SUSTAINABLE USE OF WATER IN CONSTRUCTION PROJECTS: THE CASE OF SRI LANKA

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DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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ABSTRACT

One of the major constraints for sustainable development is the limited quantity of freshwater available. However in construction projects, water is one of the poorly acknowledged resources as far as its efficiency and conservation are concerned. The waste and the misuse of water in construction sites have been identified as critical problems, although there is a high potential for saving water during the construction stage by adopting various water efficiency measures. Nevertheless, this aspect has not been explored sufficiently in current body of knowledge as per exiting literature. This induced the need for the research on sustainable use of water in construction. Therefore, the aim of this research was to develop a framework for improving sustainable water use practices in construction projects, from a Sri Lankan perspective.

Within a pragmatic philosophical view, a triangulation based mixed method approach was adopted for data collection and analysis. Four (04) case studies were carried out into building construction projects located in Colombo to explore the efficient water use practices that are being adopted. Concurrently, a questionnaire survey was administered among experienced construction professionals to identify important measures which can ensure efficient water use.

One of the key findings that emerged from the study was that water efficiency practices are strongly influenced by conditions prevailing within the operational environment of a project. However, some measures for improvement that go beyond on-site project level which have industry-wide support and intervention at policy level are required for these measures to be successful. This study revealed and clearly favoured 'soft' measures such as changes in the behaviour of workers as opposed to 'hard' measures which were primarily technology-based, for achieving water efficiency. The cost of water, sources of water, and the attitudes and behaviour of staff and workers were identified as the most relevant drivers that influence efficient water use in construction sites. The experience and commitments of the parties are also identified as an influential factor for the efficient use of water. The main barrier for achieving water efficiency was the low priority assigned to water management by the top managements of the relevant organisations due to their heavy engagements with other managerial functions.

The research findings introduced three new dimensions namely, Regulation, Responsibility, and Reward that could extend the existing 6R water hierarchy in a more effective manner. This led to the introduction of a novel 3R.6R extended water hierarchy model that can be applied to achieve the efficient use of water in the construction industry.

Among on-site construction activities, 'site cabins and sanitation' taken together was identified as consuming the highest volume of water and also as an activity that causes water wastage. It was revealed that indirect construction activities approximately consume more than two thirds of the amount of water used in a site. As a result, water wastage has become rampant among these indirect construction activities although in contrast it is minimal in direct construction activities. Therefore, the efficient use of water could be improved further by implementing the 'soft' measures in this study rather than implementing technology oriented 'hard' measures. Based on the results of the study, a framework has been proposed which provides the best practice guidelines on implementing sustainable water use during the construction stage of a project.

Keywords: *3R.6R Extended Water Hierarchy, Framework for Sustainable Water Use, Water Management, Water Efficiency, Construction Projects*

DEDICATION

I dedicate this piece of research to my loving husband and son who have always stood by me and dealt with all of my absences on many occasions with a smile.

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LIST OF PUBLICATIONS AND AWARDS

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Built Environment Project and Asset Management (BEPAM) **Highly Commended Paper Award** for the paper titled "3R.6R Extended water hierarchy model for Sustainable use of water during Construction" by Emerald Group Publishing at, The 5th World Construction Symposium Colombo, Sri Lanka, July 2016.

The best paper award was received on paper title "Water efficiency techniques and strategies for sustainable use of water during construction phase of building projects" in the 4th World Construction Symposium June 2015 awarded by The Ceylon Institute of Builders (CIOB).

RESAERCH PUBLICATIONS

Referred Index Journal

Waidyasekara K.G.A.S, De Silva M.L and Rameezdeen, R, "Water use efficiency and conservation during construction: Drivers, barriers and practices, *Journal of Build Environment Project and Assets Management.* (Full paper accepted for publication in 2017).

Referred Journal

Waidyasekara K.G.A.S, De Silva M.L and Rameezdeen, R. (2014). "Industry stakeholder perceptions on water management in construction industry in Sri Lanka: Preliminary survey", *Journal of Institute of Contractors Training and Development (ICTAD)*, November, Vol XII, pp 63-73.

Referred Conference Publications

Waidyasekara K.G.A.S, De Silva M.L and Rameezdeen, R (2016), "3R.6R Extended water hierarchy model for Sustainable use of water during Construction", The 5th World Construction Symposium: Greening Environment, Eco Innovations and Entrepreneurship, p. 1-12, 29th – 31st July, Colombo, Sri Lanka.

Waidyasekara K.G.A.S, De Silva M.L and Rameezdeen, R (2015), "Water efficiency techniques and strategies for sustainable use of water during construction phase of building projects", *The 4th world International Conference on Sustainability and development in Built environment: The way forward*, p.547-559, 12th – 14th June , Colombo, Sri Lanka.

Waidyasekara K.G.A.S, De Silva M.L and Rameezdeen, R (2014), "A critical review of water studies in construction industry", *The 3rd world International Conference on Sustainability and development in Built environment: The way forward*, p.501-12, 20th to 22nd June , Colombo, Sri Lanka

Waidyasekara, K.G.A.S, De Silva M.L and Rameezdeen, R (2013), "Comparative Study of Green Building Rating Systems: In Terms of Water Efficiency and Conservation". *International conference on socio-economic sustainability in construction: practice, policy and research*, pp. 108-117, Colombo, Sri Lanka, June, 2013.

Waidyasekara, K.G.A.S, De Silva M.L and Rameezdeen, R., (2012). "Value of Sustainable Use of Water in Construction Industry". *The 2nd International Conference on Sustainable Built Environment*, Kandy, Sri Lanka, December 2012.

Symposium and Other publications

Waidyasekara K.G.A.S (2015). Appraisal of Water Efficiency in Green Building Rating Systems, pp 17-19, Society of Sri Lankan Quantity Surveyors, Qatar, December 4th.

Waidyasekara K.G.A.S (2014). Water Management Practice in Sri Lankan Construction Industry: Project Managers' Perspective, pp 41-42, Society of Sri Lankan Quantity Surveyors, Qatar, November 27th.

Waidyasekara, K.G.A.S, De Silva, M.L and Rameezdeen, R., (2012). "Importance of Water as a Construction Commodity". *Young water professional symposium*, Galadari Hotel, Colombo, Sri Lanka, November 2012.

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LIST OF ABBREVIATIONS

AB	-	Attitudes and Behaviour
AC	-	Alternative Construction
BOQ	-	Bill of Quantities
BEAM	-	Building Environmental Assessment Method
BREAM	-	Building Research Establishment's Environmental Assessment Method
BRS	-	Building Rating System
BSR	-	Building Schedule of Rates
CE	-	Civil Engineer
CEA	-	Central Environment authority
CIDA	-	Construction Industry Development Authority
CIRIA	-	Construction Industry Research and Information Association
EIA	-	Environmental Impact assessment
EMS	-	Environmental management system
ET	-	Efficient Technologies
GBCSL	-	Green Building Council Sri Lanka
GRIHA	-	Green Rating for Integrated Habitat Assessment
ICTAD	-	Institute of Construction Training and Development
LEED	-	Leadership in Environmental and Energy Design
MC	-	Municipal Council
M & E	-	Mechanical and Engineering
NAM	-	Norm Activation Model
NBRO	-	National Building Research Organization
NCPC	-	National cleaner Production Centre
NGOs	-	Non- Government Organizations
NRBV	-	Natural Resource Based View
NRW	-	Non - Revenue Water
NWS&DB	-	National Water Supply and Drainage Board
PM	-	Project Manager
PP	-	Policies and Planning

QS	-	Quantity Surveyor
RDA	-	Road Development Authority
SFfC	-	Strategic Forum for Construction
SLS	-	Sri Lanka Standard
SP	-	Sustainability Policies
SS	-	Sustainability Strategies
TPB	-	Theory of Planned Behaviour
UDA	-	Urban Development Authority
WC	-	Water Conservation
WE	-	Water Efficiency
WEMs	-	Water Efficiency Measures
WRAP	-	Waste and Resources Action Program
WRD	-	Water Resource Department