantry and the kitchen. In those houses clay products are used mainly in the kitchen because of the ill-effects which have been mentioned earlier. The utensils which are made from other materials are used in the pantry because they have smooth attractive value. But these imitated products are good for short time usage and not good for longtime usage. Hence it is obvious that using clay products is good for human lives. People hesitate to use them much in the present due to several disadvantages. Much attention is not paid to the functional usage, aesthetical value and the attractive finish.

Clay was an ideal material for making vessels. People have identified clay as a flexible material which can be handled easily, when mixed with water. When comparing with other materials such as enamel, and stainless steel, clay can be used to create various types of clay objects with variety of decoration methods. Therefore manufacturing clay products can be seen as a structural and a systematic process. Finally a piece of clay can be turned in to a beautiful and useful clay product by adding life to it through this systematic process.

Although all the clay vessels are not manufactured attractively, it is one of the factors that have to been paid much attention in pottery industry. Because people like to use good quality product combined with design efficiency and aesthetical validity. "Purely decorative pots have total freedom of expression, while functional considerations impose compromise in both form and aesthetic development in pots that are made to be used. The various needs that domestic pottery servers predetermine to some extent the forms those were and are made. Within all of these basic forms there has usually been considerable room for invention, variation, and improvisation within a theme" (Hopper, 2000, p.29). Hence it is obvious that functional and aesthetical value of products is a key factor in domestic pottery. Generally clay vessels in the current usage, do not process a good surface quality,

structural quality, product appearance and aesthetical appearance.

It has been identified that the clay cooking pots are not used much by people in the current society. It is believed that most of these products do not consider the surface decoration of the products. The questionnaire was carried out to identify the present situation of clay vessels clearly. The questionnaire will be given to people who live in urban areas. It consists of 5 questions and will be given to 50 people to collect the data. The questionnaire will also be used to identify the problems of present decoration methods through consumers' experiences and to obtain their valid opinions regarding the development of clay vessels. The results of questionnaire survey shows that 88% people suggest that the surface decorations of clay vessels should be developed and 12% of people do not propose that idea. According to the results it is understood that the clay vessels are in a developmental stage. Therefore this research will make an attempt to identify the importance of surface decorations for earthenware clay vessels and it will also help to identify the areas which have to be developed to according to the needs of the present society.

Studying about the surface decoration methods of the ceramic ware is a vast area; this research is only focusing on the types of surface decoration techniques in low temperature earthenware vessels in Sri Lanka. Further this research will be useful for product manufacturers and users, to upgrade their products to fulfill present social needs. As a result of that, consumer will be able to get an easy product which has aesthetical validity. This research will also help to build a new trend in pottery manufacturers by emphasizing the need to improving surface decorations of clay vessels which will absolutely suit present social requirements.

Earthenware products and Decorations

As mention above earthenware can be categorized in two different types as, low temperature earthenware and high temperature earthenware. Low temperature earthenware is commonly used in Sri Lanka. It goes under 750^0C to maximum 1000^0C and limited surface decoration methods can be seen out of the body. Most of the Sri Lankan cooking pots, pans and ornaments are made out of this material and yellow, brown colours are common. Sri Lanka had a great history for the earthenware products; which can be identified from the archeological excavations and ancient sites. An idea about the technical developments, decorations and manufacturing methods in the products can be obtained from the past products and museum collections.

Decoration is the aspect that makes a piece of art more than utilitarian communicating to the user and contributing to the total appearance. Evolution and variety of decoration methods in Sri Lanka cannot be omitted because it has a great history than contemporary situation. It adds character and value giving a meaning and lie to an earthenware product. The methods which are used in the processes evolve with the time creating trends. Tracing back to the history of Sri Lankan earthenware, a number of attempts of decorating can be identified. It has variety unique designs, in the same way the decorations of one piece of art is different from another. The identical elements are used in different compositions to suit the form, function and appearance of the product. The traditional decorating methods are evolved each having a

reminiscent of the Sri Lankan identity. Decoration must have a variety and order Rhythm, Patterns and Balance, Proportions, Colour, Form, Texture are the further developed compositions of decorating.

The origin of the surface decoration methods were developed in need of the usage, aesthetic oriented. Surface decoration gives fully completed out fit to the final product. Surface decorations segregate as,

Decorative Decoration
Functional Decoration
Aesthetical Sequence; it depends on the usage of the product.

Different types of decoration methods can be identified in the earthenware in Sri Lanka. Some decoration methods are inspired from the other countries but the origin of the most of the techniques is Sri Lankan. As a decoration method same body mixture and variety of body mixtures were used to decorate surface, commonly pigments and natural colouring elements were also used for surface decorations. Comparing to the present society in past clay vessel was the most essential requirement in the society. Clay vessels can be identified as a horizon of the cultural empire and solid item which explains the past.

Early time pots were plain and undecorated & simple decoration methods were used. Glazed ware can be found in Anuradhapura excavations, it helps to understand the social and cultural situation in that period. With the need of the society and advancement of pottery forms and shapes articles were decorated more attractively. There are two types of decoration application methods according to the body condition.

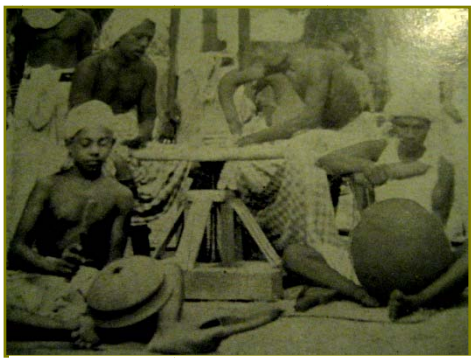

Figure 1: Manufacturing Processes

Figure 2: Leather hard Products

Decoration in before firing – Leather hard stage
Decoration in after firing – Dry/ hard stage

Working on the leather hard condition is quicker than the dry stage working. Sri Lankan pottery tradition, decoration and decoration techniques obtain a higher demand than that of other Asian countries. Surface decoration method is generally categorized in to three different ways;

Geometric Design
Naturalistic Design &
Miscellaneous Design

Geometric designs were commonly used for the decorations, for the reason that the shape and forms are very simple and it was proverbial to the potters' finger. Most of decorative shapes were inspired from nature. It can be evident from the clay vessels used in past.

Geometric Designs
Line, Dot, Wave, Cross Pattern, Diamond Shape, Circle, Triangle, Curve

Naturalistic design
Finger prints, Molding, Human forms, Floral form, Animal models

Miscellaneous design
Religious symbols, *"Dhrmachakra", "Swasthikaya"*

Most of the designs were inspired from the nature, culture and the social backgrounds. Every design added some aesthetical or functional value to the objects. Most of the designs were decorated in eye level of the pots; it gave an attraction to the objects, balance, rhythm and aesthetical beauty.

Variety of surface Decoration Methods in earthenware clay vessels

Most of the surface decoration methods were developed from trial and effort methods and experimental works, at the beginning people had lack Of resources for manufacturing and decorating methods, but comparing with present clay products they have produced quality products consisted with gorgeous surface decorations. It can be evident by examining the precedent products. A variety of traditional surface decoration methods can be identified from the earthenware products. These are the basic and important surface decoration methods that can be identified from the past;

- Pinching
- Engobing
- Engraving
- Stamping
- Springing
- Painting

Pinching

Pinching is a basic method of clay ware manufacturing. At the beginning people did not have enough facilities to manufacture designable products but it was good enough to fulfill the requirements. First the qualities of clay were identified, it helped to understand that the shape can be changed if respond with finger.

At the beginning potter's wheel was not used for clay ware manufacturing. Most of the products were decorated using fingers and thumb. Early products were circular but not perfectly circular. It can be evident from the *"Veddas"* pots in Sri Lanka. Pinching helps to develop shapes, forms and also the decorations.

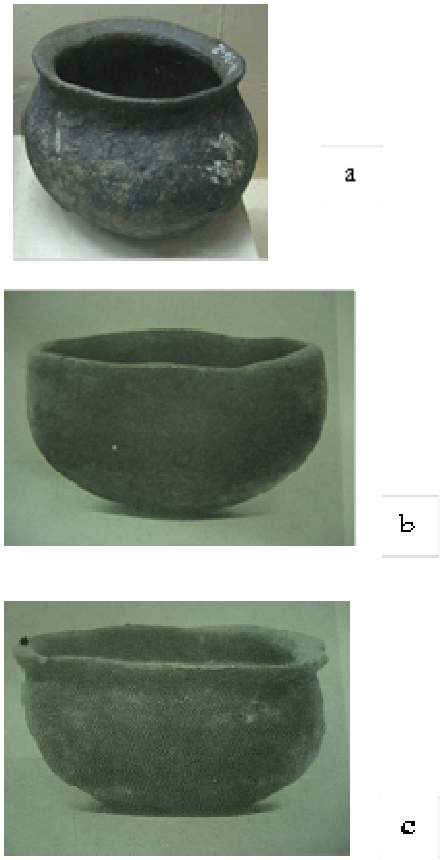

Figure 3: (a,b,c) Earthenware Products- "Veddas" Clay Pots
Source: (Seligmann & Seligmann, 1993, p.328)

Those products mainly considered about the functional usage rather than the decorations. But it has an aesthetical beauty, as all designs were different from one to another. Most of the products had unique designs where simple decorations were used; by doing with finger nails on the wet clay body. Pinching method added natural effects to the product, which is a kind of a primary decoration method. It has added a rough effect to the surface which helped to hang the object properly. It can be identified as an occasion the surface quality help to the functionality.

Figure 4: Use of Pinching Method
"Roti Thetiya"

Figure 5: Use of Pinching Method
"Kabala"

Source: Colombo Museum Collection

Engobing

Engobing is the method which uses same clay body to decorate the surface. Different types of coloured clay were mixed with same clay body and used for coloured decorations. It was made out with liquid form and applied on the leather hard products. It can be identified as a slip painting. Simple decorated patterns were drawn on the leather hard product is rotated on the wheel. It can be done in one firing at around 850^0C temperature and it was evident by the archeological excavations. Water is the mixing material of the coloured clay body. Red, white and black were commonly used for the engobing technique. Several types of surface decorations can be done using this technique.

Composition of Coloured Slips;

Dry Clay + Water = Slip
Red = Laterite *(Guru)*
White = Keoline *(Sudu Matti)*
Black = Graphite *(Miniran)*

The remains of pots which were found from Sigiriya can be used as examples to prove the history of using engobes. Five categories were identified among earthenware ware found in excavation.

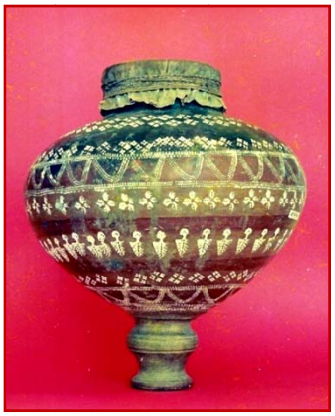

Figure 6: Use of Pinching Method
Rathnapura museum collection

One category is gray colured pots; which is made out of kaolin clay and decorated with simple line patterns. Some had red colour layers applied on top of the pots. The kaolin pots were decorated by thin layer, storage pots and large pots were decorated. Water pots, lids, plates, were made out with red clay and decorated with red engobe. Some pots found from Anurahapura period had an engobe layer of about 2mm with rough texture.

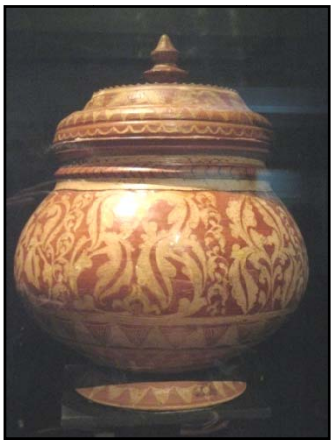

Figure 7: *"Pili Helaiya"*
Colombo museum collection

Yellow colour and light yellow engobes were rarely used for the decorations. Brown and reddish yellow engobe decorated earthenware found from Anuradhapura, Gedige, Abayagiriya, Jethawanaramaya, Manthai, Thissamaharama are believed to be imported from Persian Gulf countries through the silk route. The blue colour pots found from Mihinthale are believed to be medicine containers.

From the Kandyan period on wards *"Guru"* is used for engobe decorations. *"Guru"* is a kind of rock which can be found in Sri Lanka. Gradually people used coloured pigments to engobe decorations such as Ferric oxide (Red colour), Cobalt (Blue clour), Nickel oxide (Black clour), and Chromium oxide (Green colour), but specially Cobalt and Ferric were frequently used for the coloured slip decorations.

Figure 8: Engobe Method

Figure 9: Engobe Method

Engobe is applied in the leather hard stage; it helps to absorb the decoration layer to the wet clay body. It also applied as two layers in two different colours and after drying engraving decoration can be applied. In the firing it becomes a matt colour band, to get a shine effect it should be rubbed in the leather hard stage using seed call *"Puss Eta"*. The shiny surface helps to reduce the quality of water absorption. In present, plastic sheets are used for rubbing purpose. Engobe method is used for curry dishes, goblets, plates, ornamental items etc. kelaniya is famous for the *"Guru"* painted engobing, but surface decorations are not updated. They need to update their designs to cater new trends, without continue the ordinary designs.

Engraving

Scraping or grooving the leather hard clay product is engraving. It is mainly used to decorate the outer surface of the product, but rarely it is also used as an inside decoration. It depends on the functional value and usage of the object and can be identified as a development stage of engobe method. The engraving must be done carefully It is needed to use sharp tools to decorate the body.

Figure 10: Engraving method, Veddas pot

and skillfully. Most of low temperature earthenware products were engraved decorations, not only the two dimensional designs but also three di Engraving is done by scraping lines to form a pattern. Tools is an important fact for the decoration, design quality is depended on the use of tools and creativity. Engraving tools can be identified as sharp pointed tools and flat tools. Steel and wooden were used as tool materials.

A variety of engraving techniques can be identified from earthenware vessels in Sri Lanka. Engraving is the pattern slightly as a not very deep scraping on the surface of the clay. In most of the occasion's circular surfaces were repeating the same design around the product. It is easy as not grooving deeply. De Silva & Dissanayake (2008) stated that Grooving decoration scratched in to the surface of the vessel with a hand tool of same soft variations in the shape and size of tool and the preserve applied will affect this appearance of the surface decoration (p.15).

Figure 11: Incised decoration in *"Kalaya"* Source (Coomaraswamy, 1979, p.227)

It can be evident by the *"Kalaya"* in Kandy museum. Curved surface was difficult to engrave, flat surface was regarded as more appropriate for engraving. It goes in to 2mm or 3mm deeper and engraving lines were filled with coloured clay, it helped to enhance the decoration and the aesthetical value too. It was done either before or after firing the object.

Engraving is applied in inside and outside of the object. This method was mainly used for the functional purposes. Engraving is used at the outside of the surface as it gave a rough effect; it helps to reduce the slippery nature. *"Kalaya, Kothalaya, Gurulethtthuwa, Kendiya"* are examples for the items that were decorated by engraving method. Combing method is one of the special technique in engraving method, "Combing is a very simple technique which could be applied with a snapped lath wood" (De Silva & Dissanayake,2008,p.15)

Figure 12: "Nebiliya" –Engraving Decoration

It is one of the simple methods in which functional value is gained by simple decorations. Decorations of the *"Nebiliya"* and *" Koraha"* are good examples for this method. Surface decoration is an important fact for the functional use of the product.

From the excavations there is another kind of decorated ware found, which is difficult to make and rarely used.

Figure 13: *"Punkalasa"* – Engraving Decoration Colombo museum collection

It is called as ruelatted ware, which is also a kind of engraving method decorated on the wheel. De Silva & Dissanayake (2008) explained, in Ruelatting , a pleasing and complex pattern can be produced with a flexible blade bent over at one end and held up against the surface of the pot as it is turned round on the wheel in a rhythmic patterns (p.15).

Engobing and engraving methods can be used together. Engraving carving is done in an engobe layer. It helps to expose the colour of the clay body underneath the engobe layer. Two or maximum three layers can be used for decorations. Colours are highlighted by the thickness of the grooving. The thickness of the line and quality of the design depends on the craftsman's skills. In present, it is commonly used for the decorative objects. If it is rubbed with smooth seeds good shiny effects can be obtained before and after the firing.

Stamping

Stamping decorations is done in leather hard earthenware body. It presses one of the designs in to the wet clay body. Two types of stamping method were used in clay ware decorations. It is normally done by carving a desired decoration on a piece of wood and stamping it in the leather hard clay surface, if not that tool is sticked in to

the clay body in the leather hard stage. The important thing is that, it wants to be good enough for stamping. It is done in two ways; one is to stamp the craving on the clay or to stamp the clay on the carved piece of wood. From the two methods an embossed decoration or an engraving decoration stamp on the clay can be obtained. De Silva & Dissanayake (2008) explained as, Small metal stamps fitted to a handle, depicting floral, geometric of animal patterns are press stamped over the surface of the vessel when it is in leather hard condition. It has created beautiful patterns on the vessel surface (p.15). Tools are made out of woods like jack tree. It is like a wooden cube which can be used for two types of decorations in both sides; it called as and vessels.

Most of the ancient earthenware products were decorated with stamping letter, it can be identified as a kind of a communication method that they used, specially they have written down their names as a decoration. People have more creativity and talent to do marvellous decorations paying more attention

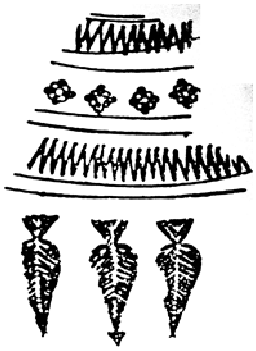

Figure 14: Stamped Decoration on Muttiya – from Kundasale temple
Source : (Coomaraswamy,1979,p.227)

Flowers, leaves, and traditional decorations were used for stamping In the past; It helps to get an idea about the craftsmen's' skills and traditions.

Stamping method is still used as a decorative method among potters. When compared with past surface decorations, present decorations are in low down status. Only few designs can be identified from the earthenware vessels.

Stamping method is still used as a decorative method among potters. When compared with past surface decorations, present decorations are in low down status. Only few designs can be identified from the earthenware vessels.

Figure 15:"Kalagediya" from – near Balangoda
(Decorated with Bo-leaves and rosettes) – Kandy museum collection

Springing

Most of the products are not in simple shapes and forms; it depends on the functional value of the product. Springing was done by adding various shapes to the clay products. It was separately casted and connected to the leather hard body with slip. These two parts should be consisted in same water content and keep carefully until it is dry. Casting is a development of the springing technique.
It is used to create difficult shapes by using moulds. It is also difficult to make some of the designs by casting; it

has to be done by springing method. It takes a long time to create objects but it is perfect and a decorated ornament after the heavy work. Limited springing objects can be identified In Sri Lankan history.

Figure 16: Ritualistic ware
Rathnapura museum collection

Most of the springing objects were ritual ware, because most of the ritual ware was too decorated and beautiful compared to present ritual objects. Springing is used to give an extraordinary appearance to the objects, it can be evident by the *"Poonawa"* which is a superstitious object found in religious places.

Figure 17: "Poonawa"- Kandy period
Colombo museum collection

The majority of the painted pottery ware used springing as a decoration method. Springing part is also decorated, as similar to the body surface, it is difficult to identify as a separate attachment.
"Pili Heliya" is another good example for the springing design. It is used to store clothes, to protect from white ants and other insects which generally used in Kandyan period elite houses. It also used snake motives, as people used snake to enhance the symbol of protection during that time. In present handle, spout, are used as attachments.

Figure 18: "Pili Heliya"
Colombo museum collection

Painting

Painting was a development stage of the other surface decoration methods. Other design was mainly depended on the body colour but in this method all over the body is decorated with colours. Kandyan period is the climax in the mediaeval period in kandy. Traditional motives and decorations were habitually used for decorations.

Entire product was creatively decorated by craftsmen. Most of the highly decorated products were used by elite people, and especially in the palaces. People thought about, not only the functional value but also the aesthetical value too. Outer appearance is a special element for the ceramic ware products. It gives the first impression of the product for the user. Decoration was an important part in every product what they produced. It is an identity of the Kandyan period arts and crafts.

Figure 19:"Liyawela" and flower decoration

Painting is a method that was used to decorate the earthenware products. It was done all over the body surface. It is difficult to identify the body colour and the material of the body. Every space was decorated with valuable decorations and each brush line adds a worth full meaning to the object. Through of decorations like motives, plants, "*Gajasinghe"*, traditional flowers, variety of "*Liyawela"* were commonly used. Other than that social situation, life stories were used as decorations. Line and symmetrical decorations were done by using wheel and others were free hand work. There are no free spaces in the background, it also filled with dark or light solid colours or decorations like "*Plapethi, Nelum mala, Arimbuwa, Gal binduwa".*

Roof tiles, Pots and Pans, "Kalaya, Bummediya (musical instrument), Punawa, Piliheliya" are special painting decorations used in earthenware products in kandy kingdom.

Bright colours were used to draw and paint the decorations, Red, Black, Yellow, White, and Green colours were essentially used for decorations. Natural materials were used to prepare basic colours. Painting was done after the low temperature firing. After the firing a thin layer of "Makulu Mati" was used as a white colour and mix with other colours to make lighter shade.

Figure 20: "Bummadiya" - Colombo museum collection Colour Preparation

Colour Preparation
Section of coloured ware

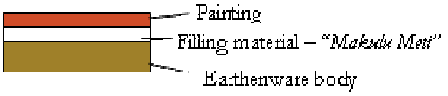

Figure 21: Section of coloured ware

Bright red colour was obtained by grinding "Sadilingam". Lighter red is made out by "Gurugal". "Sadilingam" was mixed with ground "Rathmal" bark juice as another method. Yellow colour is made out of clay called "Hariyal", and "Gokatu Kiri" was also used as a yellow colour. Yellow and yellow occur were mostly used to decorate the "Liyawela" and flower designs.

Decoration was used to enhance the shape and form of the body, it was not easy to decorate on the curved surface but it was done successfully. They thought about rhythm, balance and proportion of every product and decoration. Most of the circular decorations were done on the wheel. Black colour was made out of "kohella", "Kekuna" oil and "Hal Dummala". And also it was made out from, grinded with "Lakada", "Badulla kiri", "Hal Dummala" and "Koholla" these are the main components of

black colour. Blue colour was rarely used in surface decorations. It was made out of "Nil awariya" leaves treated by sunlight. Green colour was made by mixing yellow and blue colour.

Figure 22: Coloured ware- Kandy museum collection

Not only the natural materials but also cheical materials were also used to develop advanced colours such as gold. Gold colour was used to decorate the quality products. "Hariyalo", "Gokatu juice", Murcury, "Sinnakkaram", "Yawakara Lunu" and white lead were taken in equal quantities and ground with "Dorana" oil. After that it was polished with leopard teeth and addition to that varnish was used to get a shiny effect. "Thalathu Miniran" was used as gold colour.

Figure 23: Painted pottery – use in present

When comparing with past decorations present surface decorations are in deprived stage. "Guru" is using as a natural colouring element, other than that lacquer is used for decorations. But finish of the decorations and quality are in low level. People have the talent and creativity but they do not pay much attention to do a good product with quality decorations.

Figure 24: Painted pottery – use in present

In Sri Lankan tradition, various techniques were used as surface decoration methods. Aesthetical value is an important fact of the product and surface decoration method is also important for the product functionality. Sri Lanka had a great history for earthenware surface decorations, people had a good craftsman skill and they produced their product paying much more attention and observation. In present day most of manufactures do not consider this matter. They do not consider quality of the product and present social needs. It will effect to reduce the usage of earthenware vessels in Sri Lanka. If it has a quality, people would buy earthenware products in a reasonable price. Specially in urban areas, people have a trend to use clay products because they know the value of it, but present products cannot facilitate their needs.

Traditional methods are very creative, highly naturalistic and simple. These methods have to be brought in to the future generation, and it can be developed to suit for the present social context and people needs. Earthenware manufacturers have creativity and talents to do valuable products consisted with aesthetical appearance. The present social need is to develop and protect the Sri Lankan ancient pottery traditions for the future generations.

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The key factors affecting the competency in value addition to gem and jewellery in Sri Lanka

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Abstract

Gem and jewellery industry in Sri Lanka plays a vital role contributing immensely to foreign exchange earning to the country's economy. The industrial value chain begins with gem mining and ends with retailing of jewellery while, several stages are included amid. It is imperative to be discerned that every stage involves trading, resulting export of a larger amount of semi-finished products without adding the premium value which creates lack of competitiveness. Statistical data illustrates a clear disparity in terms of revenue generated through the gem exports as opposed to jewellery exports. Thus, the discrepancy between country's resource capacity and its level of fabrication has inspired to conduct this research work.

The main objective of this study is to explore the key factors which cause the low competency in value addition of gem and jewellery industry in Sri Lanka. The required data was collected through an extensive literature survey and several face-to-face, in-depth interviews with experts in the gem and jewellery industry.

The results of the data analysis concluded that there are six major constraints affecting the low production and exporting of gem set jewellery in Sri Lanka, namely; lack of innovation, lack of technology, lack of market, lack of competent man power, lack of financial resources and lack of integration and long term plans as the main findings of this study.

Key words: gem and jewellery, value addition, export, competitiveness

1. Introduction

The gem and jewellery industry is a very important sector in Sri Lanka which is among the major sectors contributing to foreign exchange earnings. The industry has been identified as one of the thrust areas of export development by the government of Sri Lanka. Consequently, a proposal has been made by the government to upgrade the gem and jewellery export sector to a US$ One Billion industry (Gem talk, 2008). Sri Lanka is a leading gem bearing country and retains as one of the world's largest gemstone repositories, second only to Brazil (The Competitiveness Program, 2008). It is a major producer of fine quality gemstones among the five most important countries together with Myanmar, Brazil, South Africa and Thailand (Ali consultants, 2006).

Statistical data released from the National Gem and Jewellery Authority (NGJA) spanning the last eight years of the export of gem and jewellery illustrates, a clear discrepancy in terms of the revenue generated through gem exports as opposed to jewellery

exports. The value chain of the gem and jewellery industry consists of several steps such as; mining, cutting and polishing of rough gemstones, precision & calibration of stones, setting stones and diamonds in manufactured jewellery, exporting & retailing. It was evident that every step of the industrial value chain involves trading. This leads to export semi finished products at various steps without going through the entire value chain. It was observed that Sri Lankan people have resorted to export a larger amount of cut and polished gemstones without converting them into gem studded jewellery. This solitary observation led to explore the country's gem and jewellery industry in-depth especially the gem and jewellery export sector. Thus, the main objective of this research is to explore the key factors which cause the low competency in value addition of gem and jewellery industry in Sri Lanka.

The paper begins with a literature review on current circumstances of the export sector of Sri Lankan gem and jewellery industry, and the existing industrial opportunities and strengths. The paper then presents the research method, results and discussion. Conclusions and recommendations are finally presented in the paper.

2. Literature Review

The global gem and jewellery industry is based on mining of gemstones and precious metals. Distinctive for jewellery manufacture is the strong increase in value addition that takes place when the actual raw materials are processed into the end-product. The value chain for jewellery provides a typical example of a global value chain with most of the raw materials mined in developing countries while upstream activities and consumers are mainly located in developed countries (Coenen, Gijsbers, Maier, Molen, Poliakov & Zee, 2009). Empirical evident revealed that there has been a vast disparity between the capacity of gemstones as a raw material and its intensity for the application as end products – the gem studded jewellery within the developing countries. This scenario can be observed in different contexts of the world such as the imperial topaz in the region of Ouro Preto, Brazil (Gomes, Krucken & Morais, 2009); diamonds in South Africa (De Silva, 2007). According to this phenomenon, it is important to examine the Sri Lankan context as a rich gem bearing country in the world.

2.1 Gem and jewellery industry in Sri Lanka

The total value of the gem and jewellery trade at export and retail points is estimated at about Rs.55 billion annually. The market for gems and jewellery in Sri Lanka can be divided into 3 major sectors as; export market, domestic jewellery market and tourist market. Export market is the largest market segment in value terms which consists of four main product categories namely; cut and polished gemstones, jewellery, diamond jewellery and *geuda* (refers to an unprocessed variety of corundum). Sri Lankan gems and jewellery are exported to more than 60 countries (National Gem & Jewellery Authority, n.d.). A critical point had observed when analyzing the gem and jewellery export market segment; the vast discrepancy in country's resource capacity and its level of fabrication. The export figures of Sri Lankan gem and jewellery industry differ enormously relatively to the other Asian manufacturing centers. A comparative analysis on gemstone exports vs. jewellery exports within the Asian countries in year 2000 shown in Figure 1. According to the figure, the export figures of Sri Lanka are highly differing from the export figures of India, Thailand and China.

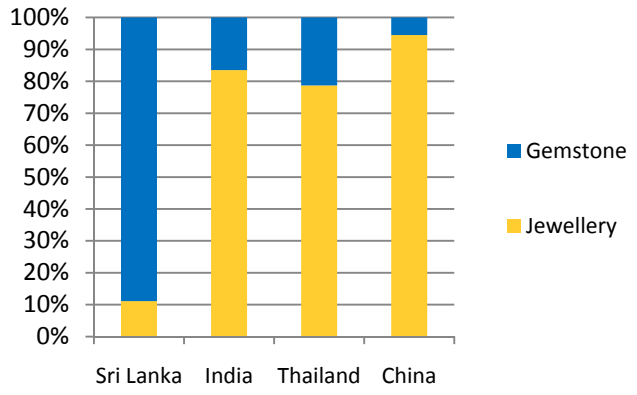

Figure 1: Jewellery and Gem Exports from Asian manufacturing centers in 2000 (US$ Million)
Source: Adapted from Competitiveness Strategy (2002)

Statistical data spanning the last eight years of the export of gem and jewellery illustrates, a clear discrepancy in terms of the revenue generated through gem exports as opposed to jewellery exports in the gem and jewellery industry of Sri Lanka. Figure 2 demonstrates the difference of the revenue generated from the gem and jewellery exports since 2004 up to 2011.

This discrepancy between the resource capacity and its level of fabrication has inspired a handful of studies (A competitiveness strategy, 2002; Ekanayake & Abeysinghe, 2010), concerning the Sri Lankan gem and jewellery industry.

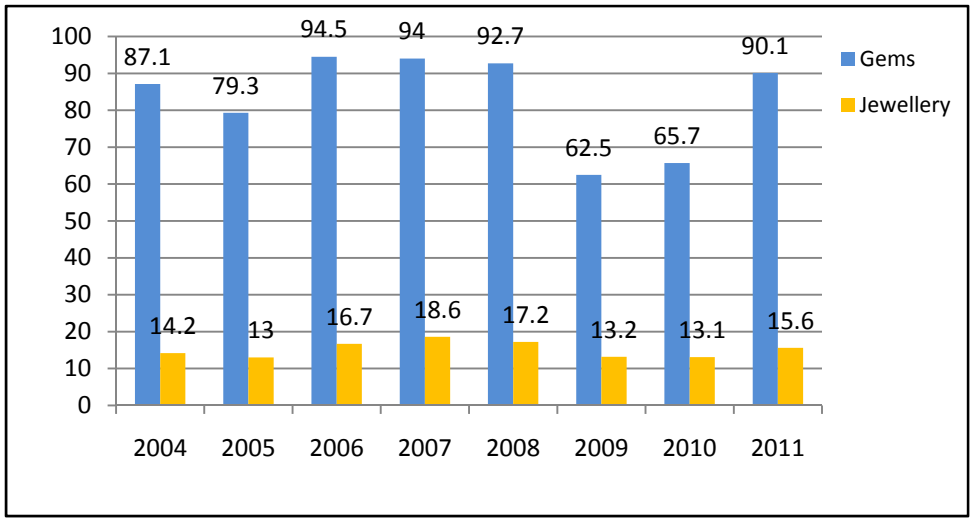

Figure 2**:** Statistical data of the exports of gems and jewellery (value US$ Million)
Source: Adapted from National Gem & Jewellery Authority

The competitive nature of the industry has led more value chain activities such as gem testing, assaying, hall marking, certification, designing, branding, promotion and marketing. As the stones move downstream along the chain, value is enhanced. An expert's view is that an over 100% value addition takes place in the normal value chain activities from rough gemstones to jewellery crafting stage. This percentage is increased to more than 300% in the *geuda* heat treatment process, where technological interventions add value to gemstones (Ekanayake & Abeysinghe, 2010). But, the bulk of Sri Lanka's mined resources is processed or has value added offshore. Disintegration of the industrial value chain and absence of knowledge transferring vastly affect the ineffective flowing of raw materials from first step (mining) to the end which is finished gem studded jewellery (A competitiveness strategy, 2002).

The Competitiveness Program (TCP) was carried out in Sri Lanka from July 2004 to November 2007. Purpose of the TCP was to improve competitiveness of Sri Lanka in the global marketplace by continuing the support provided under the predecessor task order, The Competitiveness Initiative (TCI) (2000-2003). The preliminary observations of the Initiative concluded that although Sri Lankan gems are widely viewed as some of the highest quality gems in the world, the gem industry lacked capacity and knowledge to translate this competitive advantage into high value jewelry exports (The Competitiveness Program Final Report 2008).

Sri Lanka Executive Forum (2002) explained that the export of the gem and jewellery sector in the year 2000 was US$ 70 Million and the trade could project that the same materials could easily generate US$ 110 Million in export revenue if Sri Lanka exports 25% of her gems in the form of a value added product, namely jewellery. This amounts to additional 50% revenue in foreign exchange. On the other hand if Sri Lanka could export 75% of her gems in the form of jewellery additional revenue of US$ 100 Million could be generated in foreign exchange which amount to additional 150% revenue in foreign exchange. Immediate past Chairman of Sri Lanka Gem and Jewellery Association (SLGJA) Mr. Chanaka Ellawala has asserted; *"we still sell most of our gems in the form of loose gems rather than as jewellery. If you take export revenue, about 80 percent of export revenue is in gems and 20 percent in jewellery exports. We should have to sell more jewellery than gems because that gives more opportunity for value addition. But, Sri Lanka lacks the design capabilities, technology and man power to manufacture jewellery. So, that is an area that needs to be addressed"* (Malawa, 2008, p.7).

The fundamental fact to attain the premium value from the industry is to increase the proportion of finished jewellery products. It was evident that the low amount of gem studded jewellery exports has been occurring due to low production capacity in gem studded jewellery manufacturing sector. On the contrary, the extent of involvement of a country in manufacturing will depend on a number of factors, including the level of development of the export markets (Abor & Quartey, 2010). There is a large body of research concerning the relationship between export and productivity (Anh, Chuc, Ngoc & Nhat, 2007).

Apart from the literature related to the issue involved with the industrial value chain, it was needed to analyze the strengths and opportunities available within the existing practice.

2.2 Strengths and opportunities of Gem and Jewellery Industry of Sri Lanka

Sri Lankan gem and jewellery industry possess several strengths and enormous opportunities to make premium value by producing gem studded jewellery for the global market. Report of the competitiveness strategy for Sri Lanka's jewelry industry (2002) identified following strengths and opportunities of the gem and jewellery industry in Sri Lanka.

- Sri Lanka is one of the world's largest gemstone repositories.

Sri Lanka is a leading gem bearing country and retains as one of the world's largest gemstone repositories, second only to Brazil. It is a major producer of fine quality gemstones among the five most important countries together with Myanmar, Brazil, South Africa and Thailand. Sri Lanka is said to have the highest concentration of gems in the world. The national gem deposit surveys explored, approximately 90 percent of the country's land is gem bearing. Around 75 varieties, including precious and semi-precious stones have been found in this land.

- The skilled manufacturing sector

Long tradition in various industry sectors with skilled and competitive manufacturing sector is an asset for the global competitiveness. Sri Lanka possesses a strong and rich manufacturing tradition for generations. One of the most important facts is that the traditional experts are still preserved as an asset for the gem and jewellery industry. Country's natural resource has been converted into exploitable adornments since the ancient times by local craftsmen. The industry which used to operate on a cottage system now includes small, medium and large-size enterprises and incorporates a variety of production techniques which range from producing purely hand-crafted jewellery pieces to machine-manufactured products.

- Competitive wage rates for skilled and semi-skilled workers.

Providing competitive wage rates is an advantage within the region to obtain foreign orders.

- Improved environment for the tourist market

With the improvement of the security situation in the country, tourism is expecting a big boost. It gives the opportunity to elevate the revenue of tourist market sector of the Gem and jewellery industry. According to the available statistics, a tourist visiting Sri Lanka spends on average about $45 for buying a gem & jewellery product. Focusing the gem studded jewellery itself will result the gain of premium revenue from this segment.

- Business friendly government

The government has established a reasonably "open" commercial scenario for the free flow of goods in and out of Sri Lanka. Progressive legislation manipulates within the industry over the past twenty years has been offering favorable terms and conditions for exporters. The proximity to the world's largest gem and jewellery trading countries facilitates to strengthen the gem and jewellery exports sector in Sri Lanka.

Further, Ekanayake and Abeysinghe (2010) stated that have possession of high quality and high value blue sapphires, is a competitive advantage to seize niche markets for high end jewellery products. The reputed Ceylon Blue Sapphires are supreme above all by quality and the quantity among other countries. Blue sapphires have

the ability to differentiate itself for high-end market users by being 'fashionable' and 'branded', ultimately competing with rival products such as diamonds, other-coloured gems, synthetics, and treated gems.

The report of the KPMG and Indian Export Promotion Council (2006) stated that the global gem and jewellery industry is estimated at US$ 146 billion in terms of retail prices in 2005 and has the potential to grow to US$ 280 billion by 2015. India and China are emerging centers of jewellery consumption and have increased their share to 8.3% and 8.9% of global market sales, respectively. Thus, the emerging big markets of China, India and the increasing global jewellery consumption are bringing hopes to maximize the jewellery exports.

It was evident the industry possesses an enormous potential for further development. The industry has not triggered enough even though several implementations were applied to restructure it.

The ratio between gems exports vs. jewellery exports remains stagnant constantly (refer figure 3).

Thus, a need had arisen to explore the factors hindering the successful routine of the industrial value chain. The next section explains the adopted research method to explore the scenario.

3. Research Method

An extensive literature review and several in-depth interviews were carried out with industrial experts and responsible bodies from both government and private sector to explore the factual situation behind this scenario comprehensively. The expert sample was consisted of seven experts from the said segments. The interviews were consisted of unstructured questions and were administered in face-to-face interviews with the chosen sample.

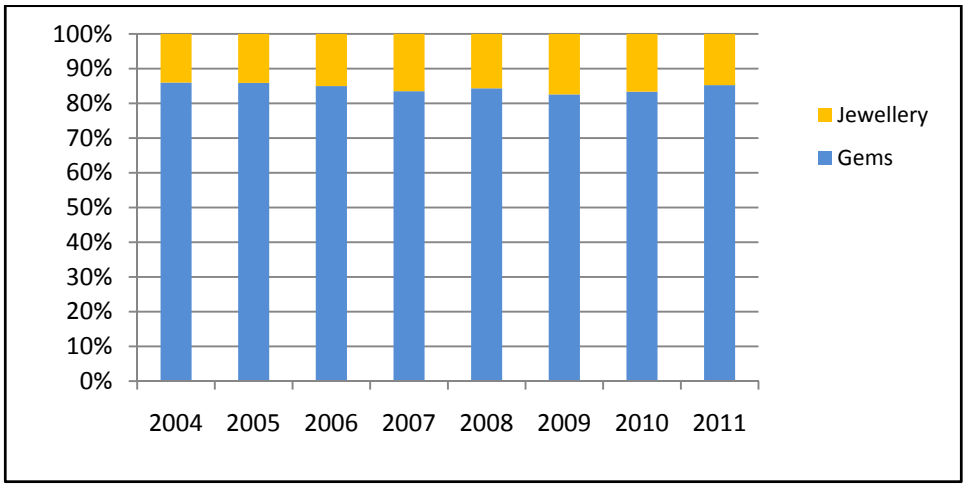

Figure 3: Proportion of the exports of gems vs. jewellery
Source: National Gem and Jewellery Authority

4. Results and Discussion

Through the research process, several vital points could be identified which is accountable for the said observation. The findings confirmed that the vast discrepancy between the gem exports as opposed to jewellery exports is a current issue and it negatively affect the competitiveness of the gem and jewellery industry in Sri Lanka. Six key factors emerged as the major findings of the research namely; lack of innovation, lack of finance, lack of technology, lack of market, lack of competent man power, and lack of integration & long term plans which affects the low competency in the industrial value chain. Those reasons have an impact on lack of gem studded jewellery production and exports which makes the majority of cut & polished gems export without converting them into gem studded jewellery.

Summary of the factors identified by the respondents are given in Table 1.
Table 1: Factors identified by the expert sample
According to the above table the respondents have identified six factors and these factors are discussed in the subsequent sections.

4.1 Lack of innovation

In today's intensely competitive business climate, innovation plays a major and massive role to sustain the competitiveness. The data revealed that the innovation factor is based on the design of jewellery product and all the respondents had pointed out innovation is a lacking factor which hinders the gem set jewellery production and exports. A responsible body (R3) from the private sector argued that "*we should have to sell more jewellery than gems because that gives more opportunity for value addition. But, Sri Lanka lacks the design capabilities*. Another industrial expert (R2) affirmed that "*lack of innovation is a major problem within the jewellery industry. People do not consider the consumer preferences when design for the international market*". The relationship between business growth and innovation is widely understood today and a number of consultants and business scholars have researched on the topic (Christensen, 1997; Foster, 1986; Leifer, 2000; Utterback, 1994). Innovation is one of the main sources of competitive advantage and is essential for company's growth. On the other hand, the competitive advantage of a company strongly depends on its possibility to benefit from innovational activities. Zakić *et al.* (2008) explain that the companies put great effort to face the market competition by introducing innovations.

4.2 Lack of finance

Financial barriers were also identified as a key constraint hampering the industrial competitiveness. A respondent (R5) from the industry asserted that *"lack of financial resources affects for lacking the application of new technology and seeking out new market opportunities*". Financial resources and sufficient quality of investment opportunities is a critical factor for the entrepreneurial success. Public Consultation on the effectiveness of innovation support in Europe (2011) found that lack of access to finance is viewed by enterprises as the main factor hampering innovation activities and lack of access to finance is considered by institutional stakeholders as the principal barrier hampering enterprises bringing innovations to the market (Shortage of financial resources, 2011, p.38). Gathered data revealed that this factor is also affects negatively for the development of Sri Lankan gem and jewellery industry.

4.3 Lack of technology

It was evident that the Sri Lankan gem and jewellery industry suffers from lack of novel technology applications and it directly affects to lower the competency in the global arena. An expert (R7) from the industry stated that "*lack of technology is another issue hindering the industrial potential*". The interview data revealed that a number of sub matters including lack of financial resources, lack of knowledge and skill, negative attitudes of the people incorporated with the issue.

4.4 Lack of market

Penetrate and sustain in the international market is a complicated and a devoted task. A numerous concerns have to be answered and faced to deal with the international market.

The export sector of Sri Lankan gem and jewellery industry suffers due to lack of market. One respondent (R2) from the industry asserted "*lack of knowledge on international market structure is mainly affect for the said problem. It is important to be aware on global marketing analysis, surveys and prospects, export documentation, foreign currency management and legal aspects to have a clear idea about the target market*". Moreover, he mentioned that "*proper identification of the target market is essential to grab the business firmly. Excellent knowledge on consumer preferences, current global trends and the external competitors will create a big stage to success in the global market arena*". It was found out that the low quality of the final product also affects for lacking the market.

4.5 Lack of competent man power

According to the gathered data, lack of skilled and qualified man power in manufacturing and the training sector badly affect the competitiveness in the Sri Lankan gem and jewellery industry. With a low population an inherent factor of this country, it is extremely difficult to compete with the global mass production sector. China and India have the opportunity of high population and well fit to the global mass production sector. Thus the most suitable market will be the niche sector for Sri Lankan gem and jewellery industry. An interviewee (R2) from the industry asserted "*we cannot compete with China or India with mass production but, there is a good opportunity for niche markets*". Low wages paid to craftsmen is sited as another factor for lack of competent man power. Wages in the manufacturing sector are not comparatively attractive and the best workers go offshore for a better salary and standard of living (A competitiveness strategy for Sri Lanka's jewellery industry', 2002). Lack of new skilled workforce is another problem occurs due to negative attitudes. There is a traditional industry passing through generation to generation and new members possess a negative and indistinctive attitude to continue the task.

4.6 Lack of integration and long term plans

The isolation and consequent disjointed functioning has permitted external influences to drive industry behavior. Industry participants are isolated and uncooperative so buyers must undertake tedious searches for goods or continue buying from larger offshore centers. Local stakeholders do not have a long-term vision or industry plan to attract investment necessary for becoming a global competitor similar to Bangkok and Hong Kong (A competitiveness strategy for Sri Lanka's jewellery industry', 2002). A large number of small companies are scattered at different points along the supply chain of the jewellery industry in Sri Lanka. There should be a continuous flow of precious stones in many shapes, sizes and cuts which is a

must to cater to high-end market of the world. Lack of trust and deprived behaviors badly affect the lack of integration and long term plans. A respondent from the industry (R1) said, "*the gem dealers want to get quick turnaround and try to sell stones to the local manufacturers with higher margins. This has led the manufacturing sector to seek offshore sources for buying the required gems for their products*". The result is wasting of domestic resources. The report of the World Trade Organization (1995) has explicated that the chain of the gem and jewellery industry in Sri Lanka is weakly integrated with a fragmented supply base. Most of the stones processed are imported rather than sourced domestically, partly because of the reduction and then elimination of import tariffs on uncut gemstones in the 1990s. The WTO notes that there are considerable opportunities for greater domestic sourcing of the industry (as cited in Macfarlane, Tallontire, and Martin, 2003). Another respondent from the government sector (R4) stated "*for an instance, people seek quick turnaround by selling geuda in bulks instead of value addition. Annually Sri Lanka exports about 1500 kilograms of rough geuda gems, which is about 80% of heat treatable gems produced in this country*". It was evident that these stones are heat-treated and small stones are calibrated particularly in Bangkok creating a vast quantity of stones for the jewellery industry. Although the technology of heat treatment is known locally, people find easy methods to make money.

5. Conclusions & Recommendations

The gem and jewellery industry of Sri Lanka possess a big opportunity to elevate its exports revenue with greater profitability. But, great potential remains untapped. Large quantities of gemstones make their way to other countries without setting in jewellery. During the recent past, countries in the region such as Thailand, Hong Kong, Singapore, and India have performed well in the global jewellery industry and have moved far ahead of Sri Lankan. Thailand and India have made special efforts to develop their industry while they do not have the same broad resource base for natural gemstones as Sri Lanka does.

The competitiveness of the Sri Lankan gem and jewellery industry is lagging behind due to numerous factors. The gem and jewellery industry is an amalgamation of a number of fields and numerous external facilitators involve for the export procedure. Thus, the dearth of intellectual capacity and the support from the responsible bodies keep the gem and jewellery industry sluggish. Six major short comings such as innovation, technology, market, competent man power, financial resources and integration & long term plans have been identified. However, most of the factors are interrelated and the total impact affects the development and the competitiveness of the industry severely.

To attain the premium value for the Sri Lankan gemstones, the final step of the industrial value chain (finished gem studded jewellery), should be encouraged and developed locally. Activities along the value chain should be integrated and the proficient knowledge should be effectively transferred and implemented. The positive government policy, business affable environment, the industrial goals and the increasing global jewellery consumption, altogether provide an optimistic platform to attain the premium value by developing the jewellery industry in Sri Lanka. Following international quality standards, identifying consumer preferences, alert with global trends and marketing surveys, innovative

designs, market innovation, application of new technology, application of high quality craftsmanship and the effective integration of industrial value chain will help to achieve the industrial goals efficiently and effectively. Identifying the competitive advantages of the industry and filling the gaps by effective transferring of tacit and codified knowledge will make the success and the goals would be attainable.

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