Proceedings of the

1st International Conference on International Conference on Construction Project Management and Construction Engineering (iCCPMCE-2018)

03-06 Dec 2018, Sydney, Australia

http://www.icaeed.net.au/

ISBN: 978-0-6482681-0-9

Payam Rahnamayiezekavat, Vivian Tam, Swapan Saha, Eds.

Proceedings of the 1st International Conference on Construction Project Management and Construction Engineering (iCCPMCE-2018), 03-06 December 2018, Sydney, Australia

Published by Science, Technology and Management Crest Australia (STAMCA)

in association with

Global Circle for Scientific, Technological and Management Research, Sydney, Australia

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Date published: 03 December 2018

Publisher:

Science, Technology and Management Crest
12 Boyer Pl, Minto, New South Wales 2565, Sydney, Australia

Paper Peer Review Process:

All full-length papers included in the Proceedings of the 1st International Conference on Advancements in Engineering Education (iCAEED-2018), 03-06 December, 2018 have been independently peer reviewed by two reviewers. The submitted abstracts were reviewed by the Technical Committee, and if the abstract was accepted, the author was invited to submit full papers. The full papers were then reviewed, and the review comments were sent to the authors to address the comments in updating his/her papers. The revised papers submitted by the authors were then checked by the Editors, and accepted once the papers satisfied the requirements of the iCAEED-2018.

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As the Co-Chairs of the 1st International Conference on Construction Project Management and Construction Engineering (iCCPMCE-2018), we would like to thank the Plenary Speakers, Keynote Speakers, Invited Speakers, Authors, Sponsors, Secretaries, IT Team Members, Authors, Conference Advisory Committee Members, Organising Committee Members, Technical Committee Members, Reviewers and Volunteers for making this conference successful.

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Topic: Future Challenges of Built Environment and Design Education in NSW and Beyond

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Mr. Md. Sabur Khan

Founder and Chairman, Daffodil International University, Dhaka, Bangladesh

Topic: Private University Sector in Indian Sub-Continent: Success story of Daffodil International University

A serial entrepreneur, Mr. Md. Sabur Khan, Chairman and Founder of Daffodil International University (DIU) and, Daffodil Education Network (DEN) has involved himself with lot of challenges while he was the President of Dhaka Chamber of Commerce and Industry (DCCI), and, the Bangladesh Computer Samity (BCS). Bangladesh government has awarded Mr. Md Sabur Khan, with the status of 'Commercially Important Person' (CIP) for his role.

His commitment has attached him as Visiting Professor with a lot of foreign universities. He has been awarded honorary professorship and honorary Doctorate degree from abroad.

World Business Angels Investment Forum (WBAF), the largest Angel investors forum designated him as the High-Commissioner of WBAF for Bangladesh. Mr. Md. Sabur Khan is the Chairman, Global Trade Committee and also Director of World IT & Services Alliances (WITSA).

Mr. Khan initiated a challenging project to create 2000 new entrepreneurs, written & published several books in two languages, and initiated business incubator, start up, venture capital, department of Entrepreneurship in the university level to promote entrepreneurship.

Mr. Khan has achieved many awards nationally, and internationally.

He established 'Daffodil Foundation' for the well-being of under privileged people.

PLENARY SPEAKER

Professor Vivian Tam

School of Computing, Engineering and Mathematics, Western Sydney University, Australia

Topic: CO_2 Concrete using Optimal Mix Design

Professor Vivian W. Y. Tam is the Associate Dean (International) at School of Computing, Engineering and Mathematics, Western Sydney University, Australia and Honorary Professor at College of Civil Engineering, Shenzhen University, China. Her research interests are in the areas of environmental management in construction and sustainable development, focusing on life-cycle analyses, green building and recycled concrete. She is currently the Editor of International Journal of Construction Management. She has published over 3 books, 19 book chapters, 215 referred journal articles and 115 referred conference articles. She has been awarded thirty-four research grants (totalled AU$2.4 million), including the first Australian Research Council (ARC) Discovery Projects, awarded under FoR 1202 (Building).

PLENARY SPEAKER

Professor Dr Firoz Alam

Program Director, School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Melbourne, Australia.

Topic: An Innovated Three-Step Teaching and Learning Approach for Laboratory Experiments of Thermal Fluids Courses

Professor Dr Firoz Alam is a Professor and Program Director in the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Melbourne, Australia. He earned his PhD in road vehicle aerodynamics from RMIT University in 2000 and Master's degree (combined with Bachelors) in Aeronautical Engineering from Riga Civil Aviation Engineers Institute, Latvia. Prof Alam has received numerous awards including 2004 RMIT University Teaching Award. His research interest includes aircraft, road vehicle, train, building and sports aerodynamics, energy and engineering education. He has over 250 publications. Prof Alam is a Fellow of Engineers Australia and active members of several other professional societies/associations.

PLENARY SPEAKER

Professor Simon Barrie

Pro Vice-Chancellor, Western Sydney University, Australia

Topic: New developments and challenges in tertiary education: An Australian perspective

Professor Simon Barrie is the inaugural Pro Vice-Chancellor Learning Transformations at Western Sydney University. He is responsible for leadership of strategic educational innovation and transformation at the University, and as part of that work he leads the University's flagship 21C Project. This work delivers the University's commitment to ensuring its students fulfill their potential to become influential global citizen-scholars in a new technology-enabled world. Simon's passions and expertise are in innovatively engaging university communities to deliver new ways to enact the 'idea of the university' in a rapidly changing world. His research is on the transformative potential of higher education and he is a multi-award-winning teacher.

PLENARY SPEAKER

Associate Professor Oliver Obst

Director of Research, Quality, and Innovation, School of Computing, Engineering and Mathematics, Western Sydney University, Australia

Topic: Learning recurrent neural network architectures

PLENARY SPEAKER

Professor Richard (Chunhui) Yang

Lead Director of Academic Program, School of Computing, Engineering and Mathematics, Western Sydney University

Topic: Engineering Education at Western Sydney University: Past, Present and Future

Prof Yang joined School of Computing, Engineering and Mathematics (SCEM) at WSU in January 2012 as Associate Professor of Mechanical Engineering and Smart Structures and he was promoted as Professor in 2018. Since 2015, he was appointed as the Lead Director of Academic Programs, Engineering and Industry Design, leading the SCEM Engineering and ID Academic Team and the curriculum review and renewal of Engineering and ID degree programs. In scientific publication, he has published more than 150 journal/conference papers and confidential reports for industrial partners in his main fields of research - Mechanical Engineering, Materials Engineering, Civil Engineering, etc., as well as in the research field of Engineering Education.

PLENARY SPEAKER

Professor Sathaa A Sathasivan

School of Computing, Engineering and Mathematics, Western Sydney University, Australia

Topic: Sydney Zoo - An experimental learning platform for sustainable water management

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Professor Wanlei Zhou

University of Technology Sydney, Australia

Topic: Preserving privacy in the digital age: Differential privacy and its applications

PLENARY SPEAKER

Associate Professor Mei-Yung Leung

City University of Hong Kong, Hong Kong

Topic: Facilities Management Guideline for Elderly in the Care and Attention Homes

Dr. Leung has more than twenty-five years practical/teaching experience in the construction industry/education. Her research areas include value management, stress management and facilities management. Dr. Leung has attracted over HK$20 million research projects including Competitive Earmarked Research, GRF and ITF grants from the Research Grants Council of HKSAR, and published over 150 research articles including international journals and conferences papers and book. Research areas covers value management, stress management, construction education, and facilities management for elderly. Some of the studies have been published a book with the title of 'Stress management in the construction industry' and ' An indoor FM guideline for care and attention homes in Hong Kong'. She has also received a number of international awards, including Tony Toy Memorial Award by the HKIVM, Thomas D. Snodgrass Value Teaching Award by the SAVE international in the USA, Academic Excellence Awards by the Pacific Association of Quantity Surveyors, Academia Best Paper Award by Miles Value Foundation in the USA, and Teaching Excellence Award by the City University of Hong Kong. Dr. Leung is also a senior Fulbright Scholar at the Pennsylvania State University and the University of Southern California in the USA in 2014-15.

PLENARY SPEAKER

Associate Professor Girija Chetty

University of Canberra

Topic: Multimodal Medical Image Analysis Based on Machine Learning Techniques

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Dr Rafiqul Islam

CEO, Solar-e-Technology, Sydney, Australia

Topic: Engineering Education in the perspective of People, Society and Sustainability

PLENARY SPEAKER

Associate Professor Adel Al-Jumaily

University of Technology Sydney, Australia

Topic: Real life challenges application for computational intelligence in biomedical applications

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Examination on the Sectoral Carbon Emissions Abatement Potential in China：a case study of Chongqing

Mengcheng Zhu[1*], Vivian W. Y. Tam[2], Ya Wu[3], Liyin Shen[4], Qingqing Wang[5]

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Abstract

Global warming caused by carbon emissions has become a major concern around the world. All industrial and economic sectors have made significant efforts on carbon mitigation. However, it is appeared that there is no existing method for examining carbon emissions abatement potential (CEAP) in each sector. This study examines a methodology for estimating CEAP at sectoral level. It is found that the transport, storage and post sectors have the highest CEAP in Chongqing followed by the industry sector. Therefore, financial or administrative support should be offered for the sectoral CEAP. The findings provide insights for decision-makers with a scientific understanding of sectoral CEAC, and thus effective emissions mitigation measures can be taken.

Keywords: *Carbon emissions abatement potential (CEAP); carbon emissions; sectors*

1. INTRODUCTION

Global warming caused by carbon emissions is threatening natural ecological system, human survival and development (Villoria-Sáez et al., 2016; Wang et al., 2018), and carbon emissions reduction has become a development principle in most countries (Shen et al., 2018b; Shuai et al., 2017). As the largest carbon emitter, China is facing immense pressure to reduce carbon emissions. In this regard, the Chinese state council announced a target that carbon emissions per GDP should be reduced by 60-65% by 2030 in comparing to the level of 2005. To achieve this commitment, the national emission mitigation goal has been distributed to individual sector, which is the direct executive sources to implement emission reduction programs. Therefore, it is important to conduct carbon emissions at sectoral level. However, due to the different energy consumption, types of fuel mix and technological levels involved in the product process, the carbon reduction scenarios are different in each sector. It is essential for the local government to understand the carbon emissions abatement potential (CEAP) in each sector, thus appropriate emission mitigation goal can be set. Sectors will lose confidence in completing the unrealistic goals, but the excessive low goal which is easily to achieve could not provide sectors enough power to push the low carbon development strategy. Yi et al. (2011) also pointed out that abatement potential, economic difference and equity are principles in allocating the carbon reduction target. CEAP is a measurement of carbon reduction capacity, which is expected to mining out by city managers to reduce the carbon emissions. Based on CEAP, the carbon reduction goal can be made more scientific and reasonable. Thus, reasonable estimation of CEAP is an important premise for conducting the carbon reduction goal set for sectors.

Nevertheless, there are limited researches related to CEAP. Previous researchers have been dedicated to studying the low carbon performance and focused on technology, strategy and policy to reduce carbon emissions.Wang et al. (2017) analyzed the role of cities, technologies, industries and energy system in China's transition from traditional development to low-carbon development. The study of Shen et al. (2018a) presented the factors affecting carbon emissions by introducing a city development-stage framework. Shen et al. (2018) examined the evolution of low carbon city from process perspective, and found that a city successively goes through three turning points and four processes to shift from carbon intensive to low carbon (Shen et al., 2018a; Shen et al., 2018b). Yang et al. (2014) analyzed the economic development under different kinds of policies in 20% and 40% carbon reduction scenarios, and found that carbon intensity policy performs better than other policies in promoting economic development. Quaresma et al. (2018) suggested to manage the greenhouse gases emissions through creating an energy planning which proposed an optimal fuel mix. Guo et al. (2016) explored opportunities for effective policy intervention for residential energy savings in Xiamen.

The few existed CEAP study focused on individual sector and scenario simulation. Yu et al. (2016) and Tan et al. (2018) estimated the CEAP of economic and building sectors based on CAS bottom-up model and environmental learning curve method respectively. Li et al. (2018) estimated the inverse U-shaped relationship of carbon reduction cost with GDP growth rate and CEAP was discussed under five scenarios of GDP growth rate. However, researches about CEAP that have considered the different sectoral carbon emissions are absent, which is not helpful for city managers to identify the different carbon emissions potential of different sectors.

Therefore, this paper aims to evaluate CEAP based on sectoral carbon emissions and provide methods for making use of CEAP. The finding will provide policy-makers reference for carbon emission reduction goal allocation and decide the focus sectors of emission reduction. Chongqing was chosen as the case study for several reasons. Chongqing is the only municipality in the southwest region of China and one of the country's first low-carbon pilot cities. It is important for Chongqing to take effective measures to achieve the carbon emission reduction missions. The estimation model is also applicable to other cities.

2. SECTORAL CARBON EMISSIONS

In this study, the selected sectors are based on China Energy Statistical Yearbooks (NBSC,2016), including S_1 (Agriculture, Forestry, Animal Husbandry and Fishery), S_2 (Industry), S_3

(Construction), S_4 (Transport, Storage and Post) and S_5 (Wholesale, Retail Trade and Hotel, Restaurants). The sectors are shown in Table 1.

Table 1: The selected sectors

Code	Sectors
S_1	Agriculture, Forestry, Animal Husbandry and Fishery
S_2	Industry
S_3	Construction
S_4	Transport, Storage and Post
S_5	Wholesale, Retail Trade and Hotel, Restaurants

The carbon emissions of each sector in table 1 is calculated according to the consumption of each type of energy using following formula which is published in the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006a; Shen et al., 2017). The energy consumption of raw coal, cleaned coal, other washed coal, briquettes, coke, coke oven gas, other gas, crude oil, gasoline, kerosene, diesel oil, fuel oil, liquefied petroleum gases, refinery gas, natural gas, other petroleum products are considered.

$$C_i = \frac{44}{12} * \sum_{j=1} E_t^j * LCV_j * CF_t^j * O_j \quad (1)$$

Where C_i denotes the carbon emissions of sector S_i, $\frac{44}{12}$ means the molecular weight ratio of carbon dioxide to carbon, E_t^j denotes the energy consumption of the fuel j in year t, and LCV_j represents the lower calorific value of fuel j, CF_t^j represents the carbon emissions factors of the fuel j in year t, and O_j is the oxidation rate of the fuel j. The values of LCV, CF and O are listed in Table 2.

Table 2: Lower calorific value (LCV), carbon emissions factor (CF) and oxidation rate (O) of energy sources

Energy source	LCV (GJ/t) Or	CF (t C/TJ) [b]	O[c]
Raw Coal	20.908	25.800	0.918
Clean Coal	26.344	27.680	0.918
Other Washed	8.363	25.800	0.918
Briquettes	21.636	33.600	0.900
Coke	28.435	29.410	0.928
Coke Oven Gas	16.746	14.000	0.990
Crude Oil	41.816	20.080	0.979
Gasoline	43.070	18.900	0.986
Kerosene	43.070	19.600	0.980
Diesel Oil	42.652	20.170	0.982
Fuel Oil	41.816	21.090	0.985
Other Gas	5.227	14.000	0.990
Other Petroleum	41.816	20.000	0.980
Liquefied	50.179	17.200	0.989

Refinery Gas	46.055	18.200	0.989
Natural Gas	38.931	17.200	0.990

a Data resource: (National Bureau of Statistics of China (NBSC), 2016).

b Data resource: (IPCC, 2006b).

c Data resource: (Geng et al., 2013) .

3. CALCULATION MODEL FOR CEAP

According to the method mentioned in the section 2, the carbon emissions of each sector (C_i) can be calculated. The carbon emission intensity of each sector is calculated by the carbon emissions of sector and the added value (Shen et al., 2018b; Wu et al., 2018) which is shown in formula (2).

$$CI_i = C_i / V \quad (2)$$

V devotes the added value of sector i. CI_i represents carbon emission intensity of sector i and refers to the capacity of energy efficiency. Its decrease can curb the carbon emissions. (Wu et al., 2018) In other words, the minimum value of CI_i ($Min_{i=1}^{5}CI_i$) indicates the best capacity of carbon emissions reduction. Thus, this study chooses it as the benchmark for CEAP of each sector. The calculation model for CEAP of each sector (ρ_i) can be developed as follows:

$$\rho_i = CI_i - Min_{i=1}^{5}CI_i \quad (3)$$

4. APPLICATION DEMONSTRATE

For better interpreting the calculation process of CEAP, Chongqing was selected as the case study city. The CEAP of Chongqing in 2016 was examined. The data of each sector's consumption for different types of energy is from China Energy Statistic Yearbook (2016) and the added value of sectors are from Chongqing Statistical Yearbook (2016). C_i is calculated according to the formula (1) in section 2. Based on the data from National Bureau of Statistics, the added value of each sector in Chongqing is shown in Table 3. Carbon emission intensity (CI_i) is available by formula (2). Based on the formula (3), the CEAP of each sector (ρ_i) can be examined. The results are shown in Table 3. It can be observed from Figure 1 that the S_4 (Transport, Storage and Post) has the highest ρ_i value and is followed by S_2 (Industry).

Table 3: calculate carbon emissions of sectors

Chongqing	S_1	S_2	S_3	S_4	S_5	Unit
C_i	175.28	6929.80	192.14	1929.27	274.11	10^4 ton
Added value	1324.66	6183.8	1715.12	848.22	1862.04	10^9 yuan
CI_i	0.0099	0.3906	0.0108	0.1087	0.0155	ton/10^5 yuan
ρ_i	0.0203	1.0086	0.0000	2.1625	0.0352	ton/10^5 yuan

Figure 1. The value of sectoral CEAP

5. MEASURES FOR MAKING USE OF CEAP

The CEAP of each sector shows the potential capacity of the sector to reduce carbon emission. CEAP can provide reference for both goal allocation and carbon reduction. According to the sectoral CEAP, policy-makers can easily identify which sectors have higher potential of abatement carbon emissions and take measures for reducing carbon emissions effectively. The bigger the value of the CEAP, the higher potential abatement carbon emission of the sector. City managers can set scientific carbon reduction goals for different sectors based on it. The lowest CEAP in Chongqing is S_3 (Construction). The top two higher CEAP sectors are S_4 (Transport, Storage and Post) and S_2 (Industry) of which the value reached to 2.1625 and 1.0086 respectively. The results indicate that the Transport, Storage and Post in Chongqing has the highest potential which is supposed to pay close attention to reducing carbon emissions. The green traveling mode need to promote widely and transportation network should be optimized by the government. S_2 represents industry sector which belongs to secondary industry. According to the government work report of Chongqing in 2018, the industrial structure of Chongqing is 6.9: 44.1: 49. From the China Statistical Yearbook, the industrial structure of China is 8.6: 39.8: 51.6. Due to the carbon intensive of secondary industry, industrial restructuring is still a necessary strategy of Chongqing. Investment priority is assumed in technical update and better management for making full use of CEAP in each sector.

6. CONCLUSION

To estimate CEAP of different sectors, this paper established a calculation model and used Chongqing as a case study. Sectoral carbon emissions in this paper are selected from energy consumption sectors and CEAP was measured based on their carbon emission intensity. This paper provided a method for policy-makers to considerate the CEAP in making carbon reduction goal. It is also conducive for the city manager to take measures in mitigating carbon emission. However, along with the city development, the CEAP of sectors is not fixed and constant attention should be paid on further study.

7. ACKNOWLEDGMENTS

This research work is supported by the National Planning Office of Philosophy and Social Science Foundation of China under Grant Nos. “15AZD025”, “15BJY038” and “17ZDA062”.

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Causes of disputes in Sri Lankan construction industry: Perspective of different parties to the contract

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Abstract
Sri Lanka is a developing country attracting many international contractors for its mega infrastructure and building construction development plans. However, these massive projects with various stakeholders with different interests always give rise to claims, if not resolved, finally leading to disputes. There are mainly three parties contributing to the construction projects, namely; Client, Contractor and Consultant. The causes that give rise to construction disputes may vary based on the perspective of eand every party to the contract. Therefore, this research aims to identifying the causes for dispute resolution in the perspective of different parties to construction projects in the Sri Lankan construction industry. Initially an extensive literature review was carried out to identify the causes of disputes. Afterwards, a comprehensive questionnaire survey was conducted involving professionals representing various stakeholders namely contractors, clients and consultants. Survey responses were analysed using special purpose statistical software (SPSS). To determine the statistical significance difference between the stakeholders' perception, Kruskal-Wallis H test was used with a 90% confidence level. This research provided significant insights on causes of claims from different perspectives. All the parties to the contract unanimously identified that 'failure to administer the contract' as the main cause for disputes in Sri Lanka.

Key words: *Construction industry, disputes, Sri Lanka*

1. Introduction

Construction industry represents a significant proportion of a country's economy. However, due to its unique nature, disputes are very common in the construction industry and therefore, dispute resolution has been part of the routine of every construction manager. If construction disputes are not resolved promptly, they tend to drag on and escalate causing project delays, and ultimately destroy business relationships.

Sri Lanka is a country in South Asia with a steady Gross Domestic Product (GDP) growth of 4.8 percent in 2016 from the previous year (The World Bank, 2017). Due to the significant development activities in construction, as well as the resumption of major projects such as Colombo Port City real estate project worth of USD 1.4 billion, have boosted the economy of Sri Lanka (The World Bank, 2017). Therefore, in such complex construction projects, resolving disputes has become an inevitable part of a project manager's work. An understanding of the various forms of the settlement of disputes processes and their critical factors will no doubt be invaluable to project managers in handling disputes (Cheung, 1999).

According to Awwad, Barakat, and Menassa (2016), literature on dispute resolution can be divided into two categories namely dispute causes and resolution methods. Many research studies identify the causes of disputes in construction in different countries (Çakmak Pınar Irlayici, 2016; Yildizel, Dogan, Kaplan, & Ergut, 2016). However, the construction practices and dispute resolution varies from country to country. Apart from that, the construction industry has a significant involvement of different parties such as contractors, consultants, and clients. According to Waidyasekara and Silva (2014), stakeholder involvement is one of the unique characteristics in construction industry compared to other sectors. However, in the existing literature, there is a clear lack of research discussing the state of construction disputes regarding different perspectives of various parties to the construction project (Awwad et al., 2016). This is applicable in Sri Lankan context as well. Therefore, this research aims to address this research gap by identifying the causes of disputes in the perspective of different parties to construction projects in the Sri Lankan construction industry.

2. Causes of construction disputes

There are many causes of construction disputes. In early 90's Jahren and Dammeier (1990), identified the preliminary causes of dispute in construction as changes in conditions, payment issues, time and delays, errors in the bid and lack of communication. These are primary causes of dispute in construction. However, by now there are deeper investigations on the causes of disputes in construction. There is a series of reports published on the global construction disputes worldwide focusing different regions (Arcadis, 2014, 2015, 2016). When analysing the reports from 2014 onwards there are six common causes of construction disputes worldwide namely; 1) Failure to administer the contract, 2)Poorly drafted or incomplete and unsubstantiated claims, 3) Errors and/or omissions in the contract document, 4) Incomplete design information or employer requirements, 5) Employer/ contractor/ subcontractor failing to understand and/or comply with its contractual obligations and 6) Failure to make interim awards on extensions of time and compensation (Arcadis, 2014, 2015, 2016).

In a similar research focusing on the Middle Eastern region by Awwad et al. (2016) identified 12 causes of disputes and categorised those into three types as administrative causes, contractual causes and cultural causes. Similarly, Çakmak Pınar Irlayici (2016) also carried out research to identify the causes of disputes in Turkey focusing on six dispute categories. Yildizel et al. (2016), also identified 31 causes of disputes in Turkish construction industry. After an extensive literature review, Cheung and Pang (2014), identified five sources of disputes and numerous causes of construction disputes underlining them

Most of these causes identified in the literature are similar in meaning. However, certain researchers identified causes of disputes in an extensively detailed manner. After reviewing all these causes of disputes, 15 causes were shortlisted in for this study. Table 1 reports the causes of construction disputes identified in this study.

Table 1: Causes of construction disputes

Causes	Arcadis (2016)	(Awwad et al., 2016)	(Çakmak Pınar Irlayici, 2016)	(Yildizel et al., 2016)	(Arcadis, 2015)	(Arcadis, 2014)	(Cheung & Pang, 2014)	(Marzouk, El-Mesteckawi, & El-Said, 2011)
Failure to properly administer the contract	✓	✓	-	-	✓	✓	-	-
Error and/or omissions in contract documents	✓	✓	✓	✓	✓		✓	✓
Incomplete design information or Employer requirement	✓	✓	✓	✓	✓	✓	✓	✓
Failure to understand and/or comply with its contractual obligations by either party	✓	✓	✓	-	✓	✓	✓	-
Poorly managed construction process leading to shortage of resources and quality issues	-	-	-	✓	-	-	-	✓
Diverse interpretation of contract terms	-	-	-	✓	-	-	✓	✓
Inadequate risk identification/allocation	-	-	-	✓	-	-	✓	✓
Lack of corporation and trust among parties	-	-	-	-	-	-	✓	✓
Opportunistic behaviour of project parties	-	✓	-	-	-	-	✓	✓
Reluctance of project participants to deal with changes	-	✓	-	-	-	-	✓	✓
Conflicting goals and objectives of project parties	-	-	-	-	-	-	-	✓
Lack of experience in construction practices and management	-	-	-	-	-	-	-	✓
Lack of interpersonal skills among professionals	-	-	✓	-	-	-	✓	✓
External uncertain factors such as weather conditions or environmental regulations	-	-	✓	✓	-	-	✓	✓
External changes such as changes in market conditions and environmental regulations	-	✓	✓	✓	-	-	✓	✓

3. Research methodologies

This research initially conducted an extensive literature survey to determine the causes of disputes in the construction industry. Table 1 reports the causes of construction disputes. To identify the perspective of parties to the contract in alternative dispute resolution a questionnaire survey was carried out. Afterwards, the survey data was analysed using special purpose statistical software (SPSS) to derive results.

The first section of the questionnaire gathered demographic information about respondents. Further, in this section respondent were asked as to which party to the contract the particular respondent is working. The second section in the questionnaire listed 15 causes of disputes as identified in the literature. Respondents were asked to rate the importance of these 15 causes based on the frequency of occurrence on an ordinal scale of 1 to 5. Relative importance index (RII) was used to rank the causes and factors affecting the selection of ADR methods. Afterwards, Kruskal-Wallis H-Test was used with a 90% confidence level to identify whether there is any difference between the parties to the contract in identifying the causes of disputes. Client, contractor and the consultant are the parties to the contract, and therefore represent the independent variables. The causes identified in the literature acts as the dependant variables. The questionnaires were distributed among 84 and received 58 responses with a response rate of 66.66%.

4. Analysis on causes of disputes

As illustration in literature, there are main 15 causes of disputes. However, out of those various causes, it is necessary to identify the most significant causes of disputes in the Sri Lankan context. Therefore, **Table 2** below lists out the causes of disputes ranked in the order of significance with the RII score.

Table 2: Ranks of the significant causes of disputes in Sri Lankan context

Causes for disputes	**RII**
Failure to properly administer the contract	0.800
Error and/or omissions in contract documents	0.786
Incomplete design information or Employer requirement	0.784
Failure to understand and/or comply with its contractual obligations by either party	0.771
Poorly managed construction process leading to shortage of resources and quality issues	0.767
Diverse interpretation of contract terms	0.743
Lack of interpersonal skills among professionals	0.741
Opportunistic behaviour of project parties	0.729
Lack of experience in construction practices and management	0.724
Lack of corporation and trust among parties	0.700
Conflicting goals and objectives of project parties	0.700
Reluctance of project participants to deal with changes	0.657
Inadequate risk identification/allocation	0.643
External changes such as changes in market conditions and environmental regulations	0.571
External uncertain factors such as weather conditions or environmental regulations	0.514

According to **Table 2**, ‘failure to properly administer the contract’ is considered the most significant factor. Similarly Arcadis (2014, 2015, 2016), statistics also shows that failure to properly administer the contract as the main cause of disputes globally and especially in Asian region. However, according to Awwad et al. (2016), this factor ranked sixth from a list of 13 causes in the Middle Eastern region. According to Arcadis (2014, 2015, 2016), even in the Middle Eastern region failure to administer the contract is the most significant cause for disputes.

The issues related to contract documents can be reduced by continuously reviewing the documents before signing the contracts. However, the failure to properly administer the contract falls within the responsibility of the Consultant. Therefore, it is interesting to analyse whether there is change in viewpoint between these three parties on the significance of causes. **Table 3** illustrates the results of Kruskal-Wallis H-Test for the causes of disputes.

According to **Table 3**, based on the Kruskal-Wallis test statistics, it is interesting to note that none of the factors showed a significant difference in the perception of the three parties. The most significant factor, ‘failure to properly administer the contract’ is therefore, accepted by the consultants as well. Therefore, there can be a lack of experience in construction management in the region. Further, there is a possibility that there are other factors that impedes the consultant from properly administering the contract.

Table 3: Kruskal-Wallis Test-Statistics for causes of disputes

Test Statistics[a,b]

	Failure to properly administer the contract	Error and/or omissions in contract documents	Incomplete design information or Employer requirement]	Failure to understand and/or comply with its contractual obligations by either party	Poorly managed construction process leading to shortage of resources and quality issues	Diverse interpretation of contract terms	Inadequate risk identification/allocation	Lack of corporation and trust among parties	Opportunistic behaviour of project parties	Reluctance of project participants to deal with changes	Conflicting goals and objectives of project parties	Lack of experience in construction practices and management	Lack of interpersonal skills among professionals	External uncertain factors such as weather conditions or environmental regulations	External changes such as changes in market conditions and environmental regulations
Kruskal-Wallis H	.190	5.356	3.592	2.128	.928	.706	.547	.041	.785	.152	1.849	.237	1.191	1.529	4.179
df	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Asymp. Sig.	.909	.069	.166	.345	.629	.702	.761	.980	.675	.927	.397	.888	.551	.465	.124

a. Kruskal Wallis Test

b. Grouping Variable: Party to the contract

5. Conclusion

This paper established the significant causes of disputes in the Sri Lankan context. Afterwards, the perception of the parties to the contract; consultant, client and contractor is considered. Initially, with an extensive study, the causes were identified, which then followed by a questionnaire survey. Based on the survey results RII is calculated to rank the factors and Kruskal-Wallis H-Test is conducted to identify the perception of the different parties. According to the results, 'failure to administer the contract' is the main cause of disputes. However it is interesting to note that all the parties have the same perception with regard to this finding. Therefore, it is necessary to conclude that there can be external factors that impede the responsible construction managers from proper administration of contracts. Further, error free construction documents can minimise the disputes as well. Therefore, both contract documentation and contract administration should be given proper attention to eliminate the main causes of disputes.

6. Acknowledgements

The authors wish to acknowledge the financial support from the Australian Research Council (ARC), Australian Government (No: DP150101015).

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Identifying the gaps between on-site personnel's awareness and activities on Green Construction in China

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Abstract

On-site construction stage has been considered as the key in practicing the view of green construction. Moreover, the unity of awareness and actions of on-site contractors on green construction plays a conclusive role through the implementation of green principles on the construction site. This study aims to investigate the awareness on green construction and to identify the gaps between the awareness and activities in adopting green specifications from the perspective of on-site personnel. A questionnaire survey will be conducted with on-site personnel in Mainland China for identifying the gaps between the awareness and activities in the adoption of green construction. As a result, the large gaps between awareness and activities will be identified. The activities which cannot support the effective implementation of green construction will also be presented. Finally, some useful implications will be suggested for governments and departments of construction administrations to take measures in ensuring the thorough implementation of green activities on the construction site.

Keywords: *green construction, green awareness, green activities, gaps*

1. INTRODUCTION

Although the whole impacts of on-site construction activities only accounts for 0.4–12% of the overwhelming impact from the operation stage, the environmental impact from the construction activities cannot be ignored (Mao *et al.*, 2013). Therefore, the concept of green construction was introduced to the construction phase borrowing the idea from the conception of sustainable development (Li *et al.*, 2013). However, on-site construction stage has been considered as the worst stage in practicing the view of green construction especially in developing countries (such as China) for the limitations in on-site construction method and the lack of environmental conscious of site personnel and management teams. Many government departments enacted various green specifications to guide and supervise on-site construction activities (Abuzeinab *et al.*, 2017). Unfortunately, many green principles and activities stated in specifications have not been incorporated to buildings effectively. It is necessary for governments to understand the critical factors that impede stakeholders towards green construction and to examine whether there are gaps between on-site personnel's awareness and activities.

Many studies have been conducted on the awareness of green construction. The lack of awareness of green construction has become the main barrier for implementing green principles in construction industry. Serpell et al. (Serpell and Vera, 2013) carried out a survey questionnaire in top managers of construction firms to explore the level of green construction awareness in Chile. The results showed that Chilean construction firms are in an early stage of the path for achieving green construction using five Likert scales. The same study with similar methodologies was developed by Ametepey et al. (Ametepey *et al.*, 2015) in the context of Ghana and similar results were drawn. In spite of the existence of numerous studies on the awareness and the promotion for the adoption of green construction, such studies within the context of gaps between on-site personnel's green awareness and activities are limitedly reported in the literature. This paper, however, empirically investigates the awareness on green construction and identifies the gaps between the awareness and activities in adopting green specifications with a specific focus: the on-site personnel. The results can provide effective information to guide the governments in targeting their efforts in the full implementation of green specifications.

2. FACTORS AND ACTIVITIES FOR GREEN CONSTRUCTION

Through a comprehensive literature review and an extraction from green specifications, such as ESGCB, a list of twelve factors affecting the awareness of green construction and sixteen construction activities that should performed on construction site have been identified. In accordance with the established principles of green construction and the criteria stated in green construction specifications, the twelve factors and sixteen activities are classified under five main categories: (1) environmental protection; (2) material saving; (3) water saving; (4) energy saving; and, (5) optimum land usage. The rationale of the five categories are discussed below and the factors and activities affiliated to the five categories are shown in Table 1.

Table 1. Five categories of green construction on construction site.

Categories	Factors/Awareness	Activities
Environmental protection	F01 Protection of water resources F02 Healthy construction environment F03 Control dust and construction waste F04 Emissions of exhaust gas and wastewater F05 Control of light pollution and noise	A01 Don’t pump groundwater A02 Separate living area from operation area and disinfect it A03 Close or cover vehicles carrying works generating dust A04 Collect construction waste separately and recycle it A05 Don’t burn wooden scraps A06 Set a drain and discharge sewage and rainwater separately A07 Take measures to prevent strong light from leaking A08 Take measures to absorb sound and to reduce noise
Material saving	F06 Adoption of green materials F07 Control of amount of usage and wastage F08 Cyclic utilization of materials	A09 Give high priority to green and sustainable materials A10 Optimize the material plan and utilize remnants properly
Water saving	F09 Cyclic utilization of water	A11 Adopt water saving devices and water recycling devices
Energy saving	F10 Adoption of energy-saving machines F11 Utilization of natural resources	A12 Adopt energy efficient machines and monitor the data of energy utilization A13 Adopt facilities of natural light and ventilation A14 Adopt construction technology with less energy consumption
Sustainable land usage	F12 Economical layout of construction site	A15 Arrange the general layout of construction site compactly A16 Take measures to prevent soil erosion and restore the vegetation after completion

3. RESEARCH METHODOLOGIES

Firstly, an empirical questionnaire was carried out in July 2017 to examine the status quo of awareness and the response to requirements of green construction. 100 responses (11 invalid) were received by the end of August 2017 from 17 cities in Mainland China.

All respondents were required to provide a statement on the importance of 12 factors (5 = strongly agree; 4 = agree; 3 = medium; 2 = disagree; and 1 = strongly disagree) and the level of implementation of the 16 green activities (5 = always; 4 = usually; 3 = medium; 2 = rarely; and, 1 = never) by using five-point Likert-scale.

After the reliability test of the Likert scales in the survey by calculating Cranach’s alpha coefficient, the mean scores were then used to determine the ranking of awareness on the twelve factors and the

Secondly, one-sample t test was performed to test the significance of the mean scores against a test value of 3.50 (Darko *et al.*, 2017) at a 95% confidence level with a 0.05 ρ-value. If the ρ-value is below 0.05, the mean score is not statistically significant.

Finally, a comprehensive analysis on the awareness of green construction, the degree of implementing green construction activities, and the gaps between the awareness and the activities were conducted based on the statistical results.

4. RESULTS AND DISCUSSION

The five-point scale measurement was reliable for the purpose of this research, because the Cranach's alpha coefficient for the awareness on implementing green construction and the degree of implementing the sixteen green construction activities was 0.981 and 0.954.

Table 2 shows the mean score and the standard deviation of each awareness statement on the twelve green construction factors. The survey results of the implementation degree of the sixteen green construction activities are shown in Table 3.

Table 2. Summary of survey results on the awareness for green construction adoption.

Code	All Respondents				Large Scale			Medium Scale			Small Scale		
	Mean	SD	Rank	*p*-Value	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank
F01	4.34	0.88	4	0.000 **	4.26	1.00	8	4.38	0.85	4	4.41	0.62	2
F02	4.65	0.68	1	0.000 **	4.63	0.75	3	4.65	0.69	1	4.71	0.47	1
F03	4.56	0.71	3	0.000 **	4.66	0.67	2	4.59	0.50	2	4.29	1.05	4
F04	4.58	0.64	2	0.000 **	4.74	0.50	1	4.53	0.61	3	4.35	0.86	3
F05	4.33	0.72	6	0.000 **	4.37	0.79	4	4.29	0.68	6	4.29	0.69	4
F06	4.26	0.73	8	0.000 **	4.26	0.79	8	4.29	0.76	6	4.18	0.53	9
F07	4.28	0.72	7	0.000 **	4.29	0.84	7	4.29	0.63	6	4.24	0.66	7
F08	4.34	0.77	4	0.000 **	4.37	0.79	4	4.32	0.81	5	4.29	0.69	4
F09	4.26	0.9	8	0.000 **	4.34	0.85	6	4.24	0.99	9	4.12	0.86	11
F10	4.16	0.8	11	0.000 **	4.18	0.83	11	4.12	0.84	11	4.18	0.64	9
F11	3.57	1.08	12	0.523	3.55	1.13	12	3.62	1.18	12	3.53	0.72	12
F12	4.20	0.84	10	0.000 **	4.21	0.93	10	4.18	0.83	10	4.24	0.66	8

Note: SD = Standard deviation; ** the one sample *t*-test result is significant at the 0.01 significance level (*p*-value < 0.01) (2-tailed).

Table 3. Summary of survey results on the degree of adopting green construction activities.

Code	All Respondents				Large Scale			Medium Scale			Small Scale		
	Mean	SD	Rank	*p*-value	Mean	SD	Rank	Mean	SD	Rank	Mean	SD	Rank
A01	3.40	1.28	15	0.482	3.29	1.43	16	3.62	1.16	13	3.24	1.15	14
A02	3.94	1.04	3	0.000 **	3.95	1.11	2	4.09	0.90	3	3.65	1.11	2
A03	4.04	0.96	1	0.000 **	4.03	1.03	1	4.32	0.84	1	3.53	0.87	5
A04	3.82	1.11	5	0.008 *	3.76	1.22	5	3.88	1.04	6	3.82	1.07	1
A05	3.49	1.12	13	0.962	3.39	1.24	14	3.70	1.02	10	3.29	0.99	12
A06	3.96	0.98	2	0.000 **	3.95	1.04	2	4.18	0.94	2	3.53	0.80	5
A07	3.43	1.08	14	0.523	3.45	1.16	13	3.50	1.11	16	3.24	0.83	14
A08	3.67	0.99	8	0.099	3.71	1.09	7	3.68	0.98	12	3.59	0.80	4
A09	3.67	1.03	9	0.115	3.68	1.09	8	3.79	0.98	8	3.41	1.00	10
A10	3.76	0.95	6	0.011 *	3.76	1.02	5	3.91	0.90	5	3.47	0.87	8
A11	3.62	1.01	11	0.271	3.66	1.05	9	3.74	1.02	10	3.29	0.85	12
A12	3.39	1.04	16	0.336	3.34	1.15	15	3.53	1.02	15	3.24	0.83	14
A13	3.60	1.00	12	0.369	3.66	1.05	10	3.62	1.04	13	3.41	0.80	10
A14	3.65	0.92	10	0.123	3.61	1.00	12	3.76	0.89	9	3.53	0.80	5
A15	3.89	0.95	4	0.000 **	3.95	0.98	2	3.94	0.95	4	3.65	0.86	2
A16	3.70	1.04	7	0.077	3.66	1.19	10	3.85	0.93	7	3.47	0.87	8

Note: * the one sample t-test result is significant at the 0.05 significance level (*p*-value < 0.05) (2-tailed).

4.1. Awareness of On-Site Personnel on Green Construction

It can be concluded from Table 2 that there was a deep perception among on-site personnel that the principle of green should be carried out in the process of on-site construction. This results show that the construction firms in China have a significantly high level of awareness on green construction. Only the factor "Utilization of Natural Resources (F11)" was considered to be less useful to enhance the environmental performance of construction activities in terms of on-site construction. "Healthy construction environment (F02)", "Emission of exhaust gas and waste water (F04)", and "Control of dust and construction waste (F03)" are identified to be the top three factors with high level awareness behind the principle of green construction. The results demonstrated there is a restricted knowledge understanding on green construction which was confined to reducing dust, construction waste, waste water, and carbon emissions. However, it is deemed that design activities, such as the selection of building envelope, material of building roof rather than on-site construction activities are the most crucial factors influencing the performance of environment (Chang *et al.*, 2011, Lou *et al.*, 2012). Therefore, the mean scores of F10, F11, and F12 were the three least factors with relative low level of awareness on green construction.

4.2. The Implementation Level of On-Site Green Construction Activities

The results in Table 3 indicated that on-site personnel had not translated the principle of green construction into action well in mainland China. In all sixteen green construction activities, only A03 got a mean score more than 4.00. This is because reinforced punitive measures were put into practice by Chinese government in order to completely eradicate the construction dust caused by earthworks. Activities A06 and A02 were ranked in the second and third places, respectively. It is demonstrated that measures related to on-site personnel's health were relatively better implemented in the process of construction than those being relevant to the health of natural environment.

Activities A8, A11, A13, and A14 showed statistically insignificant. It may be attributed to the additional financial support on construction machinery or advanced technologies for these four activities. Although measures, such as adopting water saving devices and natural light facilities, can reduce the construction cost, it is negligible to the disposable purchase cost of all the machines. For the activity A09, on-site personnel are accustomed to employ traditional construction measurements and they are reluctant to make a new attempt in green and sustainable materials out of cost, time, or the technology. The similar performance was embodied in the activity A16.

Activities A12, A01, and A07 are the last three activities behind the implementation of green construction for the low mean scores and statistically insignificant ρ-values. As expected, A12 occupied the last position (mean = 3.39). This is because the applications of information technologies, such as big data and BIM, are still at the preliminary stage in construction industry (Chan *et al.*, 2018). It was just used initially in the pre-construction stage (Santi, 2018). However, it was disappointing that the activity A01 was ranked at the second to last position with poor performance of implementation. It is contrary to policies of conserving water resource of China and relevant departments should draw enough attention on it.

4.3. Gaps between the Level of Awareness and Implementation

Table 4 shows the percentage of respondent agreeing the importance of green construction and carrying out green activities. The level of awareness agreeing on the importance of green construction and the level of carrying out green activities were determined by the highest value of percentage or frequency. For example, fifty-five percent respondents (the largest percentage) considered that they strongly agree on the importance of "Protection of water resources (F01)", and then the agreement level of F01 was affirmed the "strongly agree" level. Nevertheless, the highest frequency (39%, see Table 6) was presented to level 5 ("Always") when respondents stating the application level of green construction activity A02. Hence, it was an "Always" level in implementing this green activity.

Based on this, a comparative diagram with three types of relationships named no gap, small gap, and large gap between awareness and implementation are identified, as shown in Figure1. No gap means the percentage of awareness agreeing the importance of green construction and the frequency of carrying out green construction activities are at the same level. A one-level difference denotes a small gap and a two or more level difference represents a large gap.

Table 4. Percentage of respondent agreeing the importance of green construction and carrying out green activities.

Awareness	Percentage of Awareness (%)					*n*	Frequency of Implementation (%)					Activities
	5	4	3	2	1		5	4	3	2	1	
F01	55	28	13	2	1	89	26	22	27	16	9	A01
F02	74	19	4	2	0	89	39	25	29	4	2	A02
F03	64	31	2	1	1	89	44	21	30	4	0	A03

						89	38	19	31	9	2	A04
						89	26	19	38	13	3	A05
F04	65	29	4	1	0	89	37	28	29	4	1	A06
						89	21	19	45	10	4	A07
F05	47	38	15	0	0	89	26	26	39	8	1	A08
F06	43	40	17	0	0	89	28	24	37	10	1	A09
F07	44	40	16	0	0	89	28	27	39	4	1	A10
F08	52	30	18	0	0	89						
F09	52	26	20	1	1	89	24	27	39	8	2	A11
F10	40	35	25	0	0	89	18	22	45	10	4	A12
F11	25	26	34	13	2	89	21	30	37	9	2	A13
						89	21	30	42	6	1	A14
F12	45	33	20	2	0	89	34	27	34	6	0	A15
						89	26	**33**	29	10	2	A16

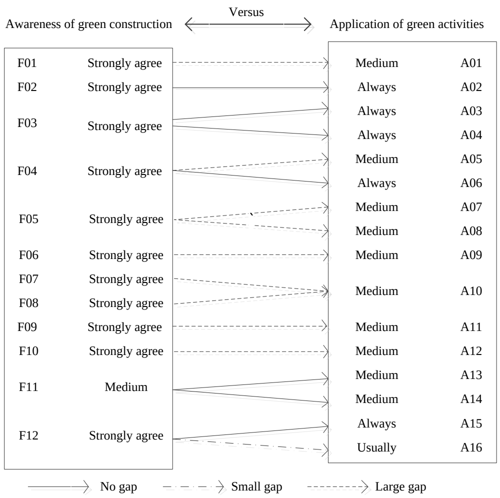

Figure 1. Relationship of green construction awareness and activities.

From the relationships between green construction awareness and activities shown in Figure 1, nine groups with large gap (F01 and A01, F04 and A05, F05 and A07, F05 and A08, F06 and A09, F07 and A10, F08 and A10, F09 and A11, F10 and A12) between awareness and activities were identified. Although on-site personnel strongly agree on the importance of these green construction factors, they are reluctant to execute the provisions of green construction. It means that high awareness without execution is not worth much for the implementation of green construction.

There was a small gap between F12 and A16. Based on green construction specifications in China, both A16 and A 15 are the supporting actions for saving land. However, on-site personnel usually focus on the general layouts of construction site due to cost reasons, whereas they consider the soil erosion and vegetation restore have a limited relationship with on-site construction. Furthermore, detailed requirements guiding on-site personnel to prevent soil erosion and to restore the vegetation are lack.

It is nice to see that seven groups of construction awareness and activities with the same level of awareness and application were determined to be no gap. All seven groups can be classified to two categories. One is with “Strongly agree” awareness and “Always” application frequency. Another is with “Medium” awareness and “Medium” application frequency. The former one is the best result for the implementation of green principles on construction site. However, it should also be noticed that the “Always” frequency for a green activity was lower than the percentage of “Strongly agree” in the corresponding awareness. It demonstrates that some disparity still exists between awareness and actions, although construction activities can support green awareness to some extent. For the relationship of “Medium” awareness and “Medium” application frequency, it is the worst result for the implementation of green principles on construction site. It is known that it is impossible for on-site personnel with lower green construction awareness to apply green activities well. Therefore, measures should be taken to arouse the green consciousness of on-site personnel first.

5. IMPLICATIONS

5.1. Narrow the Gaps between Green Awareness and Activities

For a green construction requirement with both high level of awareness and implementation, as small-scale projects have poor execution of green construction activities than large- and medium-scale projects, measures should be taken to strengthen supervision on construction site of a small-scale project. For example, although forty-four percent of all respondents considered that the activity of A03 was always implemented on their construction sites, there were only three respondents from small-scale project. The performance of small-scale projects seriously limits the implementation level of green activities.

For a green construction requirement with a high level of awareness and a low level of implementation, the reason for the low level of implementation may be because of the lack of punishment or specific requirements, which have been explained before. The contractors are reluctant to do as required or they do not know how to do. Therefore, enforcement measures and detailed implementation guidelines for this type of green activities should be formulated by government.

However, for a green construction requirement with both a low level of awareness and implementation, it is imperative to establish a publicity mechanism or an evaluation system to arouse the awareness of green construction. The ideas that green construction can improve enterprise competitiveness, increase extra benefits, and enhance social reputation should be imbued into all on-site personnel. As a result, the enthusiasm of contractors to adopt green construction activities will be naturally raised.

5.2. Strengthen Financial and Technical Support

Although high awareness of green construction is the premise, efforts should not only focus on enhancing on-site personnel's awareness excessively. Financial and technical support is the key for ensuring on-site personnel to implement green construction activities proactively.

The adoption of green building technologies and green construction activities can result in significant economic benefits for all stakeholders of a project (Ries *et al.*, 2006). However, it is hard for contractors to be recouped for implementing green activities. On the one hand, tender offer is the most prominent criterion for tenderee in selecting a contractor. Additional cost for implementing green activities affects competitiveness in a bidding competition. Therefore, the additional cost cannot be completely included in the tender offer of a project. On the other hand, cost resulted from green activities on-site belongs to tech-organizational measures fee, which is usually a lump sum according to contract clause in Mainland China. Therefore, contractors cannot be compensated for the additional cost related to green activities. To break up the barrier, returns should be provided to contractors through various financial support, such as cash allowance, tax preference, and loan interest discount. Compensation scheme and standard should be established according to the green activities implemented on construction site.

Many green construction on-site especially multifaceted technologies go beyond the scope of traditional construction. It is obviously difficult for traditional contractors to execute all of these green activities without professional guidance. Therefore, green specifications should be updated to provide technical support to on-site personnel. Detailed rules for the implementation of green activities should be introduced by government for guiding on-site personnel to correctly execute green technology and to satisfy the requirements of green construction.

6. CONCLUSIONS

This study adopted a questionnaire survey approach to examine the status of on-site green construction in China and the ultimate goal is to identify the gap between awareness and actions of on-site personnel on implementing green construction principles. The findings showed there was a high level of agreement to take green principles into consideration. However, the application level of green activities lagged behind the level of awareness as the mean score of activities was lower than their awareness. Some on-site green construction activities cannot support the high level of awareness, and large gaps were highlighted between green awareness and activities. This paper suggests some useful implications for governments and departments of construction administrations to take measures in ensuring the thorough implementation of green activities on construction site.

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Solutions for barriers against the wider use of recycled aggregate

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Abstract

Policies, regulations and specifications have proved to be one of the ways to increase the existing demand in any industry. This study investigates the current existing Australian States government policies and regulations regarding the reuse of construction and demolition waste. Literature related to the technical specifications of five state governments for the usage of recycled aggregate in the road construction section i.e. Queensland, New South Wales, Victoria, South Australia, Western Australia, have been studied. Though, the policies of local governments are encouraging for the gradual increase in the utilisation of construction and demolition waste, suggestions and recommendations have been proposed to further increase the demand for recycled material in addition to the current regulations. Two areas of usage have been covered by this study which includes road construction as well as concrete production which are the main sources for the utilization of recycled aggregate. Supply and demand curves for the purpose of microeconomic analysis have also been included to show the effect of proposed policies on the economy. CO_2 Concrete technology has been promoted as one of the solutions to satisfy the concerns regarding the performance of recycled concrete.

Keywords: Recycled Aggregates; Standards and Specifications; Supply and Demand; CO_2 Concrete

1. Introduction

The tendency of environmentally conscience communities and enterprises is not only to recycle a large percentage of construction and demolition waste, but to aim for zero waste, which means ensuring that all products be made to be reused, repaired or recycled back into the marketplace. Zero waste plans have been adopted in developed economies around the world and by the local governments in Australia and New Zealand. In Australia, the management of construction and demolition waste is not legislated by the Central Government but the environmental issues including all waste streams, is primarily the responsibility of Australian state and territory governments. The total amount of construction and demolition waste produced in Australia is around 19.3 million tons out of which 12 million tons has been recovered indicating the recovery rate of 62.2%. (Tam, Soomro, & Evangelista, 2018).

The advantages both economic and environmental, of using recycled aggregate as an alternative to natural aggregate in concrete production, are greatly affected by economic reasons. For instance, the choice between recycled and virgin material depends upon price and quality. The quality of concrete made of recycled aggregate can be the same as that of concrete with virgin aggregate if the mix design is done smartly, but recycled aggregate is regarded with suspicion. Hence, recycled concrete material will only be preferred where the price for such aggregate is considerably lower than that of natural material, even when the recycled aggregate meet with the given specifications (Tam et al., 2018). Concerning the quality of recycled aggregate and their associated performance in concrete applications, a newly developed technology called CO_2 Concrete presented a high quality recycled aggregate to the construction market. Main issues associated with the use of recycled aggregate have been depicted in Figure 1.

Figure 1 – Barriers that prevent a wider use of recycled aggregates in construction. (Tam et al., 2018)

Three of the barriers mentioned in Figure 1, will be discussed further in this study and recommendations will be made addressing a solution for each of these barriers. The barriers discussed are:

(i) Limiting standards and specifications
(ii) Low supply and demand
(iii) Low quality of recycled aggregate

2. Methodology

This paper seeks to enhance the overall use of recycled aggregate in both road construction and concrete production. Documents published by the Australian states government bodies authorized to specify the road materials have been reviewed and compared. Impact of microeconomic factors on associated supply and demand of construction and demolition waste recycled aggregate have been analysed and recommendations made upon current barriers against the wider use of recycled aggregate. This analysis suggests ways to increase the usage quantity of recycled aggregate by keeping the unit price constant. Since regulations and policies are a major contributing factor to the supply and demand equilibrium point, the Green Building Council of Australia regulations have also been reviewed. In the end, a new innovation called CO_2 Concrete, which substantially improves the mechanical properties of recycled concrete have been introduced.

3. Discussion

3.1 Standards and Specifications of State Governments

The Australian legislation and planning levels of control are as depicted in Figure 2. Each and any lower level of the hierarchy must be in compliance with the higher ranked policies and regulations. In accordance with the NSW Environmental Planning and Assessment Act 1979, it has been stated that the consent authority must not grant consent to development unless it is satisfied that adequate provisions will be made for some considerations including waste management (Stokes, 2016).

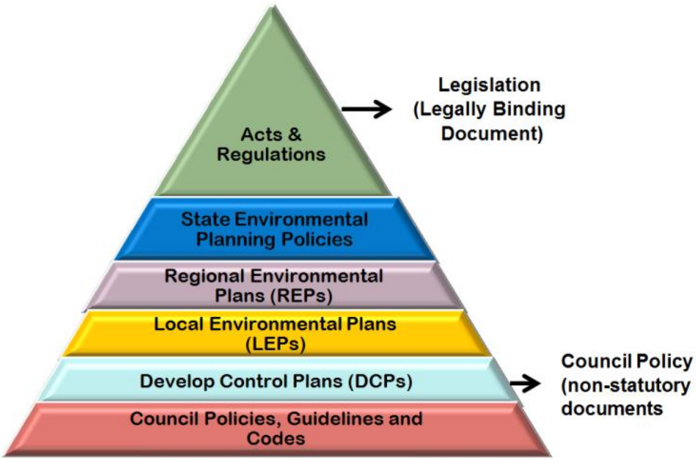

Figure 2 – The levels of control of government bodies in Australia (Crowley, 2018)

In Australia, since the major usage of recycled aggregate is currently in the road construction sector as compared to concrete industry, specifications and regulations associated by both governmental and independent bodies have been reviewed and compared. Table 1 shows the state government bodies authorized to regulate the specifications of road construction materials.

i) Queensland

Several test methods have been promoted for the purpose of evaluating the properties of recycled aggregate to be used as base and sub-base material including but not limited to California Bearing Ratio (CBR), Linear Shrinkage, Liquid limit, Moisture Content, Permeability, etc. Different types of recycled aggregate have been proposed to comply with particular technical specification. To be suitable for different road types and axle loads the Cement Concrete & Aggregates Australia (CC&AA) recommendations however, are substantially different.

ii) New South Wales

NSW government certified specifications addressing the quality of recycled aggregate suggest that for a well-performing pavement built with recycled aggregate as its base or subbase material, the maximum amount of constituent materials must not exceed from the portions provided in Table 3. However, recommendations by CC&AA vary hugely with

Table 3, giving the maximum allowance for instance, for fly ash to be up to 100% ("Sustainable use of aggregates," 2013). Such contradictions may result in confusion for the end user leading to denial of using recycled aggregate.

Table 1 - Government Bodies	
State Government	**Roads and Regulatory body**
Queensland	♦ Department of Transport and Main Roads (Roads, 2017a, 2017b)
New South Wales	♦ Roads and Maritime Services(Services, 2012, 2017a, 2017b) ♦ Environment, Climate Change & Water (Savage, 2010)
Victoria	♦ VicRoads (VicRoads, 2011a, 2011b)
South Australia	♦ Department of Planning, Transport and Infrastructure(Department of planning, 2011, 2015)
Western Australia	♦ Main Roads Western Australia (Australia, 2017a, 2017b)

Table 2 – Two major independent bodies
Cement Concrete & Aggregates Australia ("Sustainable use of aggregates,")
Green Building Council of Australia ("Introducing Green Star,")

Table 3 – Upper limit on the use of recycled and manufactured materials as constituent materials (Services, 2017a)		
Material	**Unbound or modified base and subbase**	**Bound base and subbase**
Iron and steel slag	100%	100%
Crushed concrete	100%	100%
Crushed brick	20%	10%
RAP	40%	40%
Fly Ash	10%	10%
Furnace bottom ash	10%	10%
Crushed glass fines	10%	10%

iii) Victoria

VicRoads, like the other states, outlined criteria for the approval of proposed recycled materials by road contractors to be used as base and subbase material. Each of which, is referring to specific test methods to measure the characteristics of the proposed material. One of the highlighted criteria which could not be found in other states road specifications in regards with the usage of recycled aggregate is the amount of water added to such aggregate before construction.

iv) South Australia

From the literature review, it seems South Australia clearly has a more comprehensive plan compared to the other states. The state department for planning, transport and infrastructure provide a framework to support the commitment to reduce the ecological footprint known as Green Plan. However, there are no approved technical test methods recommended in order to classify the quality of recycled aggregate types.

v) Western Australia

Except one classification for reclaimed asphalt pavement there are no other descriptions provided to address the specifications and test methods for the usage of recycled aggregate.

3.2 Supply and Demand

Supply and demand is perhaps one of the most fundamental concepts of economics and it is the backbone of a market economy. Demand refers to how much quantity of a product or service is desired by the buyers. The quantity demanded is the amount of a product people are willing to buy at a certain price; the relationship between price and quantity demanded is known as the demand relationship. Supply represents how much the market can offer. The quantity supplied refers to the amount of certain goods producers are willing to supply when receiving a certain price. The correlation between price and how much of goods or service is supplied to the market is known as the supply and demand relationship.

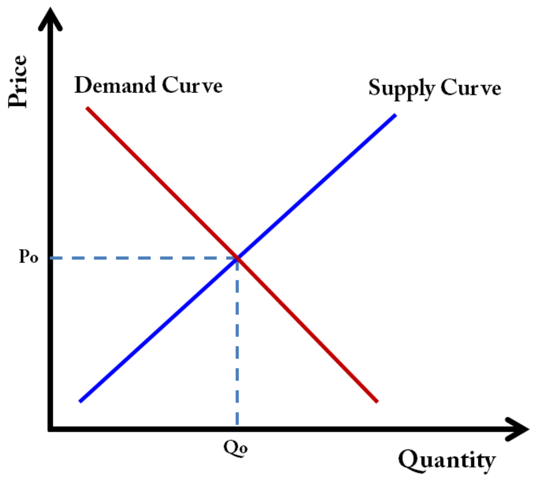

Figure 3 – Supply and demand curves for every economy (Hayes, 2003).

In any economy including the construction industry, the quantity of the demand decreases when the price increases giving the demand curve, mathematically, a negative slope. On the other hand, quantity of supply increases with the increase in price i.e. a positive slope for the supply curve. Figure 3 shows the equilibrium point of an economy where the supply and demand curves intersect and the equilibrium point indicates the actual price and quantity of goods or material (Hayes, 2003).

This study aims to increase the quantity of the usage of recycled aggregate in construction industry by keeping the per unit price constant. A new technology known as CO_2 Concrete technology has been proposed which may ultimately decrease the unit price of recycled aggregate and shift the equilibrium quantity towards right. The following flowchart (Figure 4) describes the path in regards with modification of the supply and demand barriers.

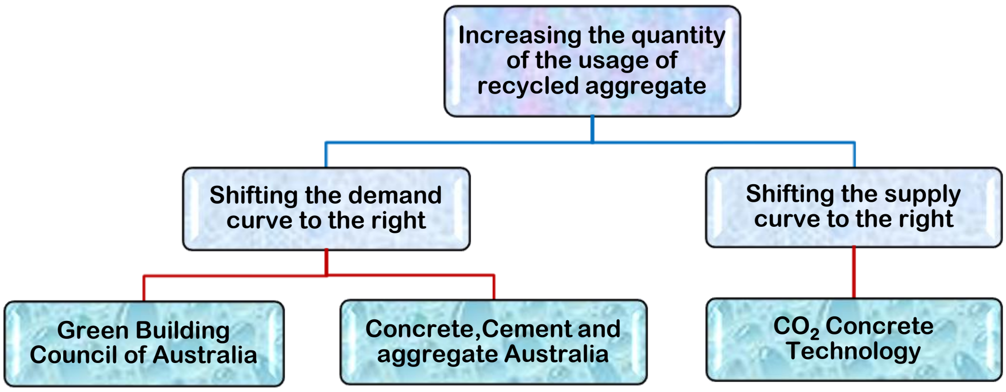

Figure 4 – Path to modify the supply and demand barriers.

3.2.1 *First scenario*: shifting the demand curve to right

Aiming to shift the demand curve to right, some desirable changes in the current legislation and policies, will result in encouraging the construction industry to use more recycled aggregate in their construction i.e. increase demand for recycled aggregate.

3.2.2 *Second Scenario*: Shifting the supply curve to right

The main consumers of recycled aggregate are road constructors and concrete producers (concrete batching plants). Interviews with concrete batching plant operators indicate lack of motivation for the usage of recycled aggregate. The main reason is due to high water absorption of such aggregate which cause the slump to drop dramatically in a short period of time. This slump issue does not allow concrete batching plants to accept orders from construction sites more than 20 minutes away from the batching plant. The other concern of concrete contractors is the shrinkage together with the lower compressive strength of recycled concrete. These problems set back the concrete industry from using recycled aggregate.

A new technology called CO_2 Concrete has been introduced recently (EcoBond), which reduces the porosity of recycled aggregates and therefore reduces the water absorption and as a result shrinkage of recycled concrete is reduced and the workability and compressive strength of recycled concrete increased. One of the benefits of utilizing such technology is the cheaper price (one-third of natural aggregate price) and financial viability of using recycled aggregate (Tam, Butera, & Le, 2016). By utilizing CO_2 Concrete technology within concrete batching plants, the concrete industry will be more encouraged to use recycled aggregate. This will lead to an increase in the supply of recycled aggregate, shifting the supply curve to right.

3.3 Low quality of recycled aggregate

The recycled aggregate industry in Australia is mostly regulated by the Roads Authority, because of the high volume utilization of recycled aggregate. The usage of such materials has been accepted for construction of roads all around the world for many decades. Recent studies on the performance of concrete made with high quality recycled aggregate for structural applications show their suitability for use in concrete production. Survey results indicate that the concrete industry's concern regarding the use of recycled aggregate roots from the limitation of its performance. Though various techniques have been researched and proposed for the quality improvement of recycled aggregate, such as (i) Two-stage Mixing Approach (ii) incorporation of mineral admixtures (iii) use of superplasticizers (iv) acid treatment (v) pre-coating with cement paste (vi) impregnation with silica fume solution etc., most of the methods were not suitable to be applied on industrial scale, however, Two-stage mixing approach (TSMA) is easier and can be operated industrially.

CO_2 Concrete technology is a new innovation for concrete applications which incorporates modified and improved recycled aggregate which could satisfy the concerns of concrete industry operators in regards with the low performance of recycled concrete. The process of producing concrete in this technology includes injecting carbon dioxide in the recycled aggregate which ultimately fills the pores with new products, reduce the water absorption of aggregate and increase the compressive strength of concrete as a result of making aggregate denser (Tam et al., 2016).

4. Conclusion

We have compared the Australian states government regulations and technical specifications; firstly, there seems to be the lack of a unified standard addressing the specifications for the usage of recycled aggregate in the pavement and road construction. This variation in the specifications and test methods of different states may result in an ambiguous situation for road contractors. The ultimate effect will be less motivation for the contractors to use recycled aggregate in their constructions.

Secondly, to provide a solution for the supply and demand issue associated with the recycled aggregate market, having both scenarios described and figured in one diagram in the figure 5, one of the objectives of this article which is to increase the quantity of the usage of recycled aggregate had been reached.

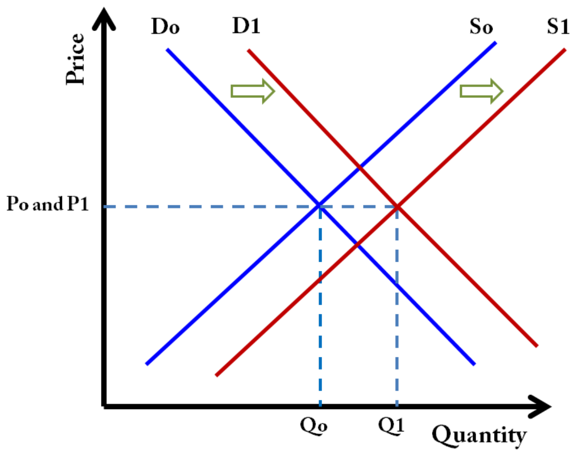

Figure 5 – The new equilibrium point after implantation of new regulations and the CO_2 Concrete technology.

The first scenario shifted the demand curve to right by having two changes in regulations of the two associated organizations, and the new CO_2 Concrete technology shifted the supply curve to the right as explained in second scenario. Indeed, by increasing the utilization of CO_2 Concrete the quantity of aggregate will increase from Q_0 to Q_1 which will then reduce the unit price of recycled aggregate simultaneously with an increase in the equilibrium quantity. As this model works if only the two proposed scenarios happen continuously un-interrupted and on consistent basis, it is recommended to address the CO_2 Concrete technology on the Australian Standards as well as on the regulations and policies of all the councils.

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A study of the use of Artificial Neural Networks in modelling compressive strength of Recycled Aggregate Concrete

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Abstract

Environmental impact concerns are increasing within Construction Industry and recycled concrete is a potential sustainable material, however it has not been typically used for structural applications. One of the reasons is the limited prediction models to obtain concrete mechanical properties, such as compressive strength. Since machine learning techniques have been used to computationally model the most varied types of engineering problems, this paper presents the use of Artificial Neural Networks (ANN) to investigate a specific problem of recycled aggregate concrete (RAC). Different types of ANN were trained and used for modelling the 28 days-compressive strength of recycled concrete based on a data set that considers different concrete mixtures. Using the best three ANNs, is done a sensitive analysis in this study to evaluate the variables contribution along the range. Additionally, the chosen ANNs are inserted into three computer programs to be used as a surrogate model the problem. The outcomes obtained by ANN through the program are analysed and compared to the results obtained using Regression Analysis (RA), as well as their possibilities of use and contributions to the industry considering that the constructed ANN models can predict the compressive strength of concrete made with recycled aggregate.

Keywords: Machine Learning, Artificial Neural Networks, Regression Analysis, Recycled Aggregate Concrete, Compressive Strength.

[redacted]INTRODUCTION

Aggregate used in construction industry is one of the most widely consumed minerals. In the middle of the first decade in the 21st century, 16 European countries were recorded an average consumption of 6-10 tons / inhabitant / year. In the United States, the rate was 8 tons / inhabitant / year. The Asia/Pacific region registers as one of the largest producers in product sales, as construction activity is rapidly rising, particularly in China and India. China alone accounts for half of all new aggregate demand worldwide during the 2010-2015 periods (Concrete Construction 2012). Considering the environmental impact by the use of natural aggregates, construction and demolition waste aggregate is revealed as an sustainable and efficient alternative to produce recycled concrete (Tam *et al.* 2016).

The planning and execution of concrete tests are important in the development of new materials. However, for each study, plenty of mixtures are demanded and time in the curing process. In addition, a significant effort expended performing mechanical tests (compression, tensile, shear, elastic

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modulus, etc.). Thus, the study of techniques aiming to facilitate the modelling of engineering problems can have advantages in making the process less costly and leading more reliable results. For example, there is also the inverse problem, where is desired a mixture that will achieve a certain 28 days compressive strength.

In order to obtain alternatives to model the mechanical behaviour of concrete as an option to regression analysis has been found in the literature since the 1990s. Yeh (1998) studied the use of a backpropagation ANN to model the compression strength of high-performance concretes with better results than those obtained by regression analysis.

In an attempt to give a destination in the ashes of hospital solid wastes, Al-Mutairi, Terro and Al-Khaleefi (2004) studied its effects on property compression strength when these ashes are mixed with concrete. For this research, the author made statistical evaluations and used a prediction model based on ANNs.

Taking advantage of the trend, Tam, Tam and Wang (2007) used ANNs to improve mixture methodology to obtain a higher performance of RACs. Using ANNs and fuzzy logic (ANFIS – Adaptive neuro-fuzzy inference systems) techniques, Topcu and Saridemir (2008) modelled the compressive and splitting tensile strengths for recycled aggregate incorporated silica fume.

Studying RACs and their characteristics for structural applications and following an experimental design using similar RACs, Kotrayothar (2012) developed a significant amount of tests which will be used as data base of this work. This decision was made considering that the recycled aggregate is a heterogeneous material and the use of a database generated in similar conditions can achieve relevant ANNs results in comparison to the authors who sought to compose their databases by gathering information from the most varied sources. Continuing the research, Tam *et al.*, (2016) developed a regression analysis to predict target characteristic compressive, tensile and flexural strengths from 44 mix designs.

Recently, the use of machine learning tools has provided significant results in previous projects. In order to model the behaviour of the modulus of elasticity at 28 days of RAC, Duan, Kou and Poon, (2013) constructed two ANNs and compared them with their experimental results and the results obtained by conventional regression analysis. The training of the first ANN was based on a dataset with 324 records drawn from 21 international papers, while the training of the second ANN considered these same 324 records plus 16 datasets from experiments done by the authors. The authors chose 16 characteristics as ANN entries and obtained precise results for both networks, with low values of Root Mean Square Error (RMSE) and Mean Absolute Percent Error (MAPE). As an extension of the previous paper, they used the same ANNs based on the same data sources and with the same input parameters to explore in detail the applicability of using ANNs in modulus of elasticity of RAC.

Some researchers (Şimşek, İç and Şimşek 2016; Paul, Panda and Garg 2018) executed a reduced experimental program and with little representativeness in certain regions of the input parameters. Several authors (Dantas, Batista Leite and De Jesus Nagahama 2013; Duan and Poon 2014) seek previous data to improve their analysis.

In this way, the intention of this work is to search among three types of ANNs: Multilayer Perceptron (MLP), General Regression Neural Network (GRNN) and a Network Group Method of Data Handling (GMDH), which is also known as Polynomial Neural Network, one that fits well for the construction of a substitute model to calculate the compressive strength for each algorithm. It was observed that ANNs achieved accurate results in the analyses and could be a very potential tool in the RCA area.

This paper aims to model the compressive strength of recycled concrete by the use of machine learning technique such as Artificial Neural Networks (ANNs) and to construct a software using this model as the core of the program.

[redacted] RESEARCH METHODOLOGIES

The methodology used in this work follows the determined flow:

- To organize the data to be used in the modelling problem focused on compressive strength;
- Train some types of ANN (MLP, GRNN and GMDH);
- Evaluate statistically the ANNs obtained and choose one that best adapted in the modelling of the problem for each type of ANN;
- Encode the analysis programs using ANN as core;
- Use the ANNs and compare their results with Regression Analysis (MR) results and the tests values.

The characteristics of the data used in the modelling, as well as details related to ANN and the programs constructed, will also be commented.

2.1. Data characteristics used to model the problem

The data used in this work extracted from Tam et al (2016) was used for the learning process of the neural network. This dataset is characterized by being relatively small (the dataset has only 47 records) and it does not well represent certain regions of input parameter information. The 47 mixtures varied for Water/Cement ratio from 0.3 to 0.6, Aggregate/Cement ratio from 3.0 to 6.0, Cement from 300kg to 600kg, Water from 120kg to 270kg and for the percentage of recycled aggregate ranging from 0% to 100%. Compressive strength responses measured in the laboratory ranged from 22.9MPa to 82.5MPa. In order to have a better idea of the representativeness of the data, the histograms of the input dataset were created and shown in Figures 1 to 5. Figure 6 presents the Pareto graph of the compressive strength obtained in the experimental program.

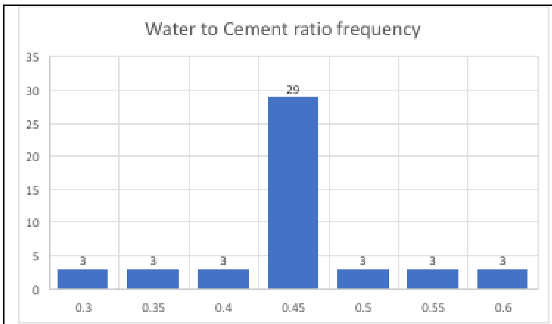

Figure 1 – Water to Cement ratio frequency

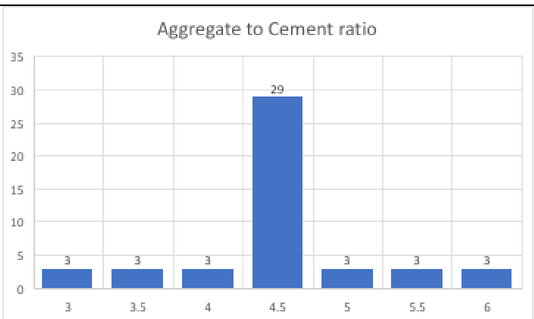

Figure 2 – Aggregate to Cement ratio

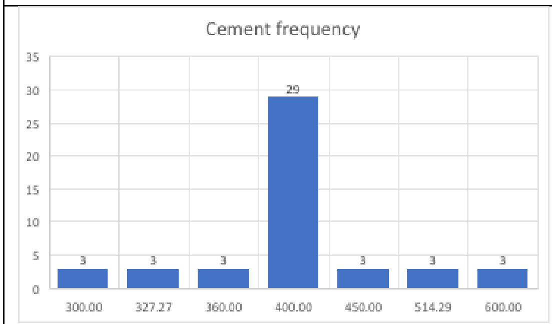

Figure 3 – Cement frequency

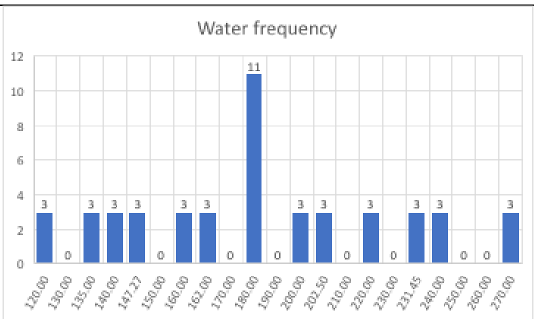

Figure 4 – Water frequency

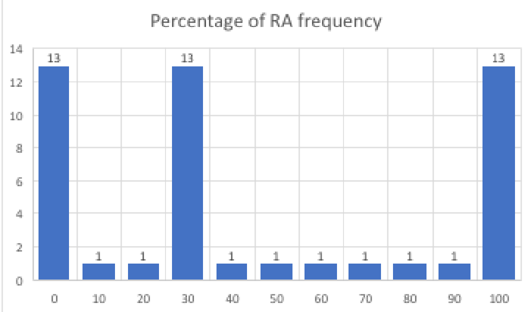

Figure 5 – Percentage of RA frequency

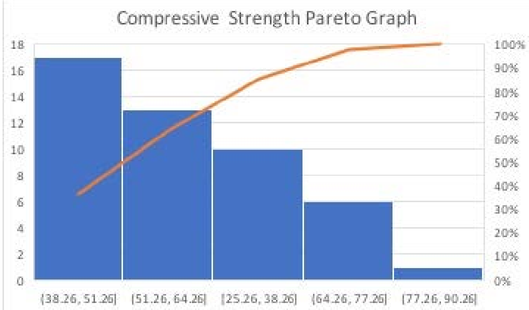

Figure 6 – Compressive Strength Pareto

Once ANNs learn from experience, ANN is expected to have the ability to model this problem, even with these input data characteristics, well representing the problem in low-frequency regions of data. This dataset was organized into a spreadsheet to serve as the ANN knowledge base to be trained and used to help the construction of a surrogate model.

In addition to the 47 records used in the construction of mathematical models (ANN, Regression Analysis) there is a set of 12 records that are not used in the modelling. This dataset will serve as verification data to analyse the performance of models when exposed to new information. This information is shown in table 1.

Table 1. RAC verification mix designs

Water to Cement ratio	Aggregate to Cement ratio	Cement (Kg)	Water (Kg)	RCA Replacement ratio	Compressive Strength (Mpa)
0.40	3.5	473.51	189.31	10	61.47
0.40	3.5	473.51	189.31	50	54.72
0.40	3.5	473.51	189.31	90	44.65
0.40	5.5	336.17	134.56	10	60.04
0.40	5.5	336.17	134.56	50	51.69
0.40	5.5	336.17	134.56	90	43.44
0.55	3.5	459.36	252.65	10	40.70
0.55	3.5	459.36	252.65	50	37.79
0.55	3.5	459.36	252.65	90	29.84
0.55	5.5	328.98	180.96	10	43.91
0.55	5.5	328.98	180.96	50	34.28
0.55	5.5	328.98	180.96	90	30.02

2.2. Artificial Neural Networks

The choice of the ANN approach comes from the good results that this technique has obtained in the most varied fields of knowledge to solve problems of classification, regression and time series prediction. This is because the technique copes well with non-linear and complex problems.
An ANN is a computational technique that constructs a mathematical model with learning capacity, generalization, association and abstraction based on information contained in data. The design of this technique was inspired by a simplified biological neural system where information is presented to the network that tries to learn its patterns in a repetitive process that must be stopped at an optimal time. During this iterative process of learning, ANN adapts its characteristics and connections between neurons in order to reduce its error in the construction of its model based on this data.
In order to facilitate the understanding, figure 7 presents one of the ANN architectures used. It is an MLP type network of simple architecture, it has a minimum of 3 layers: the input layer, the hidden layer, that can be more than one layers, and the output layer.

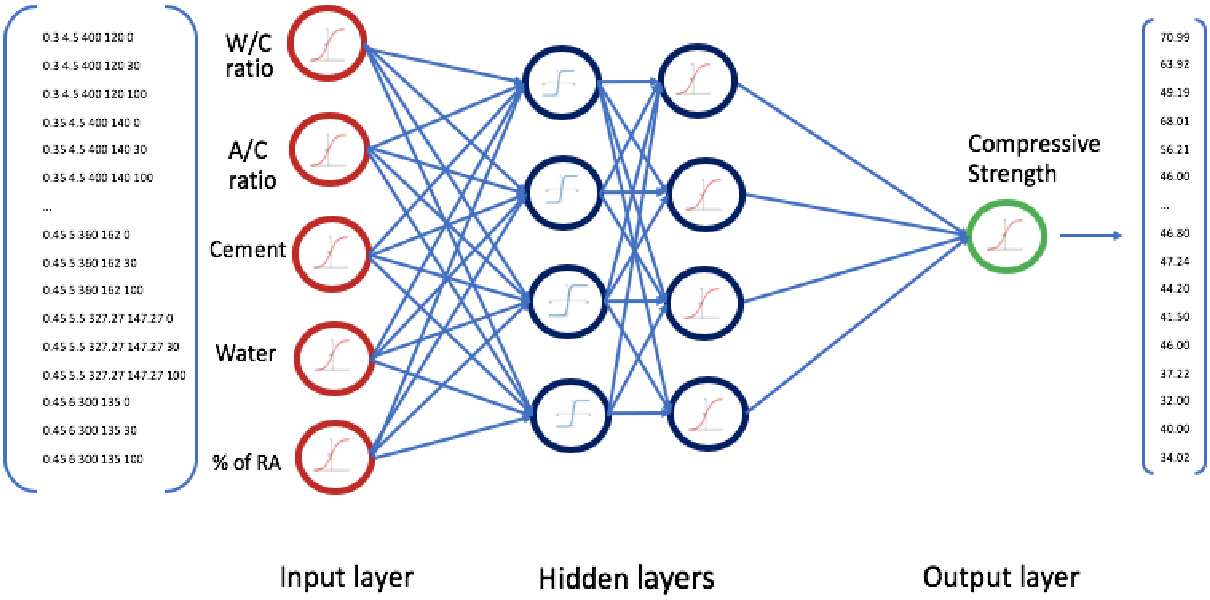

Figure 7 – Example of MLP neural network architecture used

After training, testing and evaluating the results of several ANNs, three ANNs with satisfactory modelling results were chosen: A Multilayer Perceptron neural network (MLP) with network-like architecture of figure 7, a Generalized Regression Neural Network (GRNN) and a network Group method of data handling (GMDH) which is also known as polynomial neural network.

After the ANN training process and the results of an initial test, the chosen models were exported as computer code in C. Each code will serve as a mathematical model to replace all new laboratory visits, saving material, time and effort, as we have a surrogate model to calculate the compressive strength of this family of recycled concrete. These three programs constructed using the ANNs as a core can calculate the compression strength of a RAC within the intervals trained as said before.

Additional information about ANNs, as well as other techniques can be found in references (Golub, G.H. and Loan, 1993; Haykin, 1999).

[redacted]RESULTS AND DISCUSSIONS

In order to evaluate the models results, were used some statistical measures: Mean Squared Error (MSE), Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE), Pearson Correlation, Coefficient of correlation (R), R-squared (R^2) compared do the experimental data. Table 2 shows these metrics comparing the ANNs and the RAs results.

Table 2. Statistics measures

	GRNN	MLP	GMDH	Equation 1	Equation 2	Equation 3
Mean Squared Error (MSE)	2.80	3.30	6.86	117.96	74.63	10.25
Root Mean Square Error (RMSE)	1.67	1.82	2.62	10.86	8.64	3.20
Mean Absolute Percentage Error (MAPE)	0.03	0.03	0.05	0.17	0.12	0.06
Pearson Correlation	0.86	0.95	0.95	0.79	0.80	0.96
Coefficient of correlation (R)	0.86	0.95	0.95	0.79	0.80	0.96
R-squared (R^2)	0.74	0.90	0.90	0.62	0.64	0.93

A different technique to evaluate the consistency of the models is through a graphical analysis. The graphs of figure 8 and 9 shows that the three neural network architectures have a better performance modelling the problem than the RA equations comparing to the experimental data.

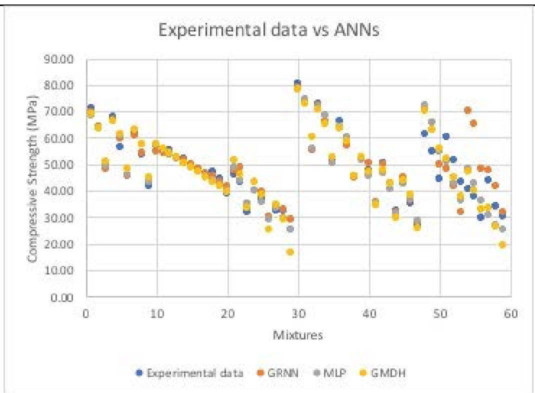

Figure 8 – Experimental data versus ANNs

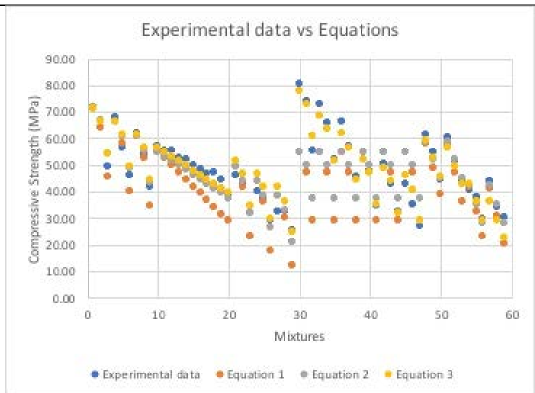

Figure 9 – Experimental data versus RAs

A useful visual method to analyse the model accuracy is using cross-plot graphs like the scatter plot confronting the results of each model in one axis against the experimental data results in the other axis of the plot. Thereby, for each point plotted it is possible to compare the value of the reference versus the value that was obtained by the ANN or RA model. So, the closer these values are, the more the points present the configuration of a 45-degree line and consequently, the greater the accuracy of the model. In this study, these graphs presented at figures 10 to 15, confirm the reliability of ANN techniques as an important tool to predict compressive strength of recycled concretes confirming the statistics measures of table 2.

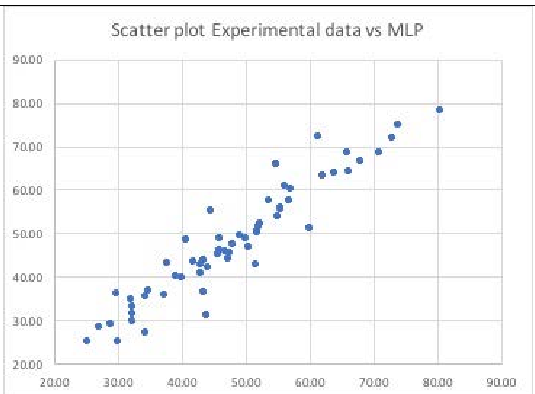

Figure 10 – Experimental data versus MLP Scatter Plot

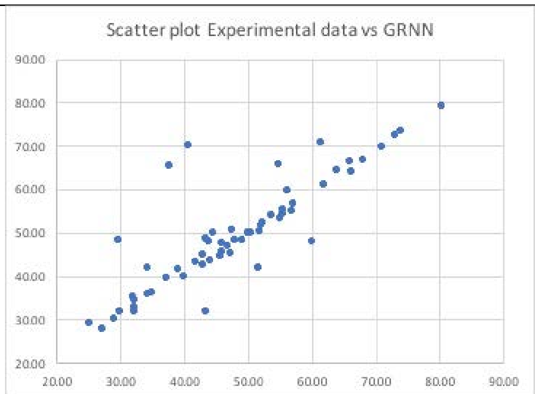

Figure 11 – Experimental data versus GRNN Scatter Plot

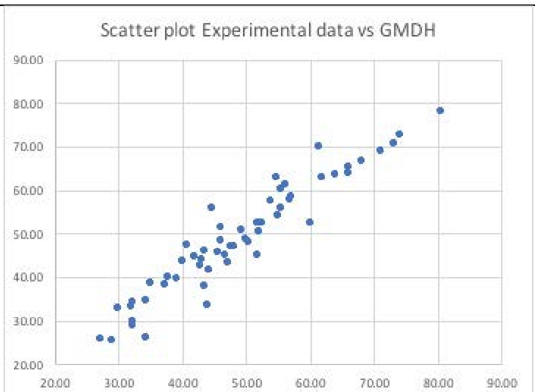

Figure 12 – Experimental data versus GMDH Scatter Plot

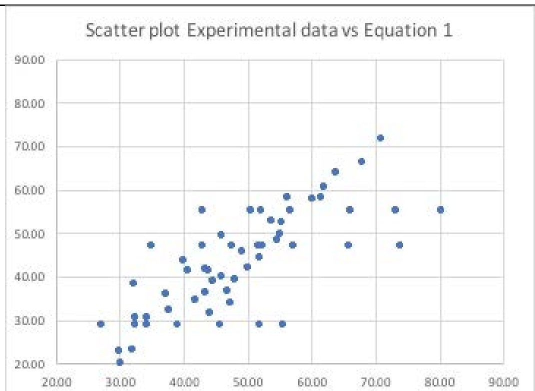

Figure 13 – Experimental data versus Equation 1 Scatter Plot

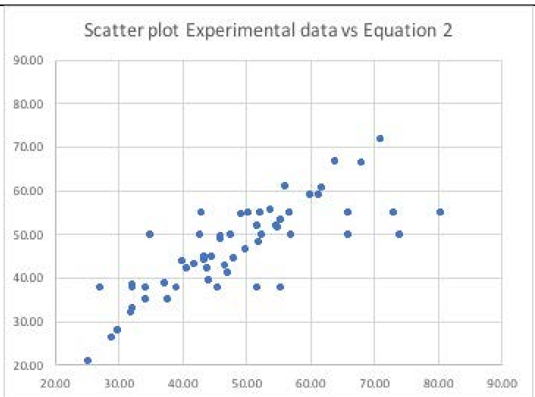

Figure 14 – Experimental data versus Equation 2 Scatter Plot

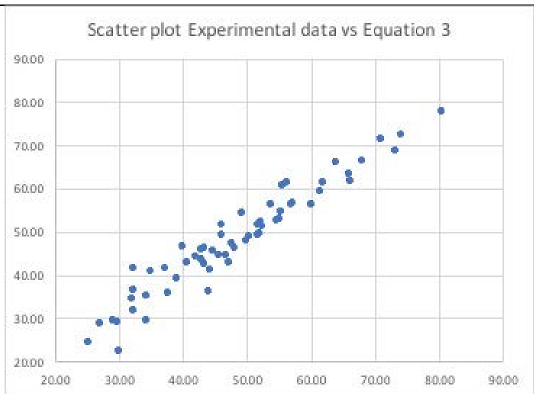

Figure 15 – Experimental data versus Equation 3 Scatter Plot

[redacted] CONCLUSION

This paper investigated the use of ANNs for modelling the RAC compressive strength for a particular data set: small and not very well representative for all the spectrum of the parameters. For this specific task, the three ANNs tested were a success, modelling the compressive strength with low errors (MSE, RMSE and MAPE) and a R2 close to 1 observing the statistic measures, better than the RAs models.

Another aim of this paper was the construction of software based on the ANNs. Three software were developed to be used as a surrogate model to calculate the compressive strength for new values of inputs. Each program uses one of the ANN algorithms to make the calculation (MLP, GRNN and GMDH). In this study, the results confirmed the reliability of ANN techniques as an important tool to predict compressive strength of recycled concretes. It is important to highlight the viability of machine learning techniques as an important and reliable tool that can be used by the construction industry. In this work, a machine learning technique, in this case, ANN was used to model a problem of materials engineering. The three ANNs architectures reached very close values for the problem in question, showing a small advantage for the MLP network, as can be seen at the following statistics measures presented in table 2. Comparing the three equations obtained with the Regression Analysis, the Equation 3 was the more accurate.

The use of most innovative techniques of machine learning is expected in the future, aiming gains for the industry in relation to an increase of reliability of the model and in obtaining data, saving time and reducing costs.

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Evaluation of prefabrication market in Australia

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Abstract

Construction is an important industry for many countries economy as it contributes mostly to their Gross domestic product (GDP). Prefabricated construction has been heavily promoted internationally due to its potential to improve construction quality and productivity. In China, the government vigorously promote prefabricated buildings, reduce construction waste and dust pollution, encourage powerful construction companies to research and develop the prefabricated construction; support construction projects with prefabricated buildings, support in project and floor area ratio control. The prefabricated construction was first written into the government work report and issued by the State Council. China strived to use 10 years to make the proportion of prefabricated construction to 30% of new buildings. In Australia prefabrication is relatively small, 3% out of the total of construction industry, compared to others countries. For example, in Sweden prefab accounts for roughly 80 % of the market; in Japan, Germany, New Zealand and England, this figure is 20% to 25%, 20%, almost 20 % and around 10 %, respectively. This paper aims to compare the prefabrication industry in China and Australia and the results present the outcomes of demand, barriers and incentives in each country.

Keywords: prefabrication, construction, modular.

1. INTRODUCTION

Construction is an important industry for many countries economy as it contributes mostly to their GDP. In Australia, waste generated from construction sites is one of the main components of landfills. Also, Construction and Demolition waste loads, which are often taken directly to landfill, around 7 Mt. In 2014-15, about 17.2 Mt, or 726 kg per capita, of waste masonry (concrete, bricks and rubble) materials was generated, 70% of which was recycled (Energy, 2016). In this scenario, prefabricated construction can be an important solution for improving productivity and reduce the environmental impacts. According to J. Hong et al. (2016) the life-cycle energy use of prefabricated components ranged from 7.33 GJ/m3 for precast staircase to 13.34 GJ/m3 for precast form. Also, the recycling process could achieve 16%e24% energy reduction.

Prefabrication is an ‘umbrella’ term and it covers a range of different systems and processes. These will include structural, architectural and services elements. It was also mentioned to as offsite construction or modular construction where building components are manufactured and assembled in a plant instead of the construction site before the final building. prefab can be categorized into components, panels (2D), modules (3D), hybrids, and unitized whole buildings (Boafo et al., 2016) . It is recognized by both design and construction professionals as one of most common methods where the benefits include its facilitation towards achieving high quality construction, reducing health and safety risks, improving in the planning, control and innovation environments, as well as, facilitating organizations to be more successful preventing injuries particularly related to hazards of sustainable elements such as “construction at height, overhead, with energized electrical systems, and in confined spaces” (Jiang et al., 2016; Zuo and Zhao, 2014).

Australia's prefab industry is relatively small. In Sweden prefab accounts for roughly 80 per cent of the market. In Japan, Germany, New Zealand and England, he says this figure is 20 to 25 per cent, 20 per cent, almost 20 per cent and around 10 per cent respectively Industry body prefabAUS estimates that prefabrication accounts for only three per cent of houses and apartments being constructed in Australia (Heaton, 2017). Prefabricated construction is environmentally positive because there is minimum wastage of materials and the quality of each module and the final building are easily controlled. According to Quezada et al (2016) ‘The prefabricated manufacturing part of the construction industry is expected to grow at 5 per cent per annum out to 2023, compared to a growth rate of 2.3 per cent for the industry as a whole. The current prefabricated building market in Australia is still comparatively small, with only A$4.5 billion of the total A$150 billion construction industry, it is expected to contribute to more affordable housing stock and to take a much greater share of creating multi-storey buildings’ (the urban developer 2017).

2. WHAT IS PREFABRICATION?

PreafAus is an important organization leading the transformation of built environment in Australia and define prefabrication as any part of the construction or a structure manufactured at any other place than its final location. However, it is also known as offsite construction or offsite manufacture. The main object is to promote a reduction at the construction time and the quantity of waste produced. I addition to that, it is possible to enhance quality, productivity and affordability. Prefabrication includes three categories of construction: prefab panelised system or 2D prefab; modular buildings or 3D prefab and hybrid system it is a combination of more than one system and most normally a combination of panelised and volumetric systems (Boafo et al., 2016).

Table 1 presents the contextual factors of prefabrication of the residential sector in three countries: China, Australia and United States. In terms of annual production, China manufactured 1.450,000m2 (2014), nearly the double of the USA production.

Table 1 - Contextual factors of the prefabricated house

Factors	China	Australia	United States
Prefabrication use	In 2016, the total area of Prefab construction in China was 114 million square meters, which was an increase of 11.4% year-on-year, accounting for 4.9% of the newly constructed buildings in urban areas.[C2]	Estimated that 3% of the current new housing market uses significant prefabrication [A2]	3–4% of new single-family, non-mobile houses are not “site-built”, including modular and panellized/precut 7% of all new dwellings are manufactured or mobile housing [US2]
Annual production	2014: 1.450,000m^2 2009: 1.,200,000m^2 2007: 600.000 m^2 [C2]	2014: 173.842 m^2 2004: 164.210 m^2 1994: 173.384 m^2 1984: 145.840 m^2 [A3]	2014: 884.000 m^2 2004:1.842,000 m^2 1994: 1.347,000 m^2 [US3]
New housing vs. renovations	none	5% of the value of residential building work accounted for by “alterations, additions or conversions” [A4]	33% of the value of new residential construction is spent again on additions, renovations and repairs (or for comparison, 25% of total residential construction value) [US4]
New housing funding models	none	2% of all newly completed dwellings not accounted for by the private sector [A4]	Public housing was <2% of all housing stock in 1994 (1.4 M dwellings), and has decreased to 2012 (1.16 M dwellings) .61,000 new public housing dwellings constructed between 2000 and 2012, or 0.4% of all new houses [US5]
Development	1. Originated in the 1950s 2. Developed from 1960s till 1980s; 3. Stagnated from 1990s; 4. 2016 is known as the “first year of policy” for the development of prefabricated buildings. “Standard for assessment of industrialized building”(2016)[C2]	1. Fast forward to the post war era in 1940s; 2. Prevalent in the 1960s 3. A largely utilitarian, industrial scaled mass-production of prefabricated buildings in 1990s.[A1]	1.Originated in the 1930s； 2.Prevalent in the 1970s； 3.In 1976, the U.S. Congress passed the National Manufactured Housing Construction and Safety Act. In the same year, it introduced a series of strict industry standards. [US1]

Components	By 2020, the proportion of prefabricated buildings in new buildings will be more than 20%, and the municipalities, cities with separate plans and provincial capitals will be more than 30%, and the proportion of affordable construction projects will be over 40%. [C3]	New residential builds (2015): 52% detached houses 35% multiresidential 13% semi-detached Recent shift away from detached, cf. 2006: 70% detached houses 16% multiresidential 14% semi-detached [A4]	New housing units 70% single-family 30% multi-family <1% town houses Shift away from single-family: 80–85% single family 2000–2004 [US6]
References	[C1] Chu, X. F. (2009). [C2] Arif, M., & Egbu, C. (2010) [C3] Standard for assessment of industrialized building (2016).	[A1] Australian Bureau of Statistics (ABS). (2012). 1268.0.55.001—Functional classification of buildings, 1999 (Revision 2011) (1268.0.55.001). Retrieved from Canberra. [A2] Australian Bureau of Statistics. (2015a). 8731.0 Building approvals, Australia (TABLE 20). Number of Dwelling Units Approved in New Residential Buildings, Original—Australia. Retrieved from Canberra. [A3] Australian Bureau of Statistics. (2015b). 8752.0 Building activity, Australia (TABLE 21). Value of Residential Building Work Done by Sector, Australia. Retrieved from Canberra. [A4] Australian Bureau of Statistics. (2015c). 8752.0 Building Activity, Australia	[US1] U.S. Census Bureau. (2015a). Characteristics of new housing – Completed. Retrieved from http://www.census.gov/construction/chars/completed.html. [US2] U.S. Census Bureau. (2015b). Characteristics of new housing—Historical data. Retrieved from http://www.census.gov/construction/chars/historical data/. [US3] U.S. Census Bureau. (2015c). U.S. and World population clock. Retrieved from http://www.census.gov/popclock/. [US4] U.S. Census Bureau. (2015d). Manufactured homes survey. Total Homes: U.S. Total—Not Seasonally Adjusted Total Placements. [US5] U.S. Census Bureau. (2009). Survey of construction. Retrieved from http://www.census.gov/econ/overview/co0400.html. [US6] US Department of Housing and Urban Development. (2013). HUD-manufactured housing and standards. Retrieved from http://portal.hud.gov/ hudportal/HUD?src=/program offices/housing/ramh/mhs/faq.

3. CASE STUDIES - SYDNEY

This study aiming to highlight the prefabrication yards located in Sydney. At this stage, this study provides insights across the manufacturing process of the prefabrication components in Sydney. Table 3 presents an actual picture of the important prefabrication companies in NSW.

Table 3 – Summary of Site Visit

Site Details	MBS	Hi Tech Homes	Built smart	Austruss
Sector	 (Source: www.mbs.com.au) Commercial, Prison Cells, Learning Spaces, Governments, Mining & resources, relocations & site services	 Caravan parks, Residential and Villages	 Commercial, Residential and Villages	Education, Age Care, Nursing homes Bath Pods / Trussers / Frames
Category	3D	2 D/ 3D	3D	2D / 3D
Recycling wastes	Yes, materials re-use	93% of the materials are recyclable	Modular factories can achieve 50% to 75% less waste than equivalent site built homes through precision cutting and factory processes	Steel - bluescope / TRUECORE® steel
Production rate	-10 projects at anytime -90-95% of the building to be finished in the factory. The remaining 5-10% work will be carried out onsite	Building life cycle is 1 month	Building life cycle is 21 days in the factory + 7 days in site	- 24 hours/day and ability to scale up or down quickly -45 staff / site
Quality Control/ Certification	Certified ISO Accreditation for Quality, Environmental and WH&S – AS/NZS4801 / ISO9001 / ISO14001/OHSAS18001	All service, such as electrical, plumbing etc are performed according to the Australian building codes.	GreenSmart Professional HIA member Master Builders Association member	AS – Fire / Structure "Fully compliant with the BCA and all Australian standards".
Building Materials	Steel / concrete	Steel / Timber / Colorbond / Vinyl cladding / Aluminium Plasterboard	Steel frames (floor), timber frame for walls, double glazing windows, weatherboard	Steel frames Concrete Gyprock
Limitations		Two-story homes Transport: up to 100 km from Bringely NSW		Skilled labors shortage

4. CONCLUSION

There are signs for the growth of prefabrication in Australia, mainly in Victoria, but it is still small compared to others countries. The awareness in the public is increasing through some advertisements and also through some conferences. Prefabrication construction has many advantages when compared with the onsite construction regarding the controlled construction environment. At this stage it is possible to say that is increasing the viability of traditional construction be gradually replaced by prefab. Mainly, with the respect of new technologies, such as green components and BIM software, enhancing innovations in terms of sustainability and automation. The limitations and barriers are related to projects customization and because of the fear to change and the shortage of skilled labors.

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Review of BIM study in infrastructure constructability

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The construction industry is rapidly evolving and it continues to evolve. The way we utilize technology and the way that this is affecting our industry will have large impact on the way its design. Building information modelling (BIM) has become a major player in AEC (architecture, Engineering and construction) everywhere. This study aims to review the relevant literature in BIM work done on infrastructure. From this review relevant gap in the infrastructure work is identified. Future work of integrating BIM in infrastructure development is outline in this study.

Key Word: BIM, Infrastructure, Construction

1. INTRODUCTION:

Building information modelling (BIM) is a process built on reliable information of a project from initial design to construction and operations. Fundamental of BIM is applicable in all construction such as building and infrastructure (Costin et al., 2018). BIM can be equally important to both architect and civil engineer. BIM gives good understanding of project before they are built. Response to any changes is design is faster and it delivers high quality documents for construction process. Building Information is transforming the way of designing, constructing and managing our assets. It's happening now due to its massive adoption around the globe. It is one of the emerging technique in construction industry. It is not only sharing information but sharing information form a common platform. There has been misconception about BIM relating it too only CAD. It has linkage with CAD as a tool but BIM is a process. BIM has helped in reducing productivity issues due to poor management of project information (Ashworth, 2012). Sufficient research has not been done in adapting BIM in large scale projects (Succar and Kassem, 2015). In any complex project in construction industry it requires a multidisciplinary collaboration and exchange of various data set. Traditionally most of the collaboration were based on 2D drawings another documents. Recently this has been replaced by object – oriented computer aided design (Singh et al., 2011).

BIM is now widely used in design and engineering process for integrated design. Constructability is a process in which different process are balanced to achieve the maximum project goals and performance of project (McGeorge, 2002) Coordination between different groups is used for construction documentation process and afterwards used during the execution phase of project. Different group such as structure. MEP, architecture, utilities, road construction and sustainability are implementing BIM for smart execution of projects. Different industry groups have been engaged in creating one standard model to integrate all data into one. BIM process has assist in setting up a base model which has helped in making decisions using one standard model. Traditional approach of data sharing and documentation for infrastructure and building project is now changed to more fast and reliable process. BIM process has helped in early determination of any design issues in projects due to several check and balance in early stage of projects. There are several Level of development (LOD) in project involving BIM design which can provide accurate information required Latiffi et al. (2015)

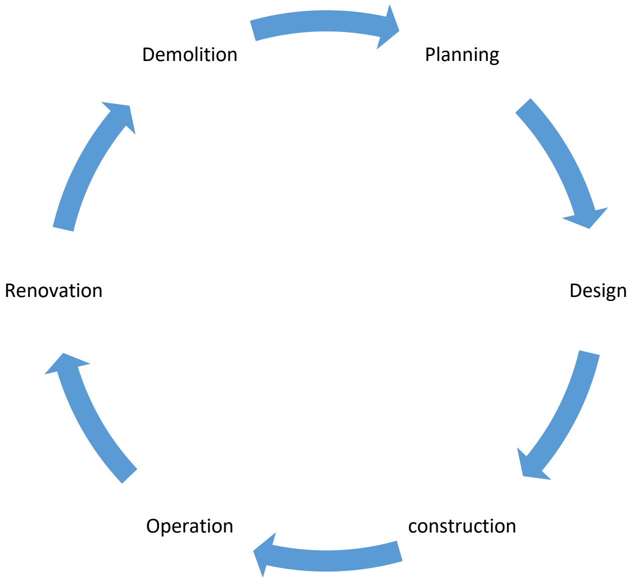

Figure 1(BIM cycle)

2. BACKGROUND:

2.1 INFRASTRUCTURE BIM MODEL:

There is a possibility of having civil engineering facility library through BIM technology and available software (Kim et al., 2015). Some of the key area of BIM in infrastructure were found implemented in bridge and development of road information model. Most of the model were found in 2D and 3D.
For managing road information model, focus was not only on 2D and 3D model but also on some conceptual design. South Korea has implemented BIM application guidelines for its facility construction project. Some of the area of BIM usage were in construction schedule, for clarity in process visualisation and construction analysis. Changes in design can be responded earlier in BIM based project which helps on early prediction of project performance (Engineer, 2014. January 29).
Infrastructure work can be benefited by BIM but this involves changes in current practice and a sustainable business model (Arayici and Aouad, 2011). IFC specification and BIM are geared towards establishing suitable ability in running whole construction project. Some of the IFC specification is not able to run in all project which makes difficulty to avoid loss of data across applications.
(Kumar et al., 2017) utilised BIM application on some key projects . Comparison was made on traditional AutoCAD method and BIM method in a small section of highway project. There was a significant save in time on the project using BIM methods.

2.2 IMPACT OF BIM:

(Ashworth, 2012) has provided precise use of BIM for construction project. BIM has been more developed in USA than any other nation. Most of the BIM system in other nation follows the template created in USA. BIM enabled projects reduces the construction and maintenance cost and results in better quality projects (Smith and Tardiff, 2009). Some of this findings needs to be examined in detail.
UK has created a milestone of BIM in the form of different levels which were identified from level 0 BIM to level 4D beam and further (Mahamadu et al., 2013). Level 0 BIM only involves 2D drawings

and is mainly for paper based information or electronic print. Level 1 BIM involves combination of 2D and 3D drafting. All CAD standards are managed as per British Standards (BS1192:2007). Data are shared from common data environment (CDE). In Level 2 BIM data and information are shared in collaboration between different parties. Level 2 BIM requires capable CAD software which can export format such as Cobie (Construction Operations Building Information Exchange) and IFC (Industry

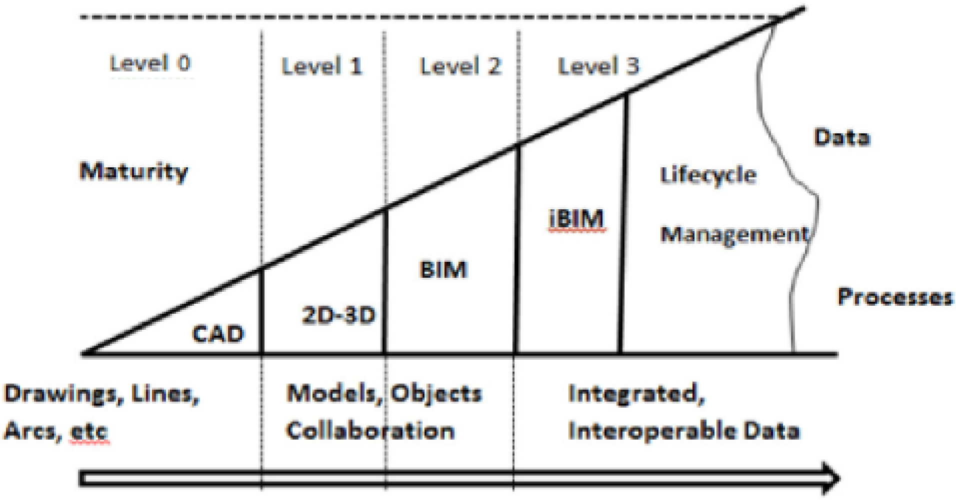

Figure 2, BIM Level (Mahamadu et al., 2013)

Foundation Class). UK government had set target of Level 2 BIM to be implemented by 2016 for all public sector work. Level 3 BIM has extensive collaboration between all groups which use single project model located in central database. All group can work on same model and modify it at any given time. 4D BIM and beyond includes data to analyse time. 5D is about cost estimate and 6D is about facilities management.

(Omoregie and Turnbull, 2016) did a qualitative research to understand traditional methods of design and BIM model. In some place traditional practice are not popular due to regulations in standardizing BIM in practice. Large amount of data is involved in BIM practice which is not easily handled in traditional method of design. There are still lack of understanding and lack participation in BIM. Recommendation was made to attract small scale participants and BIM framework to be made into conceptual understanding.

2.3 QUALITY MANAGEMENT BY BIM:

There has been significant growth of BIM in vertical construction which has increase its usage in infrastructure project (lee Namhun) . Gap in quality management of project can be overcome by BIM work. A quality management is the process of ensuring the end product meets the expectation of client. There are number of process in place for quality assurance and quality control. However, there is no perfect check and balance of accurate system to achieve this. BIM has proven helpful on this where all the information of QA & QC can be integrated in 3D model. Details of each component, materials and people responsible can be added when creating a BIM model. BIM potential of transforming the design and construction process is obvious and has been utilized widely. (lee Namhun) has worked on quality control and quality assurance aspects of infrastructure project using survey approach . A contribution factor on noncompliance on QA and QC on site were presented. Most of the response received were on model driven approach for quality control and quality assurance. This is where BIM would be more effective due its visual representation capability. provided precise use of BIM for construction project.

BIM has been more developed in USA than any other nation. Most of the BIM system in other nation follows the template.

Macleamy curve (JLArchitects, 2018) in figure 2 , explains the BIM advantage in overall process . Ability of cot and other functions gradually goes down along with time. Initial cost, effort in predesign and schematic design seems to be bit high. In the long run during the entire project cycle BIM adds more value in projects. Design changes and traditional approach can be costly and also take more effort of personal involve which will impact the project.

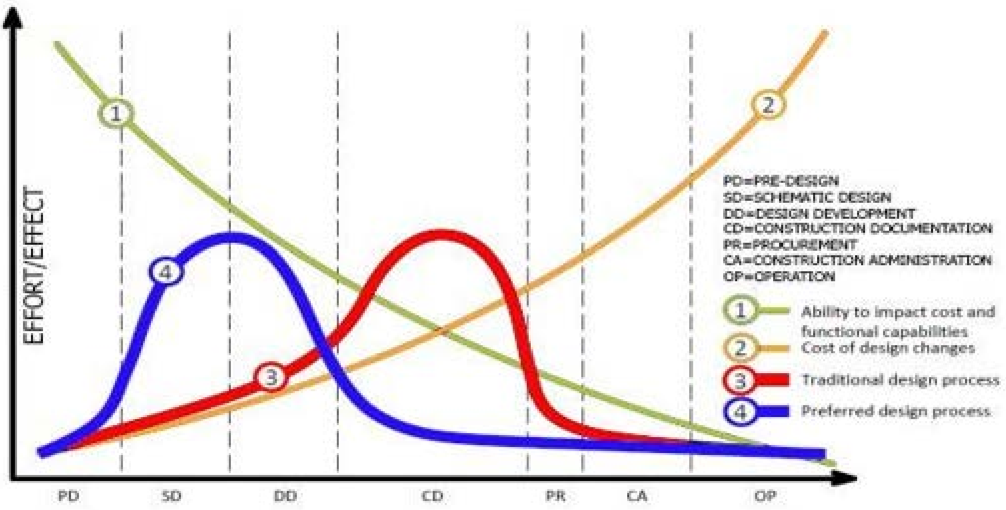

Figure 2, The Macleamy Curve (JLArchitects, 2018)

3. FINDINGS & DISCUSSION:

This research was based on review of different work done on BIM work that is related to infrastructure and construction adapting BIM process. Major work involves were (1) Identifying paper published in BIM for infrastructure work. (2) Finding different process used in designing infrastructure project. (3) Expansion of BIM in infrastructure (3) Identifying gaps and future development in infrastructure works. Significant development in BIM process is available where as in infrastructure BIM still requires more work.

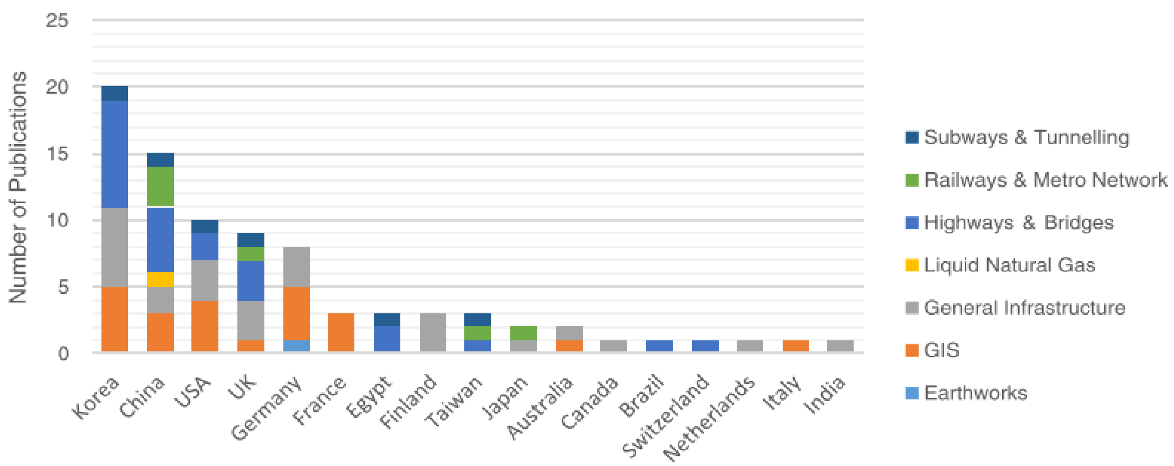

Figure3, Infrastructure publications (Bradley et al., 2016)

Infrastructure such as road, water supply system, tunnel, utilities are key to growth of economy for any nation. The work in this paper is based on BIM benefits in quality management, design and impact of BIM in infrastructure construction.

- BIM can be a good means of maintaining quality of project by a measurable mean.
- Impact of project in vertical construction has already been noticed. This can also be transferred to horizontal construction by different level of development (LOD) in BIM
- More model needs to build in BIM environment to quantify the benefits.

Infrastructure design work take nearly 7 to 10% of the total budget. This design is more code compliance than contractibility. Construction cost could be saved by another 10 to 15% when proper construability is implemented. BIM process on both design and construction can save about 15 to 17 percent of the entire cost of the project.

4. CONLCUSION:

This paper provided information on how BIM has been used in both horizontal and vertical construction. Significant work has been done in vertical construction. Benefits of BIM in quality control, cost saving and improvement in overall productivity in projects has been achieved. All research works are found to be more focused on BIM adoption and benefits. There are noticeable works in management side of BIM which presents comparison of BIM and non-BIM projects. However technical side of BIM in infrastructure is still seems to be lagging. There is still more work to be done in technical side of infrastructure projects to quantify advantage of BIM to traditional approach on projects.

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The Impact of National Subsidy Policy on the Economic Performance of Distributed Building Photovoltaic Systems across China

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Abstract

Distributed building PV systems are very promising renewable energy resources for urban areas. Chinese government puts great efforts into developing and deploying building PV systems including building-attached photovoltaic systems (BAPV) and building-integrated photovoltaic system (BIPV). The economic performance of distributed building PV systems in China closely ties to the energy policy especially the national feed-in tariff policy. At present, distributed building PV applications in China still benefit from the national subsidy, which is expected to be eliminated by 2020. Limited research has investigated the impact of national subsidy change on the economic performance of different building PV applications across China. Hence, this study aims to bridge the gap by conducting lifecycle cost-benefit analysis of various kinds of distributed building PV systems (both BAPV and BIPV) across China. Five building PV systems are selected from real-world projects covering most popular types of building PV systems in China. Twelve cities are chosen to represent the majority of urban areas in China with different solar energy intensity and local energy policy conditions. Net Present Value (NPV) per kW, Internal Rate of Return (IRR) and Payback year (PB) are utilized as economic indicators to interpret the economic performance from different perspectives. A sensitivity analysis through linear regression is carried out to investigate the relationship between the changes of the national subsidy and the economic performance of each case in all selected cities. The results present the impact of national subsidy change on the economic performance of different distributed building PV systems and in different geographic locations, which provide great insight for investors in terms of where and which kind of PV system worth investing when confronting the national subsidy change. Suggestions regarding incentive policies are also provided for policymakers.

Keywords: Building Attached Photovoltaics, Building Integrated Photovoltaics, Economic analysis, Feed-in tariff policy, Sensitivity analysis.

1. INTRODUCTION

The government supporting mechanisms are always crucial for the development and deployment of renewable energy like solar PV power. By 2010, over 85 countries have introduced specific policies for renewable energy (Jacobs and Sovacool, 2012). So far, there have been a variety of government incentive policies established to boost the promotion of solar PV generation globally. According to IEA (2008), government support mechanisms for renewable energy generation can be categorized into two groups, namely investment focused incentives (e.g. investment subsidies) and generation focused incentives (e.g. Feed-in tariff). China used to provide direct investment subsidies to encourage the uptake of distributed PV systems, like the Golden Sun projects (Zhang and He, 2013). However, the Golden Sun projects ended up with criticism such as serious subsidy fraud (Ceweeklycn, 2013). In 2013, the Feed-in tariff scheme was applied to encourage PV generation, especially for the distributed PV systems.

In the Chinese Feed-in tariff scheme, there are two kinds of benefit mode for distributed PV projects, namely "selling all to the grid" and "self-consumption". The "selling all to the grid" is to treat distributed PV systems as conventional PV plants. The Chinese government intends to improve the self-consumption of the generated power. Hence, for the "self-consumption" mode, there is a national subsidy for every kWh generated by the system. The national subsidy is considered one of the most significant policy-related factors that affect the financial feasibility of PV projects in China (Dong et al., 2017). Before 2018, the national subsidy for "self-consumption" mode was set to be RMB 0.42 per kWh, which was greatly attractive to investors. The purpose of the special subsidy for self-consumption mode is to encourage the distributed PV application and to improve the self-consumption ratio which can reduce grid instability. However, the financial incentives for renewable energy have become a significant burden on national finance, which is estimated to be RMB 120 billion in 2017 (China Energy News, 2018). Meanwhile, due to the cost reduction in PV products and the technical progress, PV technologies are becoming more and more competitive with tradition electricity generation methods. Thus, in order to promote the healthy growth of the PV market, the Chinese government decided to reduce the subsidy for PV technologies including distributed PV systems (National Development and Refrom Commission, 2018). At the beginning of 2018, the subsidy was reduced by RMB 0.05 per kWh. A second reduction happened on the 31st of May 2018, which decreased the subsidy from RMB 0.37 per kWh to RMB 0.32 per kWh. The short interval between two subsidy cuts shows the government determination to eliminate the subsidy, which is expected to be cancelled by 2020 (Lv et al., 2016).

Such a significant reduction in government incentives may lead to frustration in the energy market. For example, in Britain, after a 65% reduction in the feed-in tariff the installation capacity of small-scale systems plummeted by 74% compared with the previous year (Vaughan, 2016). Uncertainty in the financial feasibility results in the delay in the development of PV project investment (Bauner and Crago, 2015). Since the outlook of the national subsidy is less attractive, it is essential to understand under what circumstance the PV projects can still be considered as a feasible investment. For FIT research in China, many studies focus on the optimal setting of the Feed-in tariff which benefits the "selling all to the grid" mode. To the authors' knowledge, there is limited research conducting economic assessment regarding the change of the national subsidy for the "self-consumption" mode. Meanwhile, China is large in the territory with diverse energy policies. So far, there have been few economic studies covering different types of distributed PV systems and considering the differences in energy policy across China.

Hence, this study discusses the impacts of the change of national subsidy on the economic performance of different kinds of distributed building PV systems (both BAPV and BIPV) across China. There are five building PV systems from real-world projects covering most popular types of building PV systems in China. Twelve cities are selected to represent the majority of urban areas in China with different solar energy intensity and energy policy conditions. Net Present Value (NPV) per kW, Internal Rate of Return (IRR) and Payback year (PB) are utilized as economic indicators to interpret the economic performance from different perspectives. The sensitivity of the economic performance due to the national subsidy change is investigated through regression analysis. The results and discussion of this study can provide a comprehensive understanding of: (1) how the subsidy change affects the economic performance of all five PV systems; and (2) which city and system the subsidy reduction has the greatest/smallest impact on. The outcomes of the study can support the decision-making process of the subsidy policy for the policymakers. Meanwhile, investors can gain an insight into the economic performance under the circumstance of constantly decreasing subsidy. The structure of this paper is as follows: Section 2 explains the analysis process; Section 3 presents the results and discussion; Section 4 is the conclusion of the study.

2. RESEARCH PROCESS

The research process consists of: (1) the selection of representative cities and PV projects; (2) the economic analysis using different economic indicators and sensitivity analysis. A detailed explanation of each step is provided as follows.

2.1. City Selection and PV project Selection

Given China is a large country with various geographic conditions, twelve representative cities are chosen based both on the climatic condition and solar condition, which makes the study applicable to most urban areas in China. Then, a detailed policy analysis of these cities is conducted including their local price policies, retail electricity prices for commercial buildings and local subsidy policies as shown in Table 1. All the policy information is collected from government websites. The changing rate of local electricity prices is generated based on the study of Wang and Zhang (2016).

Table 1. Summary of city information

City	Local Electricity Policy	Local Electricity Price RMB /kWh	Local Electricity Price Growth Rate	Local Subsidy Policy	National Subsidy Policy
Urumqi	Fixed price	0.5850	0.59%		For self-consumed part 20-year subsidy: RMB 0.42/kWh (Before 2018)
Kunming	Fixed price	0.6550	2.08%		
Guiyang	Fixed price	0.7224	2.60%		
Hohhot	Fixed price	0.7440	-0.08%		
Chengdu	Fixed price	0.7799	-0.37%		
Chongqing	Fixed price	0.7925	0.07%		
Shenzhen	Fixed price	0.8616	2.04%		
Harbin	Fixed price	0.8665	1.12%		
Guangzhou	Fixed price	0.8983	2.04%	One-off subsidy: 0.2 RMB/w (max 2,000,000)	
Taiyuan	3-period price	0.6963 (11-18;7-8) 1.0076 (8-11;18-23) 0.4068 (23-7)	4.72%		
Tianjin	3-period price	0.8367 (7-8 11-18) 1.2035 (8-11;18-23) 0.5522(23-7)	3.17%		
Shanghai	2-season 2-period price	Summer (July, August, September) 1.095(6-22) 0.541(22-6) Other Seasons 1.060(6-22) 0.506(22-6)	7.51%	5-year subsidy: RMB 0.25/kWh	

All cases utilized in this study are real-world projects which can cover all popular building PV applications in China based on the study of Zhang et al. (2015). There are five different building PV scenarios developed from the cases as shown in Table 2. Scenario 1 in case a is a roof BAPV with large capacity. Scenario 2 and Scenario 3 are the same projects with different design assumptions. Scenario 2 assumes that the roof BIPV replaces the concrete roof while Scenario 3 assumes that the roof BIPV is substituted for a curtain wall roof. Hence, the construction costs with the BIPV offset of these two scenarios are different. Case 3 has two building PV systems, namely Scenario 4 – roof BAPV with small capacity and Scenario 5 – façade BIPV.

Table 2. Summary of the background of three projects

Case Building	**a**	**b**		**c**	
Scenario	1	2	3	4	5
Application	BAPV	BIPV	BIPV	BAPV	BIPV
PV Type	Roof	Roof	Roof	Roof	Façade (Window)
Cell type	Poly-Si	Quasi-mono-Si	Quasi-mono-Si	Mono-Si	Thin-film
Capacity (kW)	2,825.4	60	60	28.08	50.58
Solar cell Area (A) (m2)	18,025.83	914.76	914.76	183.84	865.48
Array Tile	Local latitude	0	0	Local latitude	90
Efficiency (r)	16%	17%	17%	18%	10%
Construction Cost (RMB)	20,605,098	2,157,000	2,157,000	315,628	769,107
Construction cost / kW (BIPV without offsets) (RMB/kW)	7,293	35,950	35,950	11,240	15,206
Construction cost / kW (BIPV with offsets) (RMB/kW)	7,293	29,812	17,352	11,240	7,506

2.2. Cost-benefit analysis and sensitivity analysis

A 25-year cost-benefit analysis is conducted to study the economic performance of all 5 PV scenarios in 12 cities. The cost consists of the initial construction cost with the offset of each system (see Table 2) and the maintenance cost during the 25 years. In terms of the benefit of the PV system, the first step is to calculate the energy generation of the PV system using the Equation 1.

$$\boldsymbol{E = A \times r \times H \times PR} \tag{1}$$

Where:
E is the energy output in kWh; A is the total solar cell area in m2; r is the PV product efficiency in percentage; H is the hourly solar radiation in kWh/m2; PR is the system performance ratio. The corresponding statistics of H used for each scenario in 12 cities were collected from a popular solar modelling tool – PVWatts (NREL, 2018). The PR in the study is assumed to be 86%, which is the default value set by PVWatts (NREL, 2018). A and r of each scenario are summarized in Table 2. The system attenuation rate is assumed to be 0.7% per year for all the cases and the lifespan of all scenarios is 25 years.

The second step is to determine the benefit of the system by comparing the energy out with the building energy consumption. The annual energy consumption of each case building was calculated based on the *Standard for Energy Consumption of Building* (GB/T 51161-2016) according to the climate zone. The result shows that the energy output of all five scenarios in 12 cities is higher than the energy consumption. Therefore, the study focuses on the analysis of 100% self-consumption PV projects. The benefit generated by the PV system is shown in Equation 2.

$$\mathbf{B(n)} = \textstyle\sum_{25} \boldsymbol{ep_h} \times (\mathbf{1} + \boldsymbol{\Delta ep})^{\boldsymbol{n}} \times \boldsymbol{E(h)} + \textstyle\sum_{20} \boldsymbol{Sb} \times \boldsymbol{E(h)} + \boldsymbol{sb_l} \tag{2}$$

Where:
n is the number of the year. ep_h is the electricity price of that hour; Δep is the compounded growth rate of the electricity price of the city; E(h) is the hourly energy generation using Equation 1. Sb is the unified national subsidy provided by the government lasting for 20 years. Sb_l is the additional subsidy provided by the local government. The information is summarized in Table 2.

For investors and policy-makers, different economic indicators may be favoured. In this study, the NPV per kW, IRR and PB are investigated. Equation 3 and Equation 4 present the calculation of the NPV and IRR in the study respectively. In order to standardize the comparison between each scenario with different PV capacities, the NPV per kW is adopted in the study. The PB is the number of the year when the NPV becomes positive.

$$\boldsymbol{NPV} = -\boldsymbol{C_0} + \sum_{n=1}^{N} \frac{\boldsymbol{B_n}}{(\mathbf{1}+\boldsymbol{r})^{\boldsymbol{n}}} - \sum_{n=1}^{N} \frac{\boldsymbol{M_n}}{(\mathbf{1}+\boldsymbol{r})^{\boldsymbol{n}}} \tag{3}$$

$$\mathbf{0} = -\boldsymbol{C_0} + \sum_{n=1}^{N} \frac{\boldsymbol{B_n}}{(\mathbf{1}+\boldsymbol{IRR})^{\boldsymbol{n}}} - \sum_{n=1}^{N} \frac{\boldsymbol{M_n}}{(\mathbf{1}+\boldsymbol{IRR})^{\boldsymbol{n}}} \tag{4}$$

Where:
C_0 is the net construction cost; B(n) is the benefit generated by the PV system; M_n is the maintenance cost, which is assumed to be the cost of changing the invertors every 10 years; r is the discount rate, which is set to be 5%.

Considering that two subsidy cuts in 2018 are both RMB 0.05 per kWh, the national subsidy (i.e. Sb in Equation 2) is reduced from RMB 0.42 per kWh to zero at intervals of RMB 0.05 per kWh. By changing the value of national subsidy while other variables remain the same, the results of the NPV per kW, PB and IRR of 5 scenarios in all 12 cities are generated by the equations above. The results provide the information of the corresponding value of the NPV per kW, PB and IRR in each city when the subsidy is set to a certain price.

In order to understand the impact of the subsidy on the PVs' economic performance, linear regression analysis is conducted to measure the sensibility of the subsidy to each scenario as well as each city. A simple linear regression aims to model the relationship between two variables through establishing a linear equation that can best fit in all acquired data (Lane, 2013). The slope of the linear equation can indicate the sensitivity. The bigger the slope is, the more the economic performance is affected by the variable.

3. RESULTS AND DISCUSSION

Based on the analysis of economic performance and sensitivity, a matrix is developed to indicate the results. The horizontal axis represents the economic performance while the vertical axis stands for the sensitivity when confronting the national subsidy change. The results are presented in two ways: (1) according to the PV application types, namely BAPV and BIPV (see Figure 1); (2) based on the geographic location, namely the city (see Figure 2). The matrixes can be divided into four areas as shown in both Figure 1 and Figure 2. Different implications for investors and policymakers are provided based on the division as shown in Table 3.

Generally speaking, scenarios and cities lie in Area 1 and Area 2 are suitable for investment due to the good economic performance when confronting the subsidy cut. Meanwhile, the results suggest that policymakers can reduce the subsidy in these two areas for the economic performance of the building PV application is still acceptable. For example, Scenario 1 – roof BAPV with large capacity and Scenario 3 – roof BIPV replacing glazing have the good performance in terms of all three economic indicators while Scenario 2 – roof BIPV replacing concrete roof is the opposite. Shanghai, Tianjin, Harbin, Taiyuan and Shenzhen are the cities recommended for investment or subsidy reduction. However, due to the high vulnerability to the subsidy reduction in Area 2, it is suggested that investor should take quick action when the subsidy is still advantageous. By contrast, scenarios and cities in Area 3 and Area 4 are not recommended for the investors because of low economic performance. For policymakers, Area 3 indicates that subsidy plays an effective role in improving the bad economic performance while Area 4 implies that the government should seek for other incentives to improve the economic performance regarding the type of PV application or the location of the PV applications.

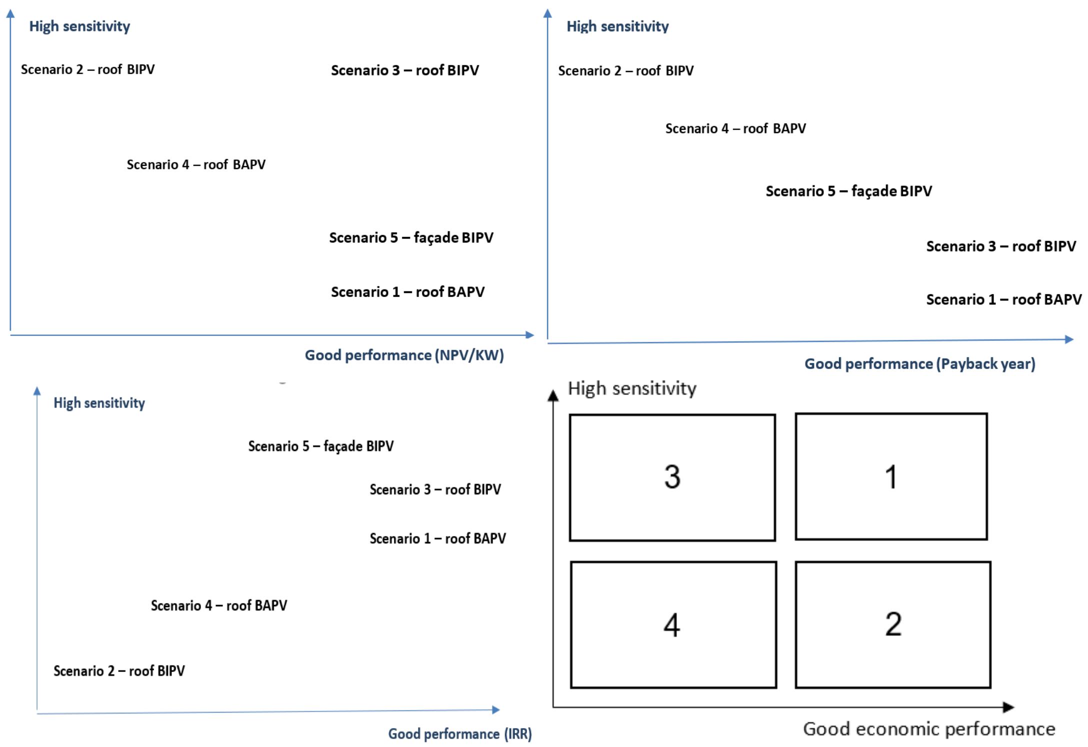

Figure 1. Combination analysis of economic performance and sensitivity across five scenarios

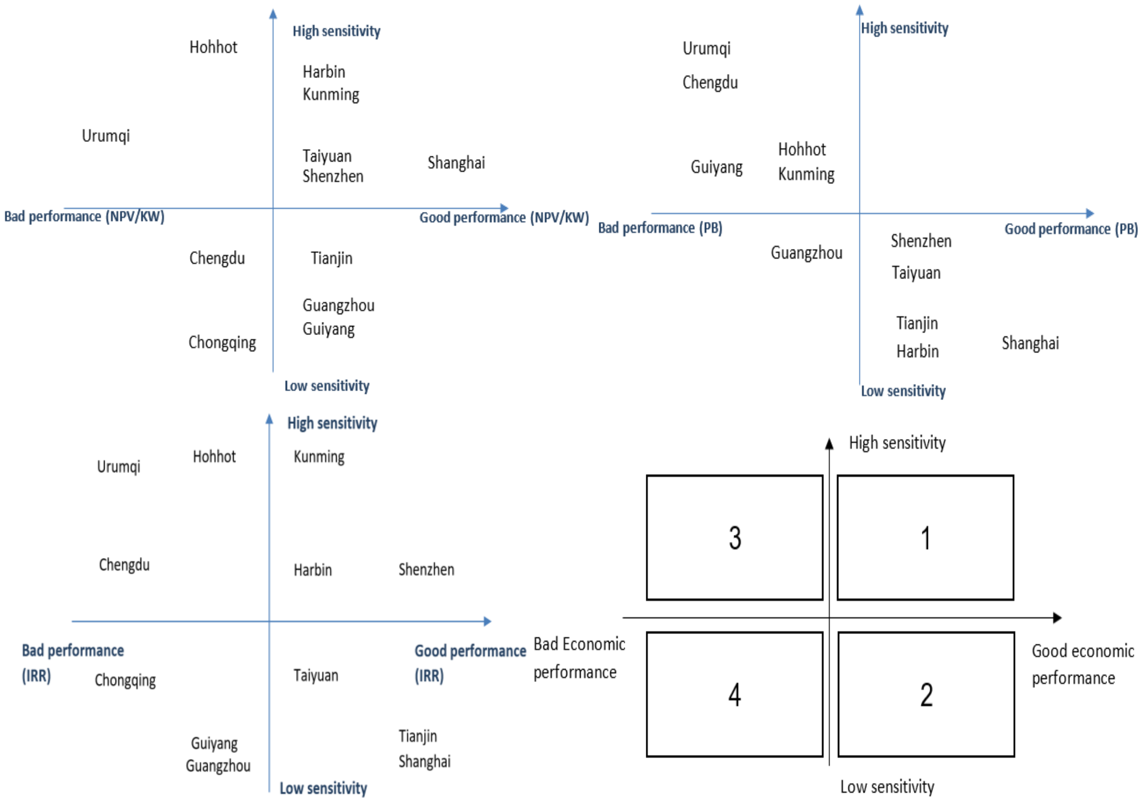

Figure 2. Combination analysis of economic performance and sensitivity across 12 cities

Table 3. Implications for investors and policymakers

Division	**Implications**	
	For investors	For policymakers
Area 1	Worth to investing; Don't delay when the subsidy is favourable.	Okay to reduce the subsidy
Area 2	Best application/place for PV projects	Okay to reduce the subsidy
Area 3	Not suitable for PV investment	Increasing subsidy can effectively improve the economic performance
Area 4	Not suitable for PV investment	Seeking for other incentives

4. CONCLUSION

At present, building PV applications in China still benefit from the national subsidy. The national subsidy was RMB 0.42 /kWh from 2013 to 2017. However, there have been two subsidy cuts since the beginning of 2018. It is anticipated that the subsidy will be eliminated by 2020. However, limited research has analyzed the impact of the subsidy on the financial feasibility of building PV systems in China. Meanwhile, China is large in territory with diverse geographic conditions and policy conditions. Considering the current research gap in this area, this study aims to investigate the impact of national subsidy change on the economic performance of different building PV applications across China. Five PV scenarios and 12 case cities are selected for the study. Net Present Value (NPV) per kW, Internal Rate of Return (IRR) and Payback year (PB) are analyzed based on the local geographic and policy conditions. Sensitivity analysis through linear regression is also carried out to investigate the relationship between the changes of the national subsidy and the economic performance of each case in all selected cities. Taking both economic performance and sensitivity into consideration, different building PV types and geographic locations can be divided into four groups. The results provide investors with a comprehensive understanding regarding where and which kind of PV systems worth investing when confronting the national subsidy change. Also, the outcomes can support the decision-making process of the subsidy policy for the policymakers. For example, PV applications such as Scenario 1 – roof BAPV with large capacity and Scenario 3 – roof BIPV replacing glazing have the good performance in terms of all three economic indicators, which indicates that the building PV applications are suitable for investing or subsidy reduction. However, the best application for PV investment is the application with low sensitivity, which means that future subsidy reduction has a relatively small impact on the economic performance of the building PV system. The application type and geographic location with bad economic performance and low sensitivity to the subsidy are also identified, which suggests that the government should consider other effective incentives to help improve the financial feasibility of the building PV and to further boost the uptake of building PV systems across China.

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The Effect of Carbon-Conditioning on Drying Shrinkage and Reversibility

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Abstract

The carbon-conditioning method delivers an accelerated injection of carbon dioxide (CO_2) into recycled aggregate. The pressurised CO_2 generates a chemical reaction that causes calcium hydroxide to be converted to calcium carbonate. Consequently, the smaller calcium carbonate crystal densifies aggregate, proving to create a concrete with an outstanding mechanical property. The densification of aggregate also lowers the water absorption of the recycled aggregate. The improved water absorption permits an improved dry shrinkage within recycled aggregate concrete. Plain, un-carbonated, recycled aggregate concretes experience a greater shrinkage than that of virgin aggregate concrete. However, carbon-conditioned recycled aggregate can attain a drying shrinkage that almost parallels that of virgin aggregate concrete.

Keywords: Carbon Conditioning, Recycled Aggregate, Recycled Aggregate Concrete, Recycled Concrete, Virgin Aggregate Concrete, Concrete Shrinkage, Reversibility

Introduction

Construction and demolition waste is attributed to a large quantity of landfill each and every year. This trend is harmful both environmentally as well as economically. In 2014-15 Australia produced 19.6 megatonnes of construction and demolition waste, 7.12 megatonnes going directly to landfills [1]. Construction and demolition waste, made of bricks crushed concrete, tile and the like should be recycled as it amounts to a large total of disposal into landfill.

Literature Review

A possible solution to this issue involves recycling construction and demolition waste into concrete, taking the place of virgin aggregate. Conversely, many researchers have found that recycled aggregate concrete has an inferior performance to that of virgin aggregate concrete [2, 3]. The compressive strength of 100% recycled aggregate concrete is generally 30% less than that of virgin concrete. Furthermore, drying shrinkage can be up to 100% greater than that of virgin aggregate concrete [4]. As recycled aggregate concrete is characterised by poor quality, supplementary measure must be put into place to help bridge the gaps between recycled and virgin aggregate concrete.

Carbon-conditioning is a process which injects CO_2 into recycled aggregate to make the aggregate denser and of higher quality. The principal objective of carbon-conditioning is to form calcium carbonates by chemical reaction. Calcium carbonates are converted from calcium hydroxides during the carbon-conditioning process which assists in the strengthening of both recycled aggregate and recycled concrete. Additional calcium carbonates generates an enhanced structural matrix filling small gaps within cement whilst densifying, lowering porosity and reducing the water absorption of the aggregate [5].

Strength increases formed from supplementary calcium carbonates can permit recycled aggregate and recycled concrete to rival virgin aggregate and virgin concrete in terms of physical and mechanical properties [6]. Whilst some investigations have found improvements in the compressive strength of concrete, concrete shrinkage should be investigated to a greater extent.

Aim

This paper aims to discover the difference in concrete shrinkage between virgin aggregate, recycled aggregate and carbon-conditioned recycled aggregate concrete. It is recognized that carbon-conditioning assists in the mechanical strengthening of recycled aggregates and concrete, however, research is required in order to attain a greater understanding of the concretes shrinkage.

Research Methodologies

Materials

Virgin aggregate used in this paper is basalt whilst the recycled aggregate used is a mixture of various constructions and demolition waste, obtained from a south-eastern Australia centralised recycling plant. Typical concrete mixing sand as well as ordinary cement, designated Type GB (General Blend) are used for the concrete production. The type GB cement contains a mixture of flyash and general Portland cement, amounting to 20% and 80% respectively.

The particle size distribution complies with Australian standards [7]. The particle size distribution for recycled aggregate can be observed in Figure 1 whilst virgin aggregate can be viewed in Figure 2.

<Figure 1>

<Figure 2>

A recycled aggregate classification breakdown can is illustrated in Figure 3. The pie chart indicates the various amounts of construction and demolition waste found within the aggregate designated as a percentage.

<Figure 3>

The CO_2 utilised in experimentation is 99.9% pure.

Carbon-conditioning chamber

The carbon-conditioning chamber utilised in the process of injecting CO_2 into recycled aggregate can be observed in Figure 4. The chambers construction consists of sturdy steel welded together in the formation of a rectangular prism. A port hole style lid sits atop the structure allowing aggregate to be placed. Following the employment of recycled aggregate within the chamber the lid can be fastened down using the chambers eight bolts. The lid and chamber are separated by a gasket to ensure the CO_2 cannot escape the chamber. The carbonation chamber connects to a CO_2 cylinder boasting a regulator which is used to control CO_2 pressure. The aggregate placed in the chamber is of natural moisture content. Silica gel is also placed in the chamber so that any water produced in the reaction is nullified.

<Figure 4>

Experimental Design

In order to gain an impactful understanding of the effects of carbon-conditioning in relation to concrete shrinkage, encompassing as well as practical variables must be taken into account. The variance of 0% recycled aggregate and 100% recycled aggregate as well as 100% carbon-conditioned recycled aggregate concrete permits a valid experiment. The variables investigated in this paper can be observed in Table 1 and amount to three different concrete mixtures.

<Table 1>

The concrete mix design applied in the creation of shrinkage prisms diversify with the aforementioned variable of recycled aggregate replacement. The mix design permits an unbiased comparison between recycled aggregate and virgin aggregate achieving the same effective water to cement ratio whilst maintaining the same amounts of cement. Furthermore, chemical additives are absent from the mix design to promote a fair, like to like, comparison.

The concrete mixture production complies with the Australian standard for laboratory environment [8]. The concrete mixing process starts with approximately half of coarse aggregate being placed in the mixer, being either virgin aggregate, plain recycled aggregate carbon-conditioned recycled aggregate as subject to individual mix designs. Fine aggregate or sand is then added, followed by cement and the remainder of coarse aggregate. No additives are used during these experiments in order to achieve a uniform comparison focusing on carbon-conditioning process.

Demoulding of the concrete specimens occurs 24 hours after pouring. Upon which, it is placed in an enclosure and controlled environmental with a temperature of 23±2°C and relative humidity level of 50±2% before conducting tests [8].

Three 280mm-long and 75mm wide/deep shrinkage prisms are cast with stainless steel shrinkage pins either end. Three samples are cast in order to promote an average between samples enabling accurate results. Measurement of samples are taken periodically in accordance with appropriate Australian standards [9]. Upon the stabilisation of concrete size the samples are then placed within water to ascertain a reversibility percentage. The samples are continually measured in water till the size stabilises once again.

Results and Discussion

<u>Non-carbonated Concrete</u>

<u>Virgin Aggregate Concrete</u>

The virgin aggregate concrete exhibited a drying shrinkage of 0.152mm attaining a reduced shrinkage compared to both the plain recycled aggregate concrete (confirming other authors

[4]) and carbonated recycled aggregate concrete. The virgin aggregate concrete demonstrated reversibility of 45.48%. The virgin aggregate concrete was able to obtain a more desirable shrinkage as the aggregate itself has smaller pores and less water absorption. Concrete shrinkage is dependent on the loss of water; unfortunately, as recycled aggregate is of inferior quality it exhibits a larger shrinkage. Figure 5 illustrates the drying shrinkage and reversibility of the virgin aggregate concrete.

<Figure 5>

Recycled Aggregate Concrete

The recycled aggregate concrete was characterised by shrinkage of 0.247mm. The recycled aggregate concrete shrank 40% more than that of the virgin aggregate concrete. The recycled aggregate robbed the cement paste of water generating an additional avenue of water loss and an increased shrinkage. The recycled aggregate concrete experienced a shrinkage reversibility of 37.31%. Alike previous authors [4] uncovered, recycled aggregate concrete has an overall diminished performance when paralleled with virgin aggregate concrete. Figure 6 demonstrates the downward trend of recycled aggregate concrete in terms of shrinkage.

<Figure 6>

Carbon-Conditioned Recycled Aggregate Concrete

The carbon-conditioned recycled aggregate concrete experienced shrinkage of 0.167mm. The shrinkage of the carbonated recycled aggregate decreased shrinkage by 33% when rivalled against plain recycled aggregate concrete. The process of carbon-conditioning transforms calcium hydroxide into calcium carbonate. The smaller calcium carbonate particle reduces porosity and water absorption, allowing for a reduced concrete shrinkage. However, a 7% performance breach still splits the carbonated recycled aggregate concrete and the virgin aggregate concrete, the latter of which still achieving a superior shrinkage. The carbon-conditioning process also enhanced the reversibility of the conditioned concrete attaining a middling result of 41.04%, again splitting that of the plain recycled aggregate concrete and virgin aggregate concrete. Figure 7 exemplifies the improvements of carbon-conditioned recycled aggregate concrete.

<Figure 7>

Conclusion

The carbon-conditioning method is an effective means of improving the shrinkage of recycled aggregate concrete. The CO_2 gas creates calcium carbonates which improves the porosity and water absorption of the aggregate and therefore drastically reduces concrete shrinkage. Whilst the carbon-conditioning process improves the aggregate it does not enhance the aggregate to become greater than virgin aggregate. This paper finds:

- Plain recycled aggregate concrete shrinks 40% more than virgin aggregate.
- Carbon-conditioned recycled aggregate can reduce shrinkage by 33%.
- Carbon-conditioned recycled aggregate fails to achieve the same shrinkage as virgin aggregate concrete, shrinking 7% more.

The process of carbon-conditioning provides an outstanding potential in improving the shrinkage of recycled aggregate concrete.

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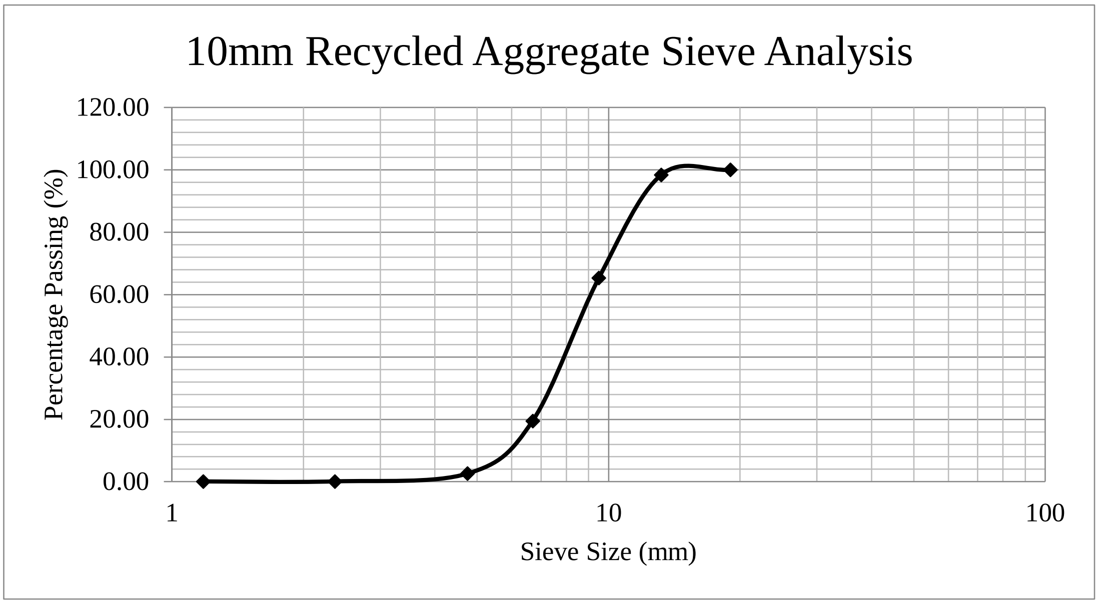


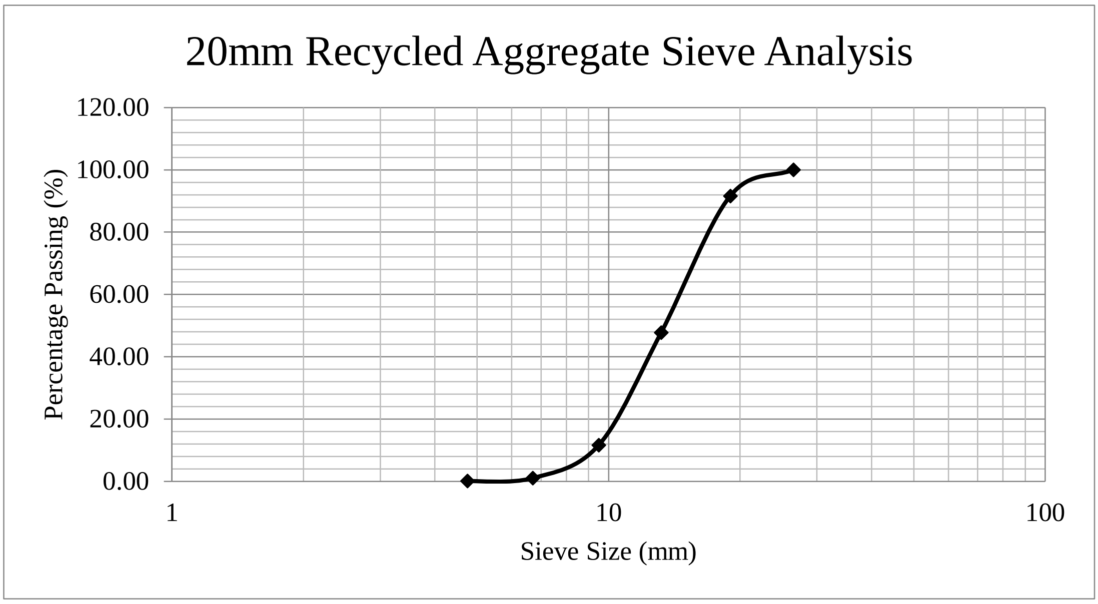
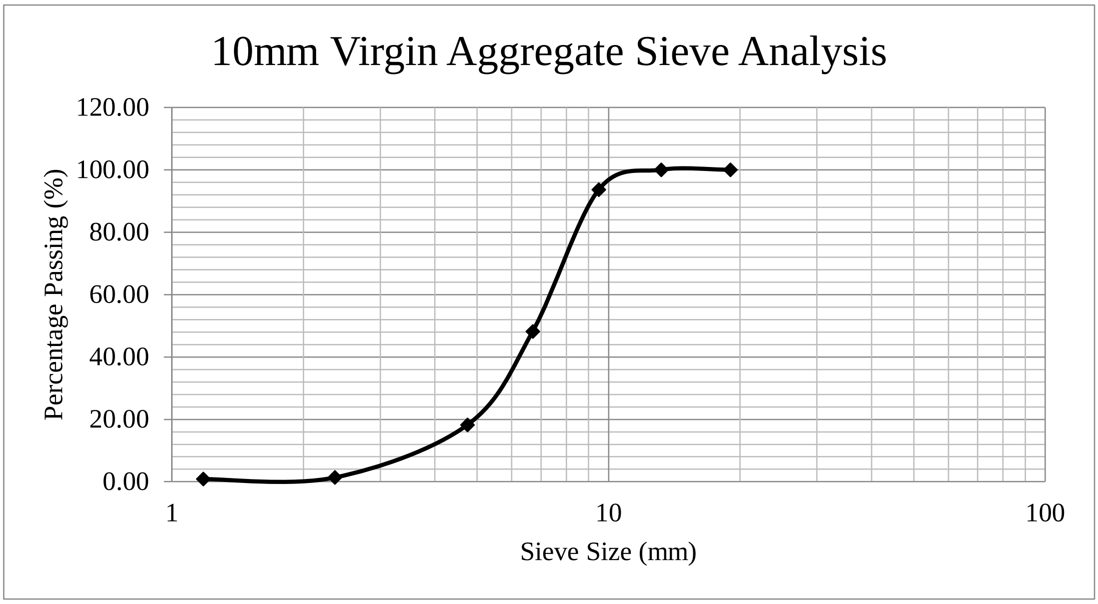


Figure 1: Recycled Aggregate Size Distribution



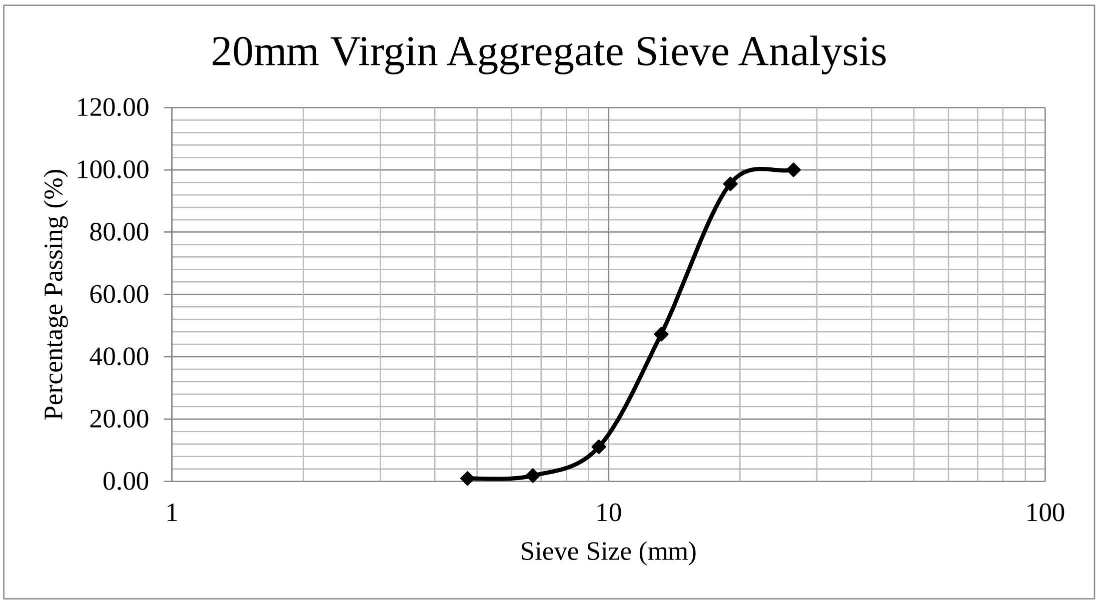


Figure 2: Virgin Aggregate Size Distribution

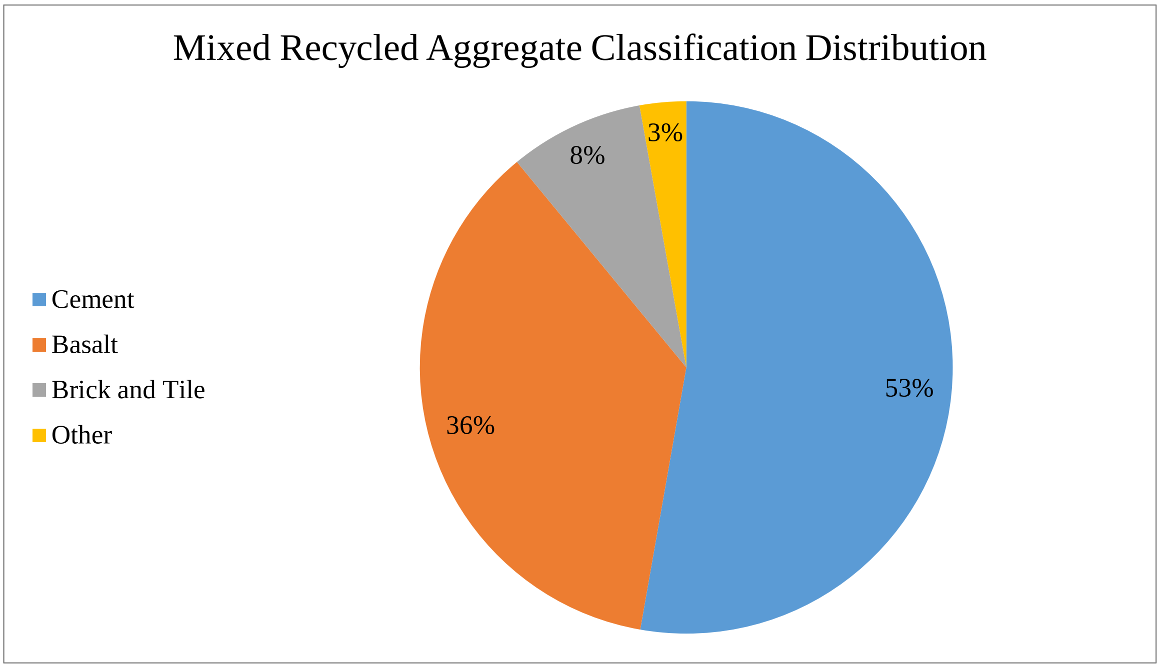


Figure 3: Mixed Recycled Aggregate Classification Pie Chart

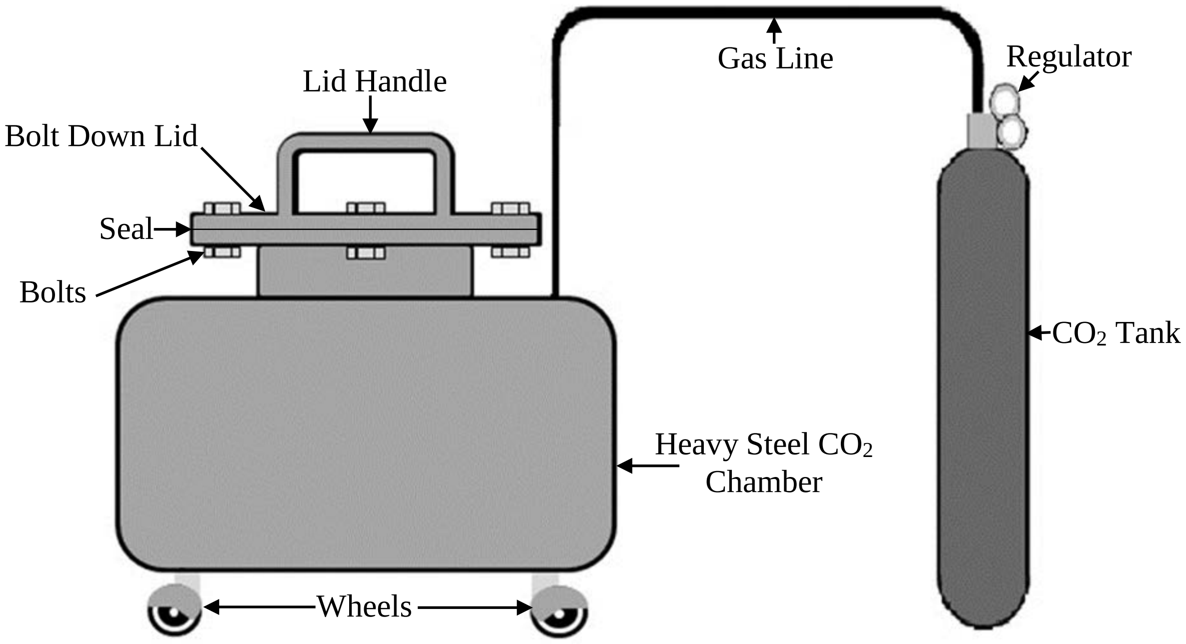


Figure 4: Carbonation Chamber

Table 1: Experimental Variables

Mix	Recycled Aggregate Replacement (%)
Virgin Aggregate Concrete	0
Recycled Aggregate Concrete	100
Carbon-conditioned Recycled Aggregate Concrete	100

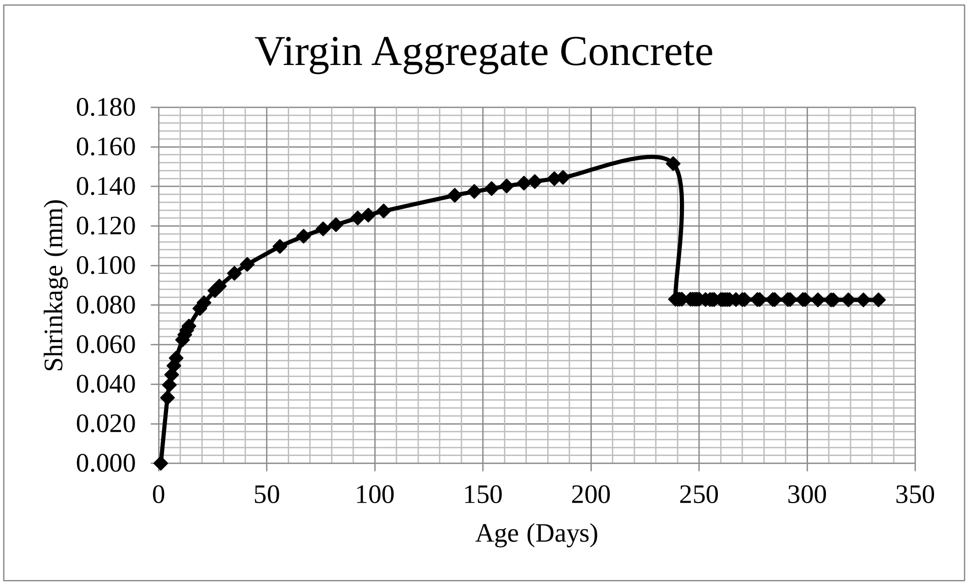


Figure 5: Virgin Aggregate Concrete Shrinkage

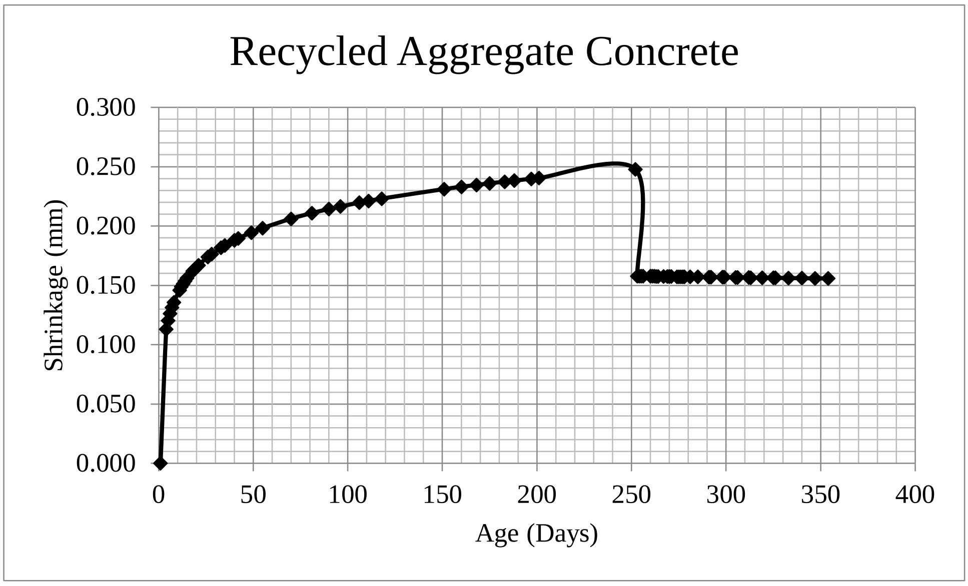


Figure 6: Recycled Aggregate Concrete Shrinkage

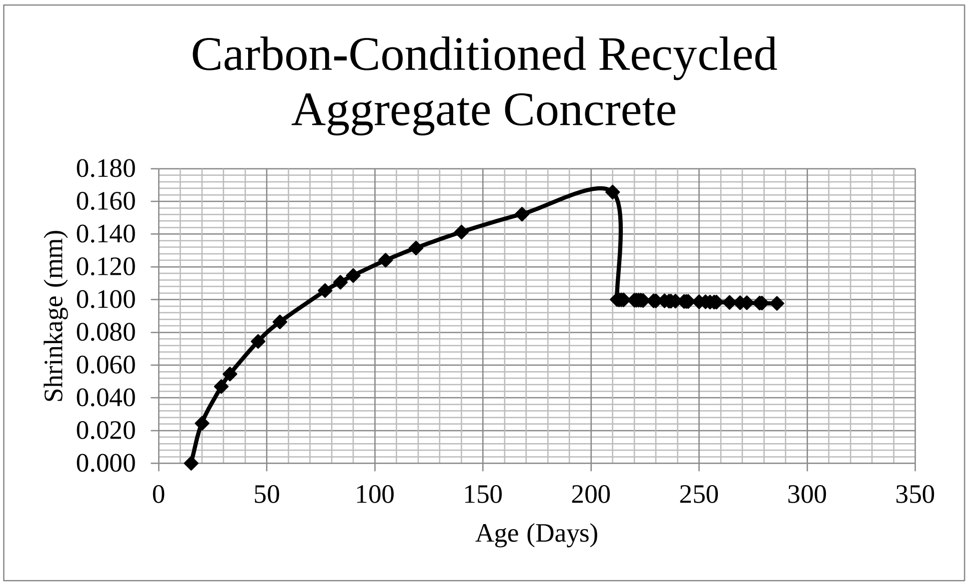


Figure 7: Carbon-Conditioned Recycled Aggregate Concrete Shrinkage

Occupant behaviour in green buildings – A case study

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Abstract

In a Green Building process, before the construction process occurs, design teams predict the overall energy expected to be used during the operational stage, using building energy dynamic simulation models. This will allow the prediction of sustainable solutions, to be implemented in order to minimize the use of energy and reduce the impacts the operation stage will have in the environment. As the operational stage is the most energy intensive stage during a green building life-cycle, it is imperative to predict the energy that will be used during this stage as accurately as possible. Therefore, past research literature identified significant differences between real energy performance results and predicted ones. These differences are related to inefficiencies, occupants and low maintenance. Furthermore, energy-related occupant behaviour is the most impacting factor to the performance of a building (Norford et al., 1994). Hence, this paper studies the overall performance of a green building, using real data and a dynamic simulation model, analysing the impact occupants have in the energy use of a green building by interacting with the building systems. The model has been developed using the simulation tools DesignBuilder and EnergyPlus in order to determine the annual energy performance of a green star building in Sydney and consequent GHG emissions, as well as to estimate the impact occupants will have in the energy use as a whole.

Keywords: *Energy use, building simulation, environment, green building, greenhouse-gas emissions, office building.*

1. INTRODUCTION

A Green Building (GB) process requires critical thinking and a life cycle approach. This includes several different stages that comprise the design, construction, operations and end of life of a building, aiming to create environmentally, socially and economically communities (USGBC, n.d.).

Overall, buildings represent 40% of the total primary energy use and 36% of the carbon emissions in a country. In Australia 58% of the final uses in electricity are related to the building sector (IEA, 2016). Therefore, buildings are relevant energy intensive users that need careful investigation throughout their whole life-cycle.

The way occupants behave in terms energy use is one of the main factors to increasing rates of energy intensity in buildings. Researchers, in the past, pinpointed the way occupants behave when using energy as the main cause to the gap between real energy and predicted energy use (Norford et al., 1994, Branco et al., 2004). Therefore, several parameters are directly and indirectly impacted by this behaviour which, according to the International Energy Agency (IEA), are identified as "driving forces", and have influence on the way occupants interact with buildings as well as with its control systems. These "driving forces" may be a consequence of the interaction occupants have with heating, cooling, lighting, ventilation (including window operation), domestic hot water (DHW), appliances and cooking (Polinder et al., 2013).

Occupants may be impacted internally through these driving forces in terms of social activities, their perception of comfort, and psychological and biological characteristics of the individuals (Al-Mumin et al., 2003, Steemers and Yun, 2009). Similarly, external factors may affect occupants behaviour, mainly when they interact with physical and environmental aspects, such as; the climate, buildings location and orientation, timeframe, etc (Mahdavi et al., 2008, Bluyssen et al., 1996, Polinder et al., 2013). Furthermore, these factors may also be impacted by external features such as politics, economics and culture.

Therefore, this study is focused on the operational stage of a Green Building and intends to simulate the interactions occupants have when in contact with the building systems. Finally, it is performed a comparison between the energy performance output data of the Green building studied in the present research and an existing building.

2. DESCRIPTION OF THE BUILDING

The building chosen for the purpose of this research study was the Western Sydney University (WSU) Building EHa, in Parramatta campus. The reason for choosing this particular building was due to its 6 Star classification, according to the Australian Green Star Rating System. In order to be rated as 6 Star, which is the highest classification according to the Green Star certification system, Building EHa had to comply with requirements in terms of management, indoor environmental quality, energy, emissions, transport, water, materials, land use and ecology. The building has a photovoltaic system to produce electricity and innovative targets such as; increasing the recycling rates more than 98%, increase cyclist facilities to carter for 15% of staff and students, reduce the use of potable water by 95%, evaluate the impacts from materials from a lifecycle perspective, etc.

The type of construction used should been traditional from where it is located and data related to its thermal and physical characteristics should be available and easily accessed.

WSU Building EHa serves the School of Science and Health, the School of Social Sciences and Psychology, as well as the Advanced Materials Characterization Facility. As the building is part of a university campus, according to the Building Code of Australia is classified as a *Class 5* activity type that corresponds to an "*office building* used for professional or commercial purposes", and a *Class 9b* activity type which relates to a "*building of a public nature*" (ABCB, 2006, ABCB, 2016). Figure 1 represents the real and the 3D model view of the building.

Figure 1. WSU Building EHa, Parramatta Campus

The present building has an area of 5733 m^2 and three levels, two above the ground level and one below the ground level. With façades oriented in all four main directions, the building main orientation is North to South. There are some neighbourhood buildings that shade WSU Building EHa and architectural features that provide shading to the internal rooms.

All the data that is being used for the present case study, related with occupancy, equipment/appliances and lighting system, is based on the "as built" design projects, as well as on a visual inspection performed to the building. Some punctual unknown data is being assumed having as reliable support the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards (ASHRAE, 2009, ASHRAE, 2007), European Directives (MAOTESESS, 2013) and Australian standards and regulations (ABCB, 2016, GBCA, 2015, ABCB, 2006).

The air conditioning system is provided for the cooling function by a chiller, with an Energy Efficiency Rating (EER) of 3.18, and a condensation boiler with an efficiency of 1.10 %, for the heating function. The building has installed 25 km of hydronic pipework that assure the cooling and the heating functions, as well as a system of several air handling units to maintain the indoor air quality according to the Green Star requirements (Australia, 2016). The set point temperature for the cooling season is 23^{o}C and for the heating season is 22 ^{o}C.

3. METHODOLOGY

In order to develop this research, it was stablished a direction plan. The first step was the selection of a Green Rated Building. The building had to comprise with similar characteristics, in terms of occupancy rates, construction solutions, floor area and activity type, as an existing building that was chosen for the purpose of a previous case study. Then, it was collected all the available technical data related with the building and its systems. The third step comprised in a dynamic simulation of a 3D model using the software DesingBuilder as an interface to EnergyPlus, that supports its nodal calculations in fundamental heat balance principles in transient state (DoE, 2016). Therefore, the dynamic simulation estimates the annual energy performance of a building and it is possible to evaluate the interaction that occupants have in its energy use.

The final step, after analysing the occupants' behaviour when interacting with the building systems, is to refine all the results with real energy consumptions and the results of a survey, where occupants were asked questions in relation to their interactions with the building and its systems.

4. BUILDING SIMULATION

4.1 3D Model

Due to the fact that the architecture plans were not available at the beginning of this study, in order to build the 3D Model of WSU Building EHa it was performed a visual inspection to the building and the plans used were from the electrical design.

Figure 2. WSU Building EHa, Parramatta Campus

4.1.1 Construction and infiltration rates

The data used for the purpose of the building envelope was the real one, provided by the Capital Works Department, from WSU. Eventually, some assumptions will be made, whenever relevant information is missing, having as support data available in the National Construction Code of Australia (NCC) (ABCB, 2016).

Windows, in general, are assumed to have dark coloured drapes as internal shading.

Figure 3. Internal shading

In terms of minimum fresh air admission, it is assumed per occupant 10 litres per second and an infiltration rate of 0.7 air changes per hour.

4.1.2 Thermal zones

The 3D Model is divided in 33 different thermal zones, according to the occupants' activity, internal loads and orientation (DoE, 2016, ABCB, 2016, GBCA, 2015). WSU Building EHa occupancy activities in are: laboratories, computer labs, offices, technical and storage areas and circulations. Figure 4 represents the thermal zones in Building EHa.

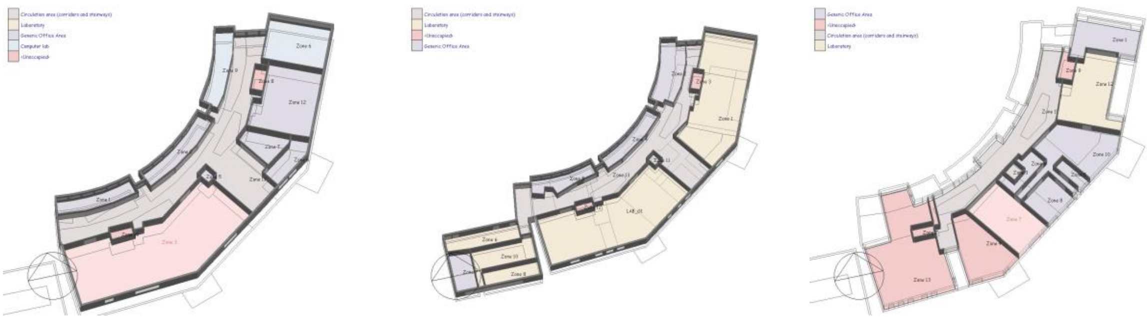

Figure 4. Thermal zones

4.1.3 Internal loads and schedules

Occupancy, light intensity and equipment are defined according to real internal loads installed in the building. Schedules were used according to the NCC (ABCB, 2016).

The air conditioning system, as referred previously, provided by a chiller, with an Energy Efficiency Rating (EER) of 3.18, and a condensation boiler with an efficiency of 1.10 %, for the cooling and heating functions respectively. A 25 km hydronic pipework assures the cooling and the heating functions, and a system of several air handling units maintain the indoor air quality according to the Green Star requirements (Australia, 2016). The set point temperatures vary between 23 ^{o}C and 22 ^{o}C.

4.2 Dynamic Building Simulations

The present case study aims to estimate the impact occupants will have in the overall energy performance of a Green building, by interacting with lighting, equipment, air conditioning and with windows. Similarly, to a previous research performed in an existing building, this study intends to draw conclusions of how occupant behavioural impacts condition the performance of a building, in order to be able to compare occupants' interactions in both buildings.

Therefore, it will be performed six different simulations, with assumptions in line with a previous study performed to an existing building. These simulations will be designed changing parameters related with occupants and/or their interaction with the building systems, such as the air conditioning, equipment/appliances and lighting. Table 1 shows all the scenarios created in order to evaluate the performance of Building EHa when occupants interact with its systems.

Table 1. Simulated scenarios

Simulations	Scenario
Baseline	Baseline simulation based in real data and schedules according to the NCC
SN2	Occupants reduce light use
SN3	Occupants reduce light use and equipment
SN4	Occupants increase the air conditioning set-point to 25°C in the cooling season and reduce the air conditioning set-point to 20°C in the heating season
SN5	Occupants reduce light use during daytime and turned off the lights and equipment when rooms are unoccupied Occupants increase the air conditioning set-point to 25°C in the cooling season and reduce the air conditioning set-point to 20°C in the heating season Occupants close doors and/or windows in 28% of the time
SN6	Occupants increase the air conditioning set-point to 26°C in the cooling season and reduce the air conditioning set-point to 18°C in the heating season

5. RESULTS

A first initial estimation of the outputs from the baseline simulation show that the most energy intensity use is: cooling, followed by interior lighting and equipment. Figure 5 is a representation of the energy distribution per end use in the baseline simulation.

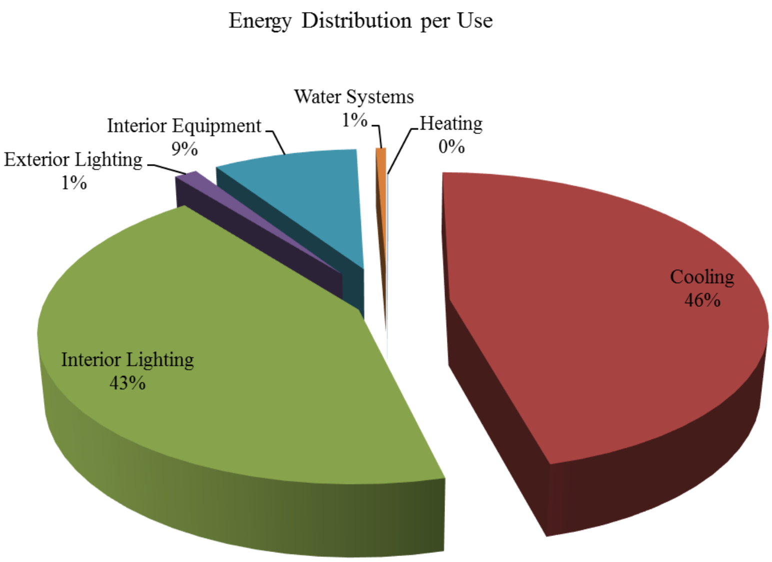

Figure 5. Energy distribution per end use from the baseline simulation

Figure 6 shows the predicted overall energy reduction potential in each scenario, by changes in occupants behaviour listed in Table 1. It quantifies the percentage of total energy that can be saved by reducing occupants' use of lighting, air conditioning and equipment/appliances, as well as closing doors/windows in 28% of the time.

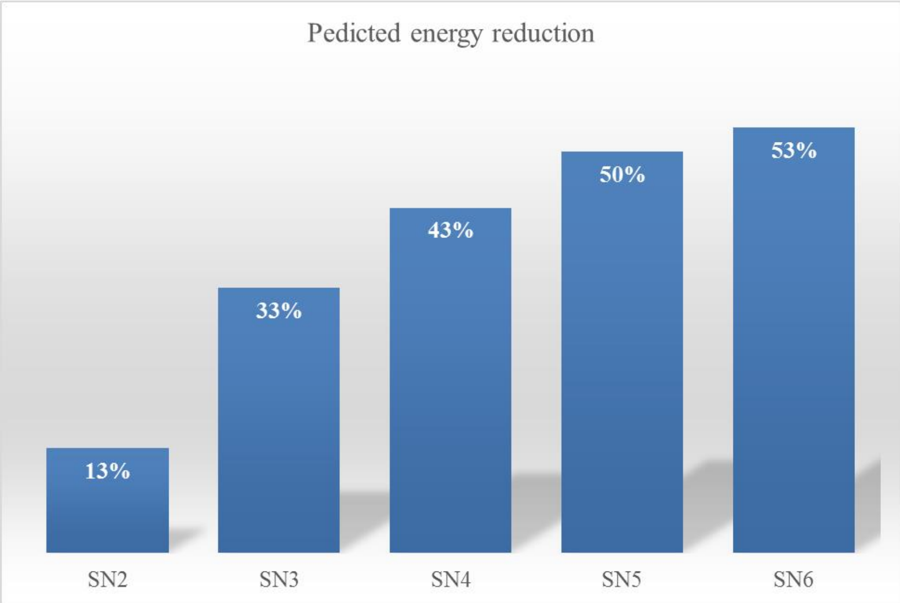

Figure 6. Predicted energy reduction per scenario

The total real energy consumption for building EHa, in a 5 months' period is 328 MWh. Assuming the expected reductions from Figure 6, it is expected to have an overall reduction of the energy intensity according to the graphic represented in Figure 7.

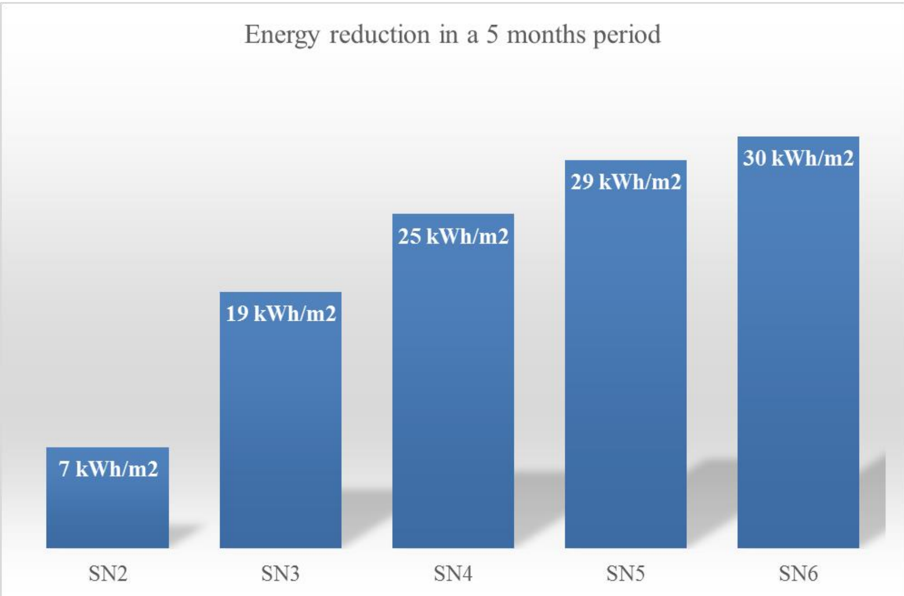

Figure 7. Predicted energy intensity reduction per scenario

Figure 8 compares the potential for reduction in the total real energy consumption between building EHa and an existing building, for the same period of 5 months, due to changes in occupant behaviour when reducing light, equipment and air conditioning use, as well as decrease the air infiltrations by closing doors and windows.

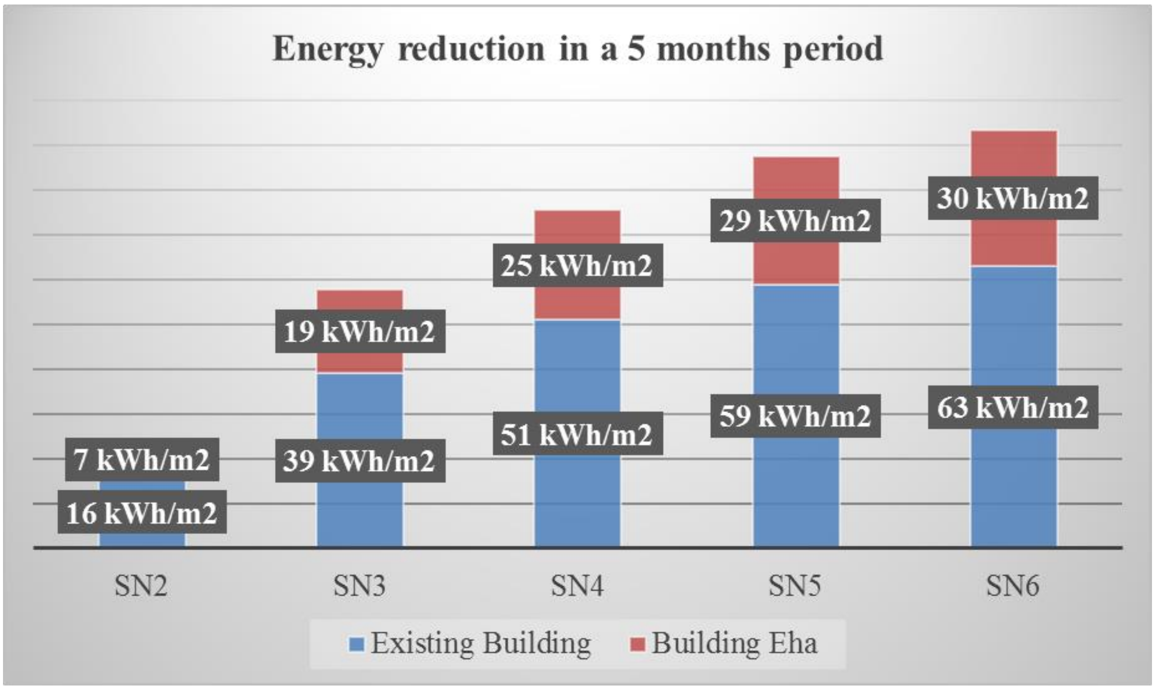

Figure. 8. Comparison between the predicted energy intensity reduction in building EHa and an existing building, per scenario

Figures 6, 7 and 8 reflect the extension of the impact that behavioural patterns will have in the reduction of energy use. The potential for energy conservation due to behaviour changes is higher in an existing building than in a green rated one. The reason for this difference is related to the fact that the energy use in a green rated building is optimized before the construction process occurs, during the design stage. Moreover, the potential for optimising the prediction of energy use for the operations stage, during the design stage is still significant. This may be analysed in the present research when the baseline model, provided by the same predictions as the models frequently used during the design stage of a Green Building process, is compared to the other scenarios.

Nevertheless, it is also relevant to notice that occupants do not control the heating and cooling operations in the majority of the spaces from both buildings.

6. CONCLUSION

Occupants are one of the most impacting variable in a building due to their permanent interaction with the building systems and features. The way occupants behave has a strong impact in the energy performance of a building, as well as in the indoor environment. Due to the fact that occupant behaviour in not accounted during the design stage of a building, this fact will promote an overestimation of the predicted energy for the operations stage of a Green Building.

The main conclusions of this study are; the potential for reduction in the energy use, due to changes in the occupants' behavioural patterns, is more significant in an existing building than in a Green Building; changes in occupant behaviour will strongly impact the overall energy performance of a building; and, there is still potential for improvement, in terms of energy use, in a Green Building process.

7. ACKNOWLEDGEMENT

The authors wish to acknowledge the financial support from the Australian Research Council (ARC) Discovery Project under grant number DP150101015.

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Uncovering the impact of urbanization on C&D waste generation based on STIRPAT model: A case of Shanghai in emerging country

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Abstract: China is experiencing rapid urbanization, in which massive construction and demolition (C&D) activities are executed accompanied by massive consumption of natural resources. C&D waste arising from rapid urbanization seriously threats sustainable development of cities in China. The impact of urbanization on C&D waste generation is investigated using the STIRPAT model (Stochastic Impacts by Regression on Population, Affluence, and Technology) in case of Shanghai over the period 1998-2015. Prior to formal econometric modelling, both Unit Root Test and Co-integration Test are applied to examine the co-integration relationship between the variables, which indicates the existence of co-integration relationship between the variables. It is suggested that C&D waste generation correlates negatively with population, while positively with affluence, technology and C&D activity. Moreover, it shows the U-shaped nexus between urbanization and per capita C&D waste generation. In other words, initially urbanization reduces C&D waste generation, but it increases C&D waste generation after a threshold level. The findings contribute to effective C&D waste management in rapid urbanization, especially for emerging countries. Various impact of urbanization on C&D waste generation at different urbanization level among different countries or cities should be taken in account in future investigation.
Keywords: Urbanization; STIRPAT model; Waste management; C&D waste generation; Shanghai; China

1. Introduction

Urbanization has become a significantly global phenomenon since decades. Globally, more people live in urban areas than in rural areas, with 54% of the world’s population residing in areas in 2014; it is estimated that 66% of the total population is projected to be urban by 2050 (UN, 2015). Although urbanization is generally accepted as the engine of economic growth (Bertinelli and Black, 2004), a great quantity of material and energy need be consumed in urbanized areas in rapid urbanization with industrialization (Gollin et al., 2016; Parikh and Shukla, 1995a). As well as ever-growing consumption of natural resources, a great amount of land is used thereby urban landscape substantially alternated by urbanization (Antrop, 2004; Foley et al., 2005). Consequently, rapid and unplanned urbanization cause various environment crisis; for instance, increasing amount of municipal solid waste without appropriate disposal is directly discharged into the soil, air and freshwater bodies in many cities especially megacities in emerging countries, thereby threatening environmental quality (Chen, 2007; Cohen, 2006).

Thus, effective management of massive municipal waste is a key challenge for cities in developing economies in case of rapid urbanization (Achankeng, 2003; Srivastava et al., 2015).

As the largest emerging country worldwide, China's urbanization level rapidly increased from 36.2% to 56.1% during 2000 and 2015, with an annual growth rate of 10.3% (NBS, 2016). It is estimated that in China about 1.13 billion tons of C&D wastes were produced, accounting for 30-40% of total municipal solid waste generated annually during 2014(Lu et al., 2016).

If there is a positive nexus between urbanization and C&D waste generation, this will has an important implication for waste management and sustainable development of cities under the circumstance of rapid urbanization. Within existing literature, STIRPAT model is widely applied to explore environmental impacts of population, affluence and technology, such as energy use, and carbon emissions (Dietz and Rosa, 1994, 1997; York et al., 2003).

However, few concerns are imposed on the impact of urbanization on C&D waste within existing studies particularly in emerging countries. Hence, the study seeks to investigate the impact of urbanization on C&D waste generation using the STIRPAT model for Shanghai, in China. This study contributes to the existing literature by exploring the nexus between urbanization and C&D waste generation using the STIRPAT model in case of Shanghai. This study bridges the research gap on the developing countries.

2. Literature review

Urbanization generally refers to the population migration from rural to urban areas, and the economy shift from agriculture to industry and modern services (Davis and Henderson, 2003). Although it is widely recognized that rapid urbanization can cause growing environmental impacts, existing literature mainly considers resource consumption, greenhouse emissions, air and water pollutants (Achankeng, 2003; Al-Kharabsheh and Ta'Any, 2003; Idris et al., 2004; Parikh and Shukla, 1995a; Poumanyvong and Kaneko, 2010; Shen et al., 2005). Hence, only few concern the effect of urbanization on municipal waste (Achankeng, 2003; Idris et al., 2004), hardly considering nexus between urbanization and C&D waste.

Poumanyvong and Kaneko (2010) pointes that environment effects of urbanization can be explained by three theories, namely ecological modernization, urban environmental transition and compact city theories. Following ecological modernization theory, although environmental issues increase as societies shift from the low to high development level; further modernization can reduce environmental impacts. Urban environmental transition theory mainly focuses the types of environmental issues that vary from the stage of economic development. The compact city theory suggests that the shape, scale and density of a city can have important implications for the environmental effects of urbanization, for instance high density may increase public transportation dependence thus reducing carbon emissions.

The nexus between urbanization and environmental impact is widely investigated by using the known IPAT and STIRPAT model (Chertow, 2000; York et al., 2003). In an innovative research on the impact of population growth, Ehrlich and Holdren (1971) initially proposed the IPAT model (I=PAT) to investigate the environmental effects of human activity. Here, *I* represents environmental impact that is driven by three interconnected factors: population scale (*P*), affluence (usually proxied by per capita GDP) (A), and technology (the environment impact of per unit human activity) (T). The value of T is often determined by the known values of *I*, *P* and *A*, which is equal to I/(PA) or I/GDP.

Due to the constraints of the IPAT model (Dietz and Rosa, 1994), (Dietz and Rosa, 1997) improved and re-developed the STIRPAT model ($I=aP^bA^cT^de$). Where I, P, A and T represent environmental impact, population, affluence and technology separately; a is the constant of the equation, b, c, and d are the estimated coefficients of P, A and T respectively; e is the estimated residual of the equation.

Since the 1990s, the STIRPAT is widely used to explore the relationship between urbanization on energy use, and carbon emissions (Dietz and Rosa, 1997; Liddle, 2013; Liddle and Lung, 2010; Martínez-Zarzoso and Maruotti, 2011; Parikh and Shukla, 1995b; Poumanyvong and Kaneko, 2010; Salim et al., 2014; Shahbaz et al., 2016; Sharma, 2011; York, 2007a, b). Generally, the majority of existing literature suggests that urban has a significantly positive impact on energy use and carbon emissions. For instance, (Dietz and Rosa, 1997) found that population size has a positive effect on carbon emissions among 111 countries in 1989. Population age structure has substantial impact on carbon emissions and residential energy use (Liddle and Lung, 2010). (Fan et al., 2006) pointed that the percentage of the population between 15 and 64 has a negative effect among the high income countries, while the effect is positive at other income level. Energy production is significantly affected by urbanization in 14 countries of South and East Asia (York, 2007a). According to (Poumanyvong and Kaneko, 2010), the impact of urbanization on energy use and emissions varies across the development stages of 99 countries over the period 1975-2005. (Martínez-Zarzoso and Maruotti, 2011) observed the existence of an inverted U-shaped nexus between urban and CO_2 emissions in 88 developing countries from 1975 to 2003.

Owing to the growing issue on municipal solid waste (MSW) (Achankeng, 2003; Suocheng et al., 2001; Zurbrügg, 2002), for last decade some literature has concerned the impact of urbanization on MSW generation, most of previous literature shows that urbanization have a significantly positive impact on MSW generation. For instance, (Idris et al., 2004), (Kumar, 2005) and (Chattopadhyay et al., 2009) find that MSW generation increases in proportion to the growth in population and urbanization in many Asia developing countries. (Khajuria et al., 2010) and (Vij, 2012) suggests that urbanization has a direct impact on the MSW generation. According to (Johnstone and Labonne, 2013), both population density and urbanization have positive impacts on household solid waste generation in OECD countries.

In summary, existing literature on the impact of urban on MSW generation is somehow scarce, descriptive and qualitative, thereby without full investigation of the relationship between urbanization on MSW generation. Moreover, although C&D waste accounting for a great fraction of total MSW generation, prior literature hardly involves the nexus between urbanization and C&D waste generation.

Hence, we seek to introduce the widely applicable and useful STIRPAT model to explore the impact of urbanization on C&D waste generation in case of Shanghai in China. This will contributes to previous literature on the environmental impacts of urbanization in emerging countries.

3. Methodology

3.1 The STIRPAT model

Following existing literatures (Dietz and Rosa, 1994, 1997; Fan et al., 2006; Liddle and Lung, 2010; Martínez-Zarzoso and Maruotti, 2011; Poumanyvong and Kaneko, 2010; Sadorsky, 2014; York et al., 2003), the widely known STIRPAT model is applied to explore the relationship between urbanization and C&D waste generation, in order to identify principal drivers of C&D waste generation in Shanghai.

Originally, the STIRPAT model stems from the IPAT model (I=PAT) ((Ehrlich and Holdren, 1971), which suggests that the environmental impact is mainly determined by population, affluence, and technology. Later, the IPAT is criticized by its limitations, such as failing to providing an adequate framework for capturing driving forces of environmental impacts, and the IPAT model is reformulated in stochastic form thereby generating new STIRPAT model ($I=aP^bA^cT^de$) (Dietz and Rosa, 1994).

In order to eliminate the heteroscedasticity of the raw data, all variables in the STIRPAT model is be expressed in natural logarithms thus all estimated coefficients can be regarded as elasticities.

$$\mathrm{lnI} = \mathrm{a} + \mathrm{blnP} + \mathrm{clnA} + \mathrm{dlnT} + \varepsilon, \qquad \text{Equ.1}$$

To investigate the impact of urbanization on C&D waste generation, especially to test the existence of the U-shaped nexus between urbanization and C&D waste generation, urbanization can be introduced to Equ.1, and thus Equ.1 can be easily re-writhed as follows.

$$\mathrm{lnI} = \mathrm{a} + \mathrm{blnP} + \mathrm{clnA} + \mathrm{dlnT} + \mathrm{flnU} + \mathrm{k(lnU)^2} + \varepsilon, \qquad \text{Equ.2}$$

Along with urbanization, it is expected that C&D waste generation can be substantially affected by various C&D activity. Therefore, Equ.2 can be reformulated by introducing C&D activity.

$$\mathrm{lnI} = \mathrm{a} + \mathrm{blnP} + \mathrm{clnA} + \mathrm{dlnT} + \mathrm{flnU} + \mathrm{k(lnU)^2} + \varepsilon, \qquad \text{Equ.3}$$

Where I, P, A, T, and U represent annual C&D waste generation per capita, total population, GDP per capita, energy use per dollar of GDP, and urbanization; a, b, c, d, f, k, and g are the constant, and estimated coefficients of $\mathrm{lnP}, \mathrm{lnA}, \mathrm{lnT}, \mathrm{lnU},\ and\ (\mathrm{lnU})^2$; and ε is the estimated residual of Equ.3.

3.2 The data sources

Shanghai is selected as the research object to empirically investigate the impact of urbanization on C&D waste generation in this study; subject to data accessibility, the research period is set between 1998 and 2015. All data required in this study can be obtained from the 1999-2016 Shanghai Statistic Yearbook, and the general picture of all raw data in the model between 1998 and 2015 is shown in Table 1.

Table 1 The description and definition of raw data in 1998-2015

Variable	Definition	Unit	1998	2015	Annual change rate
I (Impact)	C&D waste per capita	kg/per	2312	857	-5.67%
P (Population)	Total population	million person	15.3	24.2	2.73%
U (Urbanization)	Urbanization level	%	73.0	87.6	1.08%
A (Affluence)	GDP per capita	\$/per	3045	16665	10.52%
T (Technology)	Energy use per dollar of GDP	ton sec/10^4 \$	0.162	0.054	-6.26%

Shanghai is the largest megacity and highly advanced economic center in China. It is also the leading city in the Yangtze River Delta Urban Agglomeration, which is located on China eastern coast, with an area of about 6,340 km^2. Over the period 1998 and 2015, total population steadily increased by 2.73% from 15.3 million in 1998 to 24.2 million in 2015; correspondingly, urbanization level also grown from 73% to 87.6% with an annual growth rate of 1.08%. Affluence (GDP per capita) has increased from \$ 3045 to \$ 16665 over the same period.

Technology (energy use per dollar of GDP) has decreased from 0.162 ton sec/10^4 \$ to 0.054 ton sec/10^4 \$. As a pillar industry, it was reported that in 2015 value-added and employment opportunity created in construction sector reached \$ 13.7 billion and 69.2 10^4 person respectively, and the floor area of newly completed housing was 2923 10^4 sq.m.

3.3 Unit root test and co-integration test

Prior to formal econometric analysis, it is essential to conduct necessary data processing, correlation analysis, unit root test and co-integration test for all variables in order to avoid spurious regression.

(1) All raw data are processed in natural logarithms form to eliminate the heteroscedasticity. Hence, $I, P, U, A,$ and T are separately transformed to $\ln I, \ln P, \ln U, \ln A,$ and $\ln T$. Where $\ln I$ is dependent variable, and $\ln P, \ln U, \ln A,$ and $\ln T$ are independent variables.

(2) The preliminary correlation analysis is conducted to test whether dependent variable (namely annual per capita C&D waste generation) links with various independent variables, especially identifying the impact of urbanization on C&D waste generation in rapid urbanization context (see Table 2).

Table 2 The correlations between variables

Variable	lnI	lnP	lnU	lnT	lnA
lnI	1				
lnP	-0.885	1			
lnU	-0.955	0.965	1		
lnT	0.728	-0.906	-0.832	1	
lnA	-0.862	0.996	0.952	-0.932	1

The correlation analysis shows that C&D waste generation correlates positively with technology, while negatively with population, urbanization, and affluence (see Table 2). According to Fig.1, there is a negative linkage between urbanization and C&D waste generation, especially a U-shaped nexus can be observed between urbanization and C&D waste generation.

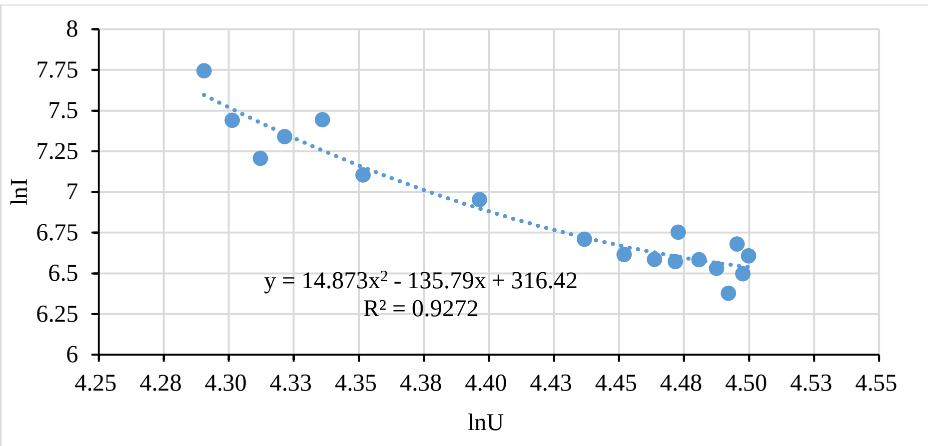

Fig. 1 The scatter plot for C&D waste generation and urbanization

(3) The unit root test can be used to examine the existence of unit roots for each series to

test whether variables are stationary. The unit root test is conducted with a constant and an automatic lag selection process using the AIC with a maximum of three lags. Although variables are not stationary in levels, neither common nor individual unit root process is observed in first different series at the 5% significant level (see Table 3). Thus, all first difference series are stationary at the 0.05 level.

Table 3 Group Unit Root Test for first difference series

Method	Statistic	Prob.
Null: Unit root (assumes common unit root process)		
Levin, Lin & Chu t*	-1.840	0.033
Null: Unit root (assumes individual unit root process)		
Im, Pesaran and Shin W-stat	-1.997	0.023
ADF - Fisher Chi-square	24.419	0.018
PP - Fisher Chi-square	23.979	0.021

(4) The cointegration test is applied to verify whether there is a relationship between urbanization and C&D waste generation. The results of Johanson Cointegration Test for $\ln I, \ln P, \ln U, \ln A,$ and $\ln T$ are presented in Table 4. The results indicate that there is a co-integration relationship among population, urbanization, affluence and technology and C&D waste generation at the 0.05 level.

Table 4 Johanson Cointegration Test

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	5% critical value	Prob.
None *	0.999632	238.297	69.819	0.000
At most 1 *	0.963451	111.765	47.856	0.000
At most 2 *	0.925440	58.819	29.797	0.000
At most 3 *	0.617582	17.281	15.495	0.027
At most 4	0.112022	1.901	3.841	0.168

3.4 The hypotheses

4. Results

Table 5 The estimated results for the STIRPAT model

Variable	Coefficient	Std. Error	T-Stat.	Prob.
constant	1353.443	347.845	3.891	0.002
lnP	-11.355	3.395	-3.345	0.006
lnU	-584.585	152.991	-3.821	0.002
$(\ln U)^2$	66.046	17.498	3.775	0.003
lnA	4.046	1.075	3.763	0.003
lnT	1.430	0.394	3.633	0.003

A. R^2=0.959; F − stat = 79.564; Prob. (F − stat.) = 0.000; D.W − stat = 2.561

Research design

1.1Research variables and data sources

1.2 Data prof

1.2.1 Construction ecosystem

1.2.2 Material, water and energy consumption

1.2.3 Land, labor and capital input

1.2.4 C&D activities and products of construction ecosystem

1.2.5 C&D waste generation of construction ecosystem

2. Results

How did you analyse the data? Why these regression models?

Drivers of C&D waste generation and hypotheses testing

3. Discussions and conclusions

Discuss the statistical results, implications of the results; highlight the theoretical contributions; discuss the limitations and recommendations.

Table 1 The estimated equations of Per capita C&D waste generation of Shanghai, in 1998-2015

Component	Explanatory variable	Equ.	$A.R^2$	Sig.
Construction ecosystem	GDP	$y = 2.52E-04x^2 - 1.3429x + 2305.32$	0.791	dual
	Per capita GDP	$y = 1.72E-05x^2 - 0.3989x + 2852.57$	0.828	dual
	Disposal income	$y = 7.12E-05x^2 - 0.7621x + 2517.00$	0.780	dual
	Industrial struc	$y = 275.74x^2 - 1479.18x + 2512.24$	0.846	equation
	Population	$y = 3.03E-03x^2 - 13.3469x + 15360.2$	0.882	dual
	Population density	$y = 1.22E-03x^2 - 8.4699x + 15372.33$	0.882	dual
	Urbanization	$y = 5.2075x^2 - 921.1454x + 41449.67$	0.886	dual
	Construction value added	$y = 0.2368x^2 - 44.6749x + 2597.79$	0.727	dual
	Total employment	$y = 5.69E-03x^2 - 13.4147x + 8509.35$	0.485	dual
	Construction employment	$y = 77579x^{-1.055}$	0.852	dual
Inputs	Steel	$y = 9.78E-04x^2 - 2.5112x + 2275.21$	0.847	dual
	Water	$y = 80.656x^2 - 1266.2x + 5119.2$	0.4705	equation
	Concrete	$y = 2948.7e^{-7E-04x}$	0.892	dual
	Wood	$y = 2.4E-03x^2 - 8.4669x + 2314.913$	0.821	dual
	Land	$y = -7.81E-08x^3 + 1.132E-03x^2 - 4.997x + 7557.9$	0.647	dual
	Energy	$y = -8.3695x + 2464.001$	0.706	dual
	Housing investment	$y = 0.0552x^2 - 22.163x + 2717.498$	0.799	dual
	Municipal investment	$y = 0.0365x^2 - 16.377x + 2450.845$	0.680	dual
	construction investment	$y = 0.0137x^2 - 11.8054x + 3198.759$	0.764	dual
	Real estate investment	$y = 0.0142x^2 - 10.1635x + 2271.002$	0.723	dual
C&D activities	Building newly built	$y = 1.67E-05x^2 - 0.5517x + 5266.473$	0.751	dual
	Housing newly built	$y = 2.04E-05x^2 - 0.5254x + 4056.854$	0.812	dual
	Residence newly built	$y = 0.2779x + 3030.168$	0.630	dual
	Pipeline newly built	$y = 126.42e^{0.2941x}$	0.269	No
	Road newly built	$y = 258.36x^{0.208}$	0.202	No
	Housing completed	$y = 4.42E-05x^2 - 0.6142x + 2853.889$	0.807	dual*
	Housing demolished	$y = -9.78E-04x^2 + 1.243x + 808.719$	0.032	No

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Parametric analysis to improve energy performance of construction projects

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Abstract

Building Information Modeling (BIM) tools provide a distinctive way of observing and estimating energy consumption in construction projects. This work presents the interests of BIM tools in examining different design alternatives in order to improve energy performance in buildings. A novel framework is proposed to enhance the design of energy output in construction projects. This work empowers decision-making process and sustainability through a parametric analysis of the selection of construction building components. The methodological framework accommodates various performance parameters through the use of experimental design for improving energy efficiency of buildings. A case study with a group of construction materials for exterior walls and roofs as well as a set of the window-to-wall ratio are examined in different climate classifications. RStudio software is applied as a linear regression analysis to determine all the variables of the design factors. Autodesk Green Building Studio software is applied as the BIM tool to estimate energy use intensity (EUI) of the applied factorial designs. This study indicates that BIM modeling is an optimal procedure towards empowering both sustainability and decision-making process in the construction sector. The results show that the climate data plays a fundamental role in determining the energy consumption in construction projects. Besides, the design factor of the window-to-wall ratio is the main agent of influencing the energy consumption in buildings rather than any other building components, hence it suggests constructing buildings within minor opening spaces at any climate zone towards nearly Zero Energy Buildings (nZEBs).

Keywords: Building Information Modeling; Sustainable Construction; Energy Use Intensity.

1. INTRODUCTION

The world is witnessing an increasing concern in the field of energy efficiency. Advanced solutions are required to achieve the sustainability standards in this field (Šaparauskas & Turskis 2006). Several tools and methods are assessed to support the implementation of sustainable strategies in the built environment. In this discipline, Building Information Modeling (BIM) is being discussed as a building tool that evaluates energy performance in the construction sector, providing users with the ability to explore the different alternatives to increase energy efficiency in buildings (Najjar et al. 2017).

The novelty is to propose a framework that utilizes BIM tools in order to improve energy performance of buildings. It is envisaged that the proposed method will empower decision-making process and sustainability of designing construction projects. The Energy Use Intensity (EUI) is evaluated, taking into consideration the building components that are constructing the envelop of buildings, window-to-wall ratio, and the installed capacity. Experimental design, which involves a systematic collection of data, is utilized to focus on the planning of the selection process itself rather than the analysis of the results, based on a linear regression analysis (Nist Sematech 2012). The methodological framework developed accommodates various global climates, in response to the consensus worldwide on the need for improving energy consumption in buildings and enhancing the sustainability of the built environment. The output results from the process modeling of the experimental design are conducted in order to evaluate the energy performance towards nearly Zero Energy Buildings (nZEBs). A case study example of a single-family house is examined in different cities with varying climate data in order to validate the developed methodological framework.

2. FOCUS AND METHODOLOGY

The methodology proposed in this paper simulates the energy performance of construction projects, considering the EUI as one of the key metrics to benchmark the energy performance in buildings. It is calculated by dividing the total annual energy consumed in the building by the total gross floor area.

2.1. Decision Support Analysis

The initial step in the proposed approach is the integration of a number of performance parameters that influence the energy consumption during the operation phase of buildings, such as building modeling and climate data, as shown in Figure 1. The design factors relevant to the building modeling parameter include the identification of the function and use of the building, type of energy use and consumption, CO_2 production, exterior area of roof and walls and the exterior space of openings associated with the building (Perrone & Filiatrault 2017). These factors need to be combined together with the design features of the climate data parameter at the construction site of buildings.

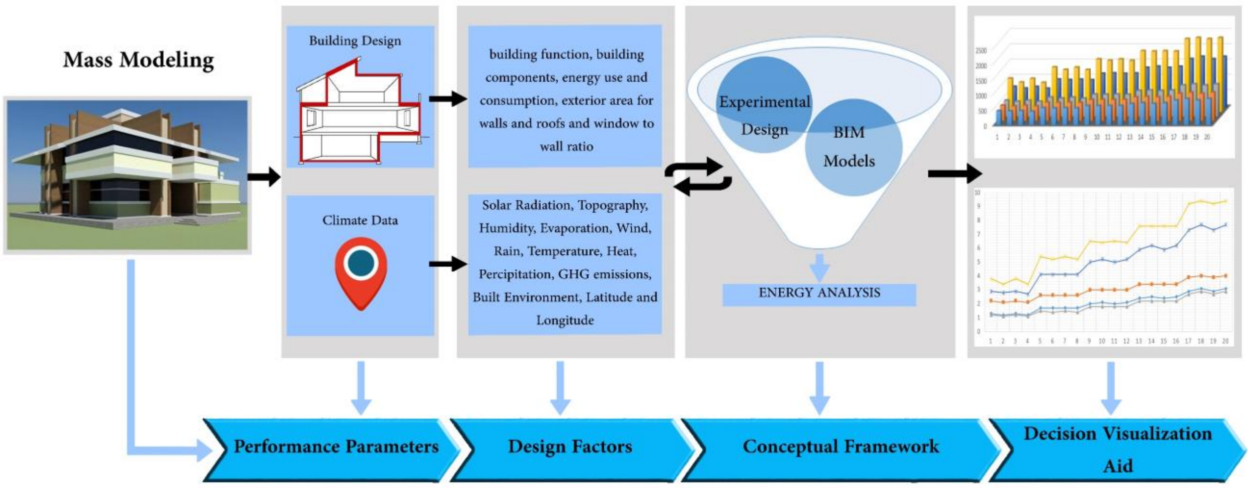

Figure 1. Decision support analysis

The evaluation process of the collected database starts by measuring the energy consumption, using BIM models as an indicator of sustainability. The methodology makes use of an experimental design procedure to indicate the best building component and window-to-wall ratio that could improve energy efficiency in buildings based on the different climate data and annual average temperature. The experimental design work is based on a parametric analysis that examines different values for several design factors. Such a process provides the maximum information at the minimum experimental cost (Callao 2014). The last step of the methodological framework of this study is to analyse and evaluate the collected results in order to simulate the energy performance in construction projects. This process starts by classifying sources of data, comparing results, and suggesting recommendations.

2.2. Linking framework components

The first step is to identify the size of the case study, which means identifying the amount, weight and quality of the specific product investigated, as shown in Figure 2. The second step is to build the inventory of database by estimating all the expected variables in an experimental design work using a parametric analysis based on a linear regression. RStudio is used for determining all the variables of the experimental design work through a regression analysis (RStudio n.d.). Autodesk Green Building Studio is adopted as an intelligent BIM model performs and estimates the energy performance in buildings (Abdulla & Jrade 2012). The third step is to evaluate the collected database for each mas modeling. At this level of the analysis, the collected EUI results in Autodesk Green Building Studio are evaluated in order to specify the impact of building components and window-to-wall ratio on energy consumption in buildings. Conducting such an analysis demands a parametric analysis involving gradual increments of the window-to-wall ratio and various building components.

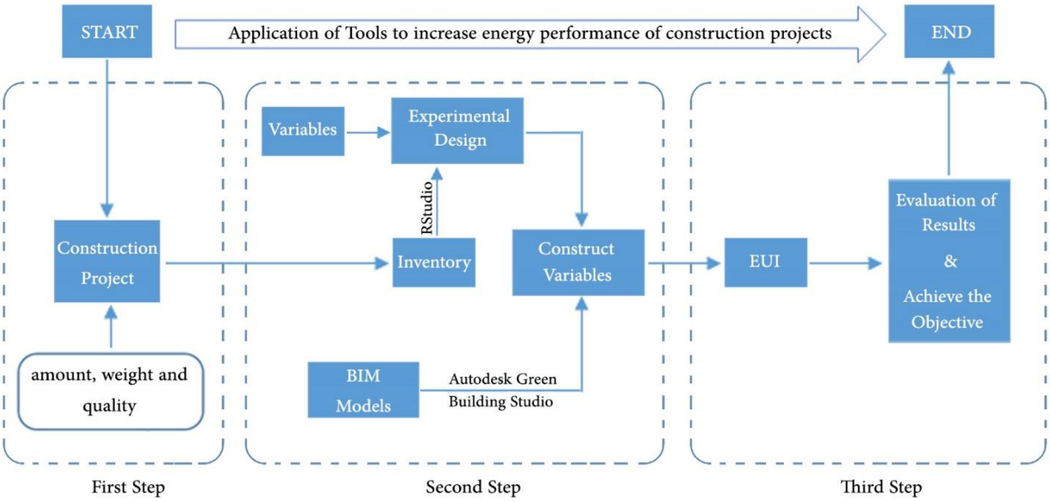

Figure 2. Linking framework components

3. CASE STUDY: VALIDATING THE METHODOLOGICAL FRAMEWORK IN A SINGLE-HOUSE FAMILY

The applied case study aims to validate the proposed framework used to model the decisions involved in choosing the building materials for construction projects. In order to showcase the versatility of the proposed framework, the proposed analysis is conducted in six different cities with different climate data. The chosen cities include Dubai in United Arab of Emirates, Moscow in Russia, Mount Wellington in Australia and Porto in Portugal that are located in dry climates, continental climates, polar climates, and mild temperate climates, respectively. In addition to this, there are Kuala Lumpur in Malaysia and Rio de Janeiro in Brazil that belong to the tropical climates within different sub-type classifications; tropical rainforest climate and tropical savanna climate, respectively.

3.1. Size of the case study

The case study of this work examines the energy efficiency of a single-family house, within a total floor area of a 60 m^2, consuming the energy for purposes of heating, cooling, lighting, equipment, pumps and hot water. The analysis takes into consideration two types of building materials that are constructing the exterior walls and roof, namely Insulated Concrete Form (ICF) wall, 10 thick form, and Insulated Concrete Form (ICF) wall, 14 thick form for walls. While Continuous Deck Roof with Code Compliant Insulation and Continuous Deck Roof with Super High Insulation for the roof. Additionally, the parametric analysis considers a range of different window-to-wall ratio (15%, 30%, 40%, 50%, and 65%).

3.2. Inventory of database

The inventory of database focusses on the operation phase of the case study and is constructed through two main steps. The first step is that the assigned design factors determined in the case study, Table 1, are integrated into a linear statistical regression, in order to cover all the expected variables of the experimental design. Applying the experimental design work, outlined in the proposed framework, to estimate the EUI, is known as mixed-level design or general full factorial design. Mixed-level design or general full factorial design allows the consideration of different levels for each factor (Nist Sematech 2012). In this study, three factors with different levels are incorporated. The first factor is the wall type (C_W), consisting of two levels. The second factor is the roof type (C_R), consisting of two levels as well. The third factor is the window-to-wall ratio (C_{WR}), which is associated with five levels, as displayed in Table 1.

Table 1. The applied alternatives of construction objects in the functional equivalent

Wall (C_W)	Roof (C_R)	window-to-wall Ratio (C_{WR})
- Insulated Concrete Form (ICF) wall, 10 thick form (1). - Insulated Concrete Form (ICF) wall, 14 thick form (2).	- Continuous Deck Roof with Code Compliant Insulation (1). - Continuous Deck Roof with Super High Insulation (2).	- 15% (1) - 30% (2) - 40% (3) - 50% (4) - 65% (5)

The model for such an experiment analysis is presented in Equation (1). The number of sequences will be the result of multiplying the number of levels associated with each factorial design considered within a single analysis together (Nist Sematech 2012; Collins et al. 2009). As an example, the number of sequences that are required to cover all the expected variables is 20 ($2 \times 2 \times 5$).

$$E = \beta 0 + \beta 1.CW + \beta 2.CR + \beta 3.CWR + \beta 1\,2.CW * CR + \beta 1\,3.CW * CWR + \beta 2\,3.CR * CWR + \beta 1\,2\,3.\,CW * CR * CWR + \epsilon \quad (1)$$

The second step is to apply the Autodesk Green Building Studio to estimate the EUI based on the running sequences that were previously built in the regression model. At this step, the database for each sequence is constructed individually. This means that 20 separate analysis is performed in Autodesk Green Building Studio application.

3.3. Assessment of design factors

The experimental design is applied at this level of the analysis to clarify the various effects of the assigned design factors. **Table 2** presents the estimated values of the EUI of the case study based on the examined cities in this work.

Table 2. Experimental design outputs

NO	Factorial Design			Energy Use Intensity (MJ/m2/year)					
	C_W	C_R	C_{WR}	Dubai	Kuala Lumpur	Moscow	Mount Wellington	Porto	Rio de Janeiro
1	1	1	1	497.1	502.2	1,091.7	679.6	517.0	462.2
2	1	2	1	472.4	489.8	963.0	621.0	481.0	450.5
3	2	1	1	496.5	502.7	1,085.8	675.8	513.4	462.1
4	2	2	1	471.2	489.3	955.4	616.2	476.9	439.0
5	1	1	2	597.9	574.5	1,460.7	916.0	619.2	558.1
6	1	2	2	586.5	562.1	1,380.6	900.2	583.3	548.5
7	2	1	2	597.8	575.7	1,457.2	912.1	616.3	557.2
8	2	2	2	586.8	563.7	1,375.5	896.4	580.0	547.7
9	1	1	3	685.1	629.3	1,727.2	1,108.1	715.6	628.4
10	1	2	3	688.3	626.9	1,681.1	1,120.9	710.5	629.0

11	2	1	3	685.6	630.7	1,724.9	1,103.9	713.1	627.3
12	2	2	3	688.4	627.5	1,677.6	1,116.7	708.2	627.9
13	1	1	4	770.0	681.4	1,995.9	1,302.5	834.0	697.5
14	1	2	4	786.4	696.6	1,985.2	1,341.2	847.0	720.7
15	2	1	4	770.4	682.8	1,994.6	1,299.3	832.1	696.5
16	2	2	4	786.3	698.2	1,982.4	1,337.5	845.0	719.9
17	1	1	5	888.1	765.4	2,394.2	1,590.0	1,015.3	810.8
18	1	2	5	925.3	796.2	2,430.7	1,665.0	1,051.6	859.5
19	2	1	5	888.1	766.9	2,393.4	1,587.5	1,013.8	809.7
20	2	2	5	925.1	797.3	2,429.5	1,662.2	1,050.2	858.9

Table 2 shows that installing the case study within a window-to-wall ratio of 15% in Rio de Janeiro disregarding any other components of walls and roofs, and in Dubai using super high insulation for roofs would consume almost the same EUI. While disregarding the insulation factor for roofs would consume more energy in Dubai than in Rio de Janeiro. Moreover, installing the case study within a window-to-wall ratio of 15% in Mount Wellington would consume almost the same EUI compared to the same installation within a window-to-wall ratio of 30% in Dubai and Porto. Installing the case study in Moscow within a window-to-wall ratio of 15% would cause the same consumption in Dubai within a window-to-wall ratio of 65%. While installing the case study within a window-to-wall ratio of 40% in Dubai and Porto would consume the same EUI in Kuala Lumpur and Rio de Janeiro within a window-to-wall ratio of 50%, disregarding all other building components.

3.4. Evaluation of Results

The analysis of the collected results sorts out that there are several performance parameters to be considered in order to increase energy efficiency in construction projects such as insulation and thickness of the building components, a space area of the exterior openings and climate data. The results show that the same building would consume high energy in continental climates and polar climates whereas the consumption would reduce dramatically in other climate classifications such as dry climates, tropical climates, and mild temperate climates. For example, EUI of the case study installed in Kuala Lumpur and Rio de Janeiro are slightly different, while the consumption of energy differs noticeably between the other cities located in different climate classifications. This proves that the sub-type climate classification plays a minor role in determining the energy efficiency whereas the climate group is the main agent of manipulating the energy consumption in construction projects.

After classifying and evaluating the results collected in the previous section, the aim is to increase the energy efficiency in construction projects, while highlighting the building components that could affect the consumption of energy in the case study is a secondary objective. The results of Table 2 illustrate that constructing buildings within minor openings (window-to-wall ratio) using different building components for walls and roofs consume less EUI than using wide opening spaces. In other words, using super high insulation building materials and increase the thickness of building components would slightly reduce the consumption of energy in buildings, however, the space area of the exterior openings is the main building component influences the energy consumption at this level of the analysis. Besides, Table 2 shows that sequences (2 and 4) maximize the efficiency of EUI of the case study building in the six examined cities whereas sequences (18 and 20) consume the most EUI.

4. DISCUSION AND CONCLUSION

A framework to increase the energy efficiency of construction projects was proposed, simulating the ability of BIM models and considering the building components that are constructing the building envelop, window-to-wall ratio, and the installed capacity. An integrated methodological framework was presented based on the experimental design to enhance the decision-making process and sustainability in buildings. The framework determined various performance parameters related to several design factors to maximize the energy efficiency, based on a parametric analysis. RStudio was utilized to conduct a linear regression analysis to cover all the possible variables of the assigned design factors. Besides, Autodesk Green Building Studio application was adopted as a BIM model to analyse and estimate the consumption of energy. This study points out that BIM models are optimal procedure towards empowering both sustainability and decision-making process in the construction sector.

A case study of a single-family house was examined in six cities, each with a different climate classification. Cities analysed included Dubai, Kuala Lumpur, Moscow, Mount Wellington, Port, and Rio de Janeiro. The results of this work indicate that the performance parameters suggested in the framework significantly influence the energy consumption in buildings. These parameters include the type of building design and the climate data and integrated through the use of experimental design and BIM models. The results also display that applying high insulation and increase the thickness of building components would slightly impact the energy efficiency in construction projects, while the design factor of the window-to-wall ratio plays a major role in influencing the energy consumption towards nZEBs. However, this work suggests constructing buildings within minor opening spaces in order to improve energy efficiency. Another result of this work is that it proved that the sub-type climate classifications have a minor role in influencing the energy consumption in buildings, while the climate group plays a fundamental role in determining this fact in construction projects.

5. ACKNOWLEDGEMENTS

The authors would like to thank the Brazilian Education Ministry for the financial support received under the Capes fellowship (Coordination for the Improvement of Higher Education Personnel) and CNPq "National Counsel of Technological and Scientific Development" who supported scholarships and grants for some of the authors of the paper.

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Practices applied to the execution and control of the quality of foundations in building work

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Abstract

The foundations are the elements of a building that have the function of transmitting loads of the building to a resistant soil. A drawback of foundations is the difficulty of identifying execution failures upon completion, because their elements are buried. Therefore, these errors are often discovered only when pathologies arise in the building, such as cracks. In order to avoid the occurrence of failures in a building, it is essential that the engineer and his team have full control of the execution of foundations and the company has a strict quality control system. Thus, this article aims to conceptualize briefly the execution techniques of foundations applied in building construction and analyse their quality control. In addition, the procedures adopted by construction companies in terms of execution of foundations and quality control are evaluated through the case study of a construction of a multifamily residential project from a large construction company in the city of Rio de Janeiro, Brazil. In this construction were implemented three different types of foundation, namely: spread footings; steel piles; and micropiles. Finally, the main practices to be adopted by construction companies toward making the execution and quality control of foundations more effective are identified.

Keywords: Quality Control, Foundation, Execution.

1. INTRODUCTION

Foundations are responsible for supporting and transferring loads from the structure to the ground. Execution errors in foundations are hardly observed during execution or soon after its completion. This difficulty occurs because once completed and buried, failures are not visible. Generally, the effects of the poor execution of the foundation are experienced after the end of the construction, in terms of quality, performance and reinforcement expenses (Pinto, 2015).

Construction companies should focus on improving the knowledge of execution techniques of different types of foundation by construction engineers and the staff involved in the service. In addition, the implementation of an effective quality control system, which ensures that the execution of the services follows the technical standards, is fundamental. Therefore, the identification of good practices that make the execution and the quality control of foundations in building constructions more efficient is an important strategy for construction companies.

This article aims to evaluate the execution techniques of different types of foundations applied in building construction and their quality controls. Thus, it is analysed the practices adopted by a large construction company, through the study of the construction of a multifamily residential building located in the city of Rio de Janeiro, Brazil. Although the diversity of foundation types available is vast, this article analyses the types of foundation used in the case study, namely: spread footings; steel piles; and micropiles.

2. THE CONSTRUCTION SITE OBJECT OF STUDY

The project under study is located in the neighbourhood of Andaraí, in the city of Rio de Janeiro, Brazil. The enterprise consists of four residential buildings in structural masonry. The blocks 1 and 2 have four floors and the blocks 3 and 4 have three floors. The project has 99 apartments with an area ranging from 53 m² to 65 m².

In order to design the projects of foundation, 24 Standard Penetration Tests were performed. According to the investigation results, it was determined that it should be executed 61 spread footings and 48 steel piles in Block 1 , 81 steel piles and 10 micropiles in Block 2, 81 steel piles in Block 3 and 44 spread footings and 68 steel piles in Block 4.

3. EXECUTION AND QUALITY CONTROL OF FOUNDATIONS

In this project, all the services of formwork, reinforcement assembly, concrete production and concreting were outsourced. The execution of steel piles and micropiles were also outsourced. The construction company was responsible for providing materials, locating foundation elements and supervising all services.

The company hired to elaborate the projects of foundation, also elaborated projects with details and specifications for each type of foundation. In these projects are presented the execution sequence, pertinent observations, quality control items and details to facilitate its execution. In parallel, the quality sector of the construction company prepared an execution procedure regarding the execution of foundations in a construction site.

The quality sector also provided a check form for each type of foundation, which includes the inspection of several steps of foundation execution. By correctly filling it, it is unlikely that there would be any nonconformity. The first check form for each service should be filled by the construction engineer, who provides guidance to the trainees responsible for filling it in next times. In addition, monthly visits of quality teams are scheduled to verify that services are being performed correctly and that service check forms are being filled in properly.

The location of foundation elements in the site was made by a worker of the construction company, using benchmarks located by an outsourced topographer. The location method adopted was the contour method, which spikes are driven in the building contour, where wooden boards are nailed in. The alignments of the foundation elements are marked on the boards and, by stretching lines or wires in both directions, it is possible to locate the foundation elements (Veiga, 2017). The verification of the location was made by the construction engineer and also by an external engineer, in order to prevent the occurrence of errors in the location of the elements.

3.1. Spread footings

The execution plan of the footings was indicated in the geotechnical design of foundations of each block, based on their predicted settlement quotas. Footings that had deeper settlement quotas should be executed first, as recommended in NBR6122 (ABNT, 2010).

The geotechnical consultant recommended that the excavation should be done until finding a strong residual soil or an altered rock. In the case of footings settled on soil, it was necessary to perform the Manual Dynamic Penetrometer test. According to Custódio (2003), this test consists in the drilling of a bar with conical tip in the soil with blows of a hammer of 10 kg in a free fall of 23 cm. The penetration resistance index is the number of blows required to a penetration of 20 cm in the soil. The results obtained and photo of the surfaces on which footings would be placed were sent to the consultant. When it was approved, the execution of the lean concrete was allowed. Otherwise, it was necessary to continue the excavation to the new recommended depth.

After levelling the settlement quotas, the bases of the footings were placed and verified. The formworks should be assembled according to the dimensions specified in the project, guaranteeing their alignment and square. Before locking the formworks, the reinforcements were inserted.

The concreting of the footings was executed after cleaning the formworks and wetting them with water. The concrete abatement test was performed, as described in ABNT NBR NM 67 (1998). Also, there were prepared specimens for the compression test. After these steps, the concreting was started, using a needle vibrator to obtain a well-compacted concrete.

In general, the forms of footings were removed 24 hours after concreting. The footings' necks were executed and removed 24 hours after their concreting. The backfill was performed using mechanical socket for soil compaction.

One of the main difficulties found during the execution of the footings was the occurrence of intense rains in the period of its execution. According to the initial schedule of the enterprise, the footings of Block 1 and Block 4 delayed 7 weeks and 2 weeks, respectively. Often it was necessary to use pumps to drain the water and remove the soil that was deposited in the excavation. It was also necessary to relocate the footings that did not have the lean concrete executed.

In the execution of the footings of Block 4 an error occurred in locating a footing, in which its base was displaced in 5 cm. The solution found by the foreman to adequate the location of the footing's neck was to cut the bars from the left and glue them to the right using an epoxy-based adhesive, as shown on figure 1.

Figure 1. Inappropriate solution for footing location correction. Source: Authors (2016)

This solution was not appropriate, because the footing's neck is not centred with its base and that three bars replaced do not reach the bottom of the footing. Therefore, it is very important to follow the whole execution of the service, because if the trainee had not observed this, the neck would be executed and it could have compromised the performance of the structure. Finally, it was necessary to demolish this footing and redo it.

3.2. Steel piles

There were used two pile driving equipment, one had a hammer of 3,500 kg and a dropping height of 0.8 m and the other had a hammer of 5000 kg and a dropping height of 0.6 m. It was responsible for driving H-piles with the sections W150cmx37.1cm and W200cmx59.0cm.

The execution plan of piles driving was defined by the geotechnical consultant with the construction engineer. Usually the pile driving was initiated by the edge of the building. The main control made during the pile driving was the verification of the verticality of the pile by a worker of the construction company, using a plumb bob.

During pile driving, the outsourced foreman of steel piles was responsible for completing the steel pile driving register, according to the model provided by the geotechnical consultant, with information such as type of pile, hammer weight, pile identification, number of blows, pile set and elastic rebound.

The splicing of the piles was performed in the field using metal splice made from the profile itself.

The piles should be driven to the depth indicated by the geotechnical consultant. However, it was necessary to observe the maximum pile set of 3 mm per 10 blows, which is obtained by averaging the final five groups of ten hammer blows and provide the elastic rebound of the final ten hammer blows. After completing the pile cutoffs, the trainees and the construction company foreman measured the eccentricities of the piles.

The NBR 6122 (ABNT, 2010) establishes the need to perform load tests on a sample of the piles to verify its load capacity and condition of integrity. In construction site it was performed the PDA dynamic load tests on 15 steel piles. The main information obtained in this test was mobilized load, maximum displacement recorded, energy transferred to the pile and its integrity.

The connection between the pile and the pile cap was similar to the alternative solution proposed in ABMS/ ABEF (2009), in which the last 50 centimetres of the pile were wrapped in helical stirrups in a concrete block. Finally, the pile cap was executed above this element.

In Blocks 1 and 4, which had steel piles and footings, grade beams were executed connecting the pile caps and the footings, and finally a 10-centimenter slab was executed. In Blocks 2 and 3, which had only piles, a 30cm slab was executed on the pile caps.

During the execution of the steel piles, a series of inaccuracies were observed, including wrong H-pile section drilling, buckling of piles, inadequate pile set and high eccentricities.

In the cases where the section W200cmx59cm was driven instead of W150cmx37.1cm, the pile was approved. However, the section W150cmx37.1cm was driven instead of W200cmx59.0cm, the geotechnical consultant determined the addition of two extra piles, ensuring the coincidence between the centre of the pile cap and the pillar. These mistakes indicate that the steel pile foreman was not supervising the execution using the foundations project. As a result, it required the drilling of 16 extra piles.

The buckling problems occurred in piles with W150cmx37.1cm section, hammered with the 5000 kg with a dropping height of 0.60 m, in cases where the soil was showing great resistance to pile driving, as shown in figure 2. In this case the steel pile foreman should stop the pile driving before the permanent deformation of the profile. According to the geotechnical consultant, one of the causes of profile buckling was the non-uniformity of the stresses generated by the impact of the hammer on the helmet, which indicates that the hammer-helmet system should be set and the worn hammer cushion replaced.

Figure 2. Bucking of a steel pile with W150x37.1. Source: Authors (2016)

There was also a misunderstood made by the outsourced foreman of steel piles in the stop criteria of pile driving. He confused that the last ten blows obtained should be lower than 3mm, instead of the average of the last 5 groups of ten blows should be inferior to this value. For instance, in the pile E3061A of Block 3, although the last group of ten blows was 3mm, the average of the last 5 groups of ten blows was 9mm. Due to this confusion, it was necessary to repeat the pile set and elastic rebound in 16 piles of Block 3.

Although the error was made by the outsourced foreman, the geotechnical consultant or construction engineer should have instructed him prior to the service execution. In addition, the records of pile driving were delivered daily to the construction engineer, so it should not be necessary to repeat the pile set of 16 piles.

Eccentricity problem also occurred due to the displacement of the pile during its driving. It would be important that the outsourced foreman noticed this displacement, which was visible due to the cavities created by the pile driving. The cavities should have been backfilled with sand as recommended by the geotechnical consultant.

The piles with high eccentricities were checked individually by the geotechnical consultant and piles that exceeded the limits stipulated during the structural design required reinforcements. As the reinforcement report was received by the construction team after assembling the frame of pile caps, it was necessary to replace it, delaying the concreting of the pile caps. Therefore, it is important that the construction engineer send the eccentricities to the geotechnical consultant as soon as possible in order to receive the adjustments proposed on time.

3.3. Micropiles

For the execution of the micropiles, it was used a drilling equipment with a steel drill casing of 410mm (diameter). The drilling was performed under the injection of water.

At the end of the drilling, internal cleaning of the casing segments was performed using water circulation until the returning material had no excessive soil. Then the reinforcement was inserted. The cement grout was then injected from the bottom of the pile until the surface level, being interrupted when the cement grout had emerged clean. This sequence is in accordance with the ABEF (2012).

That reinforcement inserted in the micropile had already been assembled by the outsourced company of reinforcement and inspected by the trainees. It was settled at the bottom of the pile and should be over the surface level by 80 centimetres, which would be anchored in the pile cap lately.

During the micropile execution, the outsourced foreman of the micropiles was responsible for completing the micropile execution record for each pile. This document contains information such as pile identification, diameter, drilling depth and material classification, drilling time, cement proportion, injected volumes and reinforcement used.

The verticality of the pile was verified by the outsourced company responsible for the micropiles execution. Their eccentricities were obtained in a similar way that the steel pile. The verification of the integrity of the micropiles was made through an excavation of around 3 meters around a sample of it. In general, the failures observed were the responsibility of the construction company. Among them it is the lack of cement to fill the micropiles and the damage to the top of some piles.

An irregularity observed was the lack of cement in the construction site, which interrupted the activities during three days, delaying the completion of the service. The worker in charge of material requests should have identified the need for replacement in advance.

Due to the absence of isolation of the location where the micropiles were executed, heavy machinery circulated over them, damaging the longitudinal bars. In order to repair them, it was necessary to replace the damaged section of the rebar and to demolish the length of cement damaged. The section demolished was filled with cement of resistance not inferior than the one used in the execution, as it is recommended by NBR6122 (ABNT, 2010). These damages caused delays in the execution of the pile caps.

4. CONCLUSIONS

According to the analysis of the execution techniques implemented in the foundations of the case study, it is observed that the construction company presents a good control of the services in the construction site. Since these services are outsourced, the main responsibilities of the construction company are to provide a framework for the outsourced companies to execute the service with quality, presenting project guidelines, providing materials, monitoring the execution of the services and inspecting them. Therefore, analysing the practices adopted in the construction site under study it is possible to identify the main practices to be considered by a construction company toward minimizing execution errors in a foundation construction. The development of a document with the execution procedure for each type of foundation with a step-by-step description of the necessary activities is essential to standardize the execution of the service in the various construction sites of a construction company.

The engineer must schedule a meeting with the outsourced company responsible for the execution of a service. This meeting aims to discuss the execution procedure, the particularities of the project, the quality standards required by the construction company and other relevant matters. Filling out the service check forms by trainees is also a best practice to ensure the quality of the services. The strategy implemented by the company to ensure that the trainees would fill out the form properly was the requirement that the engineer fill out a service check form model with the trainees.

In relation to the footings, attaching photos of the surface where the footing would be settled to its Manual Dynamic Penetrometer test represents an important practice. Since geotechnical consultants often make sporadic visits to the construction sites, it helps them to have a greater control of the services that are being executed in the construction site and to provide adequate assistance.

In the case of piles, using execution records for each pile facilitates tracking the activities. It makes material consumption analysis, productivity and measuring for payment simpler.

The adoption of these practices is not a guarantee that a construction will present excellence in terms of the quality of its foundation. The presence of specialized, motivated and properly trained employees of the construction company is essential.

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Construction Safety Leadership: A Complexity Perspective

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Abstract

Even with improvements in safety management practices, the number of fatal and non-fatal injuries in the construction industry is unacceptably high. These injuries result in substantial losses, not only to workers and employers but also to the society as a whole. Thus, the construction industry remains a high reliability industry. However, disappointments in the results achieved by the classical safety management paradigm together with the evolution in several scientific disciplines have led to an emerging view of safety as something more than the negation of risk. This new paradigm for safety management is supported by an increased application of complexity theories to safety science. This paradigm views leadership styles as critical in the transformation of high reliability organisations and in improving safety outcomes. This research will be based on the principles of complexity leadership theory and will use a two-phased mixed method research design to understand how the behaviours of the complex leadership theory can influence safety leadership for construction professionals. The study is poised to demonstrate the relationship between safety leadership and complexity leadership theory, and the role that the construction industry play in supporting safety leadership.

Keywords: Safety Leadership, High Reliability Organisations, Complexity Leadership Theory.

1. INTRODUCTION

The construction industry in Australia accounted for 9% of total employment in 2017, with employment growing strongly by 18% over the five years to 2017 (more than double the rate of overall employment growth at 8%). Employment in the industry is projected to continue to grow at a higher rate than the average over the next five years, increasing by 11%. This growth is expected to be driven by strong infrastructure investment and non-residential building activity, along with continuing high levels of residential construction (albeit more in line with population growth). This industry includes three sub-industries: building construction (both residential and non-residential); construction services (site preparation, installation services, completions services); and heavy and civil engineering construction (Safe Work Australia, 2018).

Despite continual efforts to improve safety performance, the construction industry continues to account for a disproportionate number of occupational injuries. Apart from long-term physical and emotional distress to workers and their families, these injuries have a devastating economic impact on the sustainability of the industry (Albert, 2013). Every year, over 60,000 fatalities are reported from construction projects around the globe. Even with improvements in safety management practices, the number of fatal and non-fatal injuries in construction is unacceptably high. These injuries result in substantial losses, not only to workers and employers but also to the society as a whole. About 4% of the world's gross domestic product (US$1,251,353 million) is lost with the cost of injury and death. Thus, the construction industry remains a high reliability industry (International Labour Organisation, 2018).

Historically, the frequency and severity of injuries in the construction industry are greater than similar statistics in other industries. In addition to worker pain and suffering, the direct costs associated with workplace injuries can significantly reduce project revenues. Furthermore, injuries can have indirect costs in the form of elevated insurance premiums, increased regulatory intervention, project delays, declines in employee morale, and other adverse impacts (Baud, 2012).

To address the issue of poor safety performance and high injury rates, scholars and construction professionals have dedicated much effort to studying and identifying precursors to safety incidents. More specifically, researchers have reviewed and analysed construction injury reports to understand injury causal factors. Among these, *human factors* have received much recent attention. For example, Rasmussen (1997) found that human error is a key causal factor in 70% to 80% of safety incidents in construction. Haslam et al. (2005) reviewed 100 construction injury reports and found that over 70% of the injuries can be attributed to unsafe behaviour.

When occupational accidents occur, they may be either due to lack of knowledge, or training, or lack of supervision, or lack of rules implementation. All these factors have influence on the safety performance or weakening safety performance and the rate of accidents (Tharaldsen et al., 2010).

The way safety is managed in an organisation depends heavily on the beliefs and assumptions the management and personnel have concerning organisational behaviour and safety. Safety management has thus focused on identifying the possible ways things can go wrong, and then seeking to prevent such possible deviations by implementing barriers, emphasizing procedural adherence, creating redundant systems, supervising work and making clear the distribution of responsibilities (Ojuola et al, 2018). The numbers of accidents and other negative events, such as breakdowns, adverse events and process leaks, have been used as indicators of safety. This classical safety management paradigm views organisations as machine-like entities (Reiman et al., 2015).

However, disappointments in the results achieved by the classical safety management paradigm together with the evolution in several scientific disciplines have led to an emerging view of safety as something more than the negation of risk. This new paradigm for safety management is supported by an increased application of complexity theories to safety science (e.g. Dekker et al., 2014).

2. LITERATURE REVIEW

The literature review provides a clear understanding of the research topic by first discussing high reliability organisations. Secondly, safety leadership, complex systems and complexity leadership theory are discussed. Finally, the framework for complexity leadership theory is reviewed.

2.1. High Reliability Organisations

Three common themes have been identified as essential criteria for concluding that an organisation is a high reliability organisation (HRO). These organisations (1) actively manage *complex*, demanding activities; (2) have significant potential for catastrophic accidents; and (3) are able to achieve exemplary performance in both safety and reliability over a long period of time (Weick and Sutcliffe, 2011).

A key assumption of HRO theory is that significant accidents can be prevented through active management of prevention and mitigation activities. This is in contrast with the *Normal Accident* theory (Perrow, 2011) which holds that accidents are inevitable and expected to occur in complex systems in modern society. Systems that are tightly-coupled and interactively-complex are more prone to accidents. In such systems, according to Perrow (2011) catastrophic accidents are bound to happen. Charles Perrow, who coined the term “normal accidents,” recognized that some organisations are unusually adept at avoiding “normal” accidents. Similarly, HRO authors, such as Weick and Sutcliffe (2011), recognized that perfection, zero errors, flawless performance, and infallible humans are unreasonable expectations, and that errors and the unexpected are pervasive. Despite inevitable human errors, the HRO theory holds that management can establish sufficient and effective defences, controls, and barriers such that these errors do not propagate into significant accidents.

2.2. Safety Leadership

Accidents in any industry can cost tens of thousands of dollars for an organisation, but loss of profits pale in comparison to the human toll. When accidents occur in the construction industry, lives can be lost. (Eckle and Burgherr, 2013). This is why it is vital for corporate leadership to discover ways to improve safety performance. Leaders need to understand the cultural influences, social values, learning behaviours, and the different type of safety leadership behaviours necessary to improve safety performance (Cohen, Gottleib, Linn, and Richardson, 2011).

Safety in any organisation should be the leader's top priority. Approximately one million people around the world experience accidents in the workplace; and on a daily basis, more than 5,500 workers die from work-related accidents (Li et al., 2013). Leaders at the senior most level of any organisation should understand that strong safety leadership is essential to managing a hazardous business environment and is needed to ensure that risks are managed effectively (Guo, Yiu, and González, 2016). Dunlap (2011) found that "safety management must rise to be a core issue that leadership sees as an important area for which they are directly responsible" (p.45).

In recent years, interest in safety leadership has increased as researchers have consistently found that leadership is an important antecedent of employees' safety perceptions, attitudes and behaviours that drive HRO (Conchie and Donald, 2009). Safety leadership generally refers to a set of leadership behaviours that influence subordinates' behaviours to attain particular safety goals. Specifically, safety leadership can affect subordinates' behaviours on handling safety issues in both direct and indirect ways. The indirect ways could be the establishment of norms relating to safety practices and procedures, thus cultivating a particular safety culture. The direct ways could relate to their reinforcement of employees' safe behaviours through monitoring and control. As a result, these leadership behaviours directly and indirectly influence subordinates' expectations and motivations, thus influencing subordinates' safe or unsafe behaviours (Flin and Yule, 2004).

2.3. Complex Systems

According to Snowden and Boone (2007), complex systems incorporate myriad interacting elements. The interactions between these elements are non-linear and minor changes can cascade into large-scale consequences. Such systems are dynamic, with a whole greater than the sum of its parts. It is impossible to impose solutions or order upon them; rather, such novel forms arise from the circumstances within them (called *emergence*). The elements of complex systems evolve with one another, integrating their past with the present, and their evolution is not reversible. Due to the constant fluctuations and changes of external conditions and connected systems, complex systems are not predictable, although they may seem ordered and predictable in retrospect. As such, no forecasting or prediction of their behaviour can be made. This is due to the fact that the elements and the system itself constrain one another over time. Such mutually constraining behaviour is different than in ordered systems, in which the system constrains the elements, or in chaotic systems which have no constraints.

The contemporary view of safety emphasises that HRO should be able to proactively evaluate and manage the safety of their activities instead of focusing solely on risk control and barriers. Safety, however, is a phenomenon that is hard to describe, measure, confirm and manage. In the high reliability field there has been an increasing interest in organisational performance and organisational factors, because incidents and accidents often point to organisational deficiencies as one of their major precursors. Research has identified numerous human and organisational factors having relevance for safety. Nevertheless, the *human* and *organisational* factors are often treated as being in isolation from and independent of each other (Woods and Hollnagel, 2017).

2.4. Complexity Leadership Theory

Complexity leadership theory (CLT) is a framework that enables the learning, creative, and adaptive capacity of complex adaptive systems (CAS) in organisations. This framework seeks to foster CAS dynamics while at the same time enabling control structures appropriate for coordinating formal organisations and producing outcomes appropriate to the vision and mission of the system. It seeks to integrate complexity dynamics and bureaucracy, enabling and coordinating, exploration and exploitation, CAS and hierarchy, and informal emergence and top-down control (Uhl-Bien et al., 2007).

As described above, CAS are intensely adaptive and innovative (Marion, 1999). CAS obtain the flexibility to adapt that has been attributed to lose coupling and the capacity to coordinate from a more interdependent structure that is best described as moderately coupled (Marion, 1999). Moderately coupled interdependency (the actions of one agent are dependent on or limited by those of another) imposes restrictions on behaviour. Thus, flexibility and what might be called, *auto-coordination*, derives from informal but interdependent structures and activities (auto-coordination emerges from the nature of system dynamics and is not imposed by authorities).

2.5. Framework for Complexity Leadership Theory

The framework for CLT envisions three leadership functions that is referred to as *adaptive*, *administrative*, and *enabling* (Uhl-Bien et al., 2007). *Adaptive leadership* refers to adaptive, creative, and learning actions that emerge from the interactions of CAS as they strive to adjust to tension (e.g., constraints or perturbations). Adaptive activity can occur in a boardroom or in workgroups of construction workers; adaptive leadership is an informal emergent dynamic that occurs among interactive agents (CAS) and is not an act of authority. *Administrative leadership* refers to the actions of individuals and groups in formal managerial roles who plan and coordinate activities to accomplish organisationally-prescribed outcomes in an efficient and effective manner. Administrative leadership (among other things) structures tasks, engages in planning, builds vision, allocates resources to achieve goals, manages crises and conflicts, and manages organisational strategy (Mumford et al., 2008). Administrative leadership focuses on alignment and control and is represented by the hierarchical and bureaucratic functions of the organisation. *Enabling leadership* works to catalyse the conditions in which adaptive leadership can thrive and to manage the entanglement (described below) between the bureaucratic (administrative leadership) and emergent (adaptive leadership) functions of the organisation. Managing entanglement involves two roles: (1) creating appropriate organisational conditions (or enabling conditions) to foster effective adaptive leadership in places where innovation and adaptability are needed, and (2) facilitating the flow of knowledge and creativity from adaptive structures into administrative structures. Enabling leadership occurs at all levels of the organisation (as well as within the adaptive dynamic), but the nature of this role will vary by hierarchical level and position.

As shown in Figure 1 below, in CLT, the three leadership functions are intertwined in a manner that is referred to as *entanglement* (Kontopoulos, 2006). *Entanglement* describes a dynamic relationship between the formal top-down, administrative forces (i.e. bureaucracy) and the informal, complexly adaptive emergent forces of social systems. In organisations, administrative and adaptive leadership interact and may help or oppose one another.

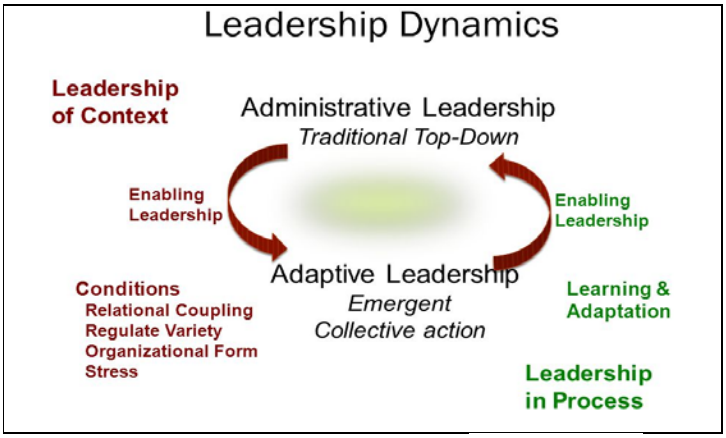

Figure 1. Leadership Dynamics (Mennin, 2010)

As evident in Figure 1, the administrative leadership can function in conjunction with adaptive leadership or can thwart it with overly authoritarian or bureaucratic control structures. Adaptive leadership can work to augment the strategic needs of administrative leadership, it can rebel against it, or it can act independently of administrative leadership. The enabling leadership function helps to ameliorate these problems; it serves primarily to enable effective adaptive leadership, but to accomplish this it must tailor the behaviours of administrative and adaptive leadership so that they function in tandem with one another.

3. CONCLUSIONS

This study consists of a two-phased mixed method research design poised to demonstrate the relationship between safety leadership and CLT, and the role that the construction industry play in supporting safety leadership. The first phase of the research will collect data from engineers, supervisors and project managers using a quantitative questionnaire survey of companies in the construction industry. The second phase of the study involves a series of qualitative case studies carried out to verify factor-level relationships.

As the study of CLT primarily focuses on the relationships between adaptive, administrative and enabling leadership, and their interdependencies, applying the same principles to safety and leadership provides guidance in practice and presents an alternative leadership model that enables managers in the construction industry to embrace leadership suitable for the twenty-first century. There is greater demand for leadership that understands and values the nature of this high level of interactivity as the traditional approaches are not only outdated but incongruent.

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The 3D Laser Scanning Technology Application within Construction Industry

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Abstract

Worldwide new technologies within the construction industry have been increasing significantly during the recent years. The advance of the BIM (Building Information Modeling) technology around the world incorporates the use of innovative types of equipment such as 3D laser scanners. This equipment read the space in 3D, take pictures and store information from the points read. This study presents a deeper perspective on the usage of these new technologies. The methodology includes the literature review and a case study using the FARO Focus 3D scan to map a building adopting three different scan algorithms:"non guided scan, semi-guided scan and guided scan. The case study served to present a detailed discussion on the topic of 3D scanning in an as-built detailing. It is possible to highlight the versatility of the new technologies, although it needs skilled labours for data manipulation in BIM models. The results indicated that, if properly used, 3D laser scanning can provide a significant increase in the productivity of the construction industry, from architectural projects to those of structure and installations.

Keywords: BIM, 3D laser scanner, data manipulation, as-built.

1. INTRODUCTION

3D scan technology uses scanners that project lasers and measures the distance between the object to the scanner. This process creates a point cloud data system that is used to create 3D models that can be exported to CAD software. These scanners are very similar to regular cameras, they have a conic sight and only can read what is visible (Guidini, 2017; Mostafa, 2011)

Scanning areas and buildings demands several scans to create a 3D model. Therefore, a sequence of scans must be made in order to catch enough parts of the scanned object. The process of making the 3D model by putting all the scans together is called "alignment" or "registration". (Bernardini, 2002)

1.1. Main Applications

The 3D technology combine a variety of applications in many different areas such as quality control, measurements, restoration of statues, forensic science and orthodontic prosthesis. (Sansoni, 2009)

1.2. Construction Applications

There are many applications in construction such as land surveying, offshore repairs, tunnel monitoring, bridge repairs and retrofit. 3D laser scanning is a very powerful tool in retrofit. According to the December report, about the construction market in the US, high precision and quick data collection make have differentiated 3D scans other methods of measurement and mapping, particularly in the construction. The report pointed out that the construction sector seeks to reduce project costs as the global technology market advances from $ 959 million in 2016 to an estimated $ 2.5 billion by the end of 2023 (Wood, 2016).

2. CASE STUDY WITH 3D LASER SCANNING

2.1. Objectives

The Arizona State University "CAVC" building is approximately 3,321 m^2 in area and 288 m in perimeter, located at 660 S College Commons Avenue within the campus itself. LEED Gold certification was achieved, where the building achieved the highest levels of energy efficiency, performance, use of resources and materials, community connectivity, innovative design, quality of internal environment, water resources efficiency and reduction of heat islands' impact.

The research consisted in performing external 3D scans of the university's "CAVC" building through two Matlab algorithms created to demonstrate its efficiency and to prove the productivity gains in the field when compared to scans without the algorithms.

2.2. Methodology

For the execution of the scans, a plan of implementation was divided in three stages with two series each taking into account the algorithms. The steps consisted of scanning the building three different ways twice. The first one was called "non guided scan", no algorithm was used. The second was called "semi-guided scan", was used a range algorithm. Finally, the last one, called guided scan, was used a positional algorithm.

Each algorithm required different input data. The first one used required the distance from the scanner to the object to be scanned, the level of detail, the resolution, the height of the building and the scanner to provide a view of the scanning range at the chosen distance. The author did not have access to the input data of the second algorithm, but he provided the position of the scanner in relation to the building and the resolution suitable for scanning.

The equipment operated for the execution of the scans was only the FARO Focus 3D scanner and signaling cones to delimit the scanning area to mitigate the traffic of people. The programs used in the process were the FARO Scene, program provided by the manufacturer of the scanner for the manipulation of the data and MatLab, for the execution and programming of the algorithms.

The entire process was done between the months of June and July and the time of execution of the scans varied according to the stage and the weather conditions.

2.3. Non Guided Scans

In this step, the objective is to simulate the process of scanning against an unhandled operator with the 3D scanner. To do this, the scans were carried out around the building without the aid of algorithms and manuals, timing the time spent by the scanner and the route as well as the number of scans required for data generation.

The calibration of the equipment is very simple. In this phase the tripod is positioned that will support the 3D scanner in an approximate way, without algorithms that detail this positioning. After the positioning, the tripod liming is done, verifying if the spherical bubble is in the plumb. Finally, the resolution and quality for the scans, in this case, of 1/4 and between 3x and 4x respectively, are defined in the scanner.

The total time of data collection lasted 2 days due to the availability of the equipment. In the first series, 14 scans were performed and the process lasted 2 hours and 34 minutes for the complete process. In the second series, to be more precise, 19 scans were done in 2 hours for the complete process.

The process for generating the digital models took about 2 weeks to be ready due to the size of the data, the number of scans and the configuration of the computers used. The "Registration" process consisted in loading the data from the scanner to the computer (load scans), preprocessing them to prepare the points for the preprocessing and to perform the assembly of the scans (place scans). A manual process of data organization is done before, so the program automatically performs the "Registration" process.

Figures 1a and 1b show that it is possible to identify the enormous amount of scans around the building represented by the red dots. Figure1c and 1d show the verification viability of the 3D model of the building after the registration process.

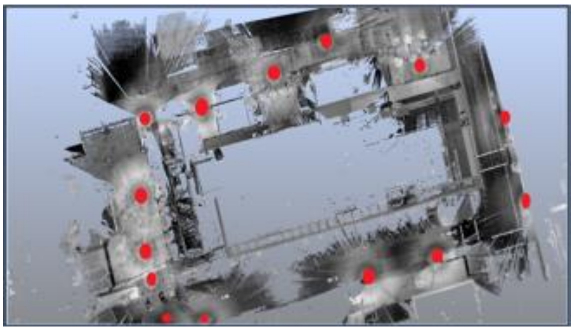

Figure 1a. Position of 14 scans

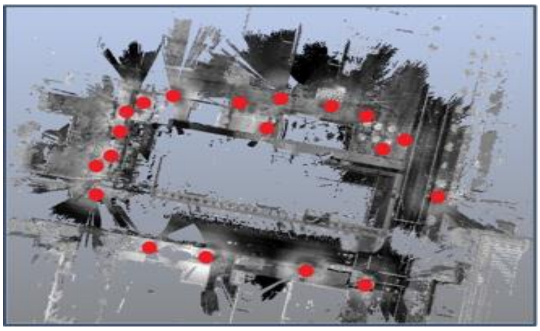

Figure 1b. Postition of 19 scans

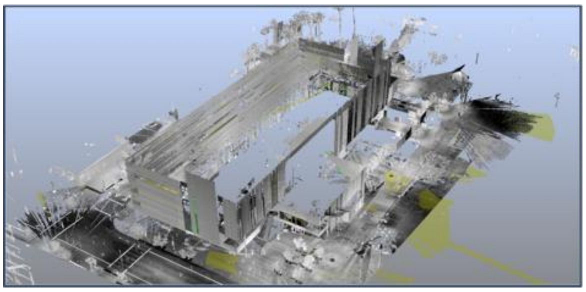

Figure 1c. Model of 14 scans

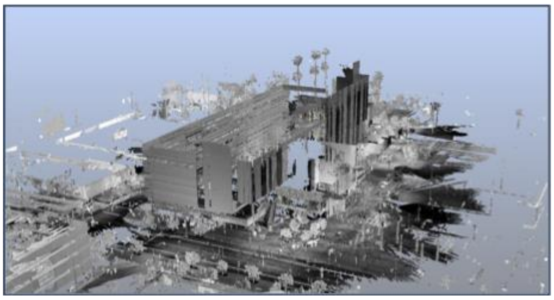

Figure 1d. Model of 19 scans

2.4. Semi Guided Scans

In this step, the objective is to simulate the scanning process around the building with the previous aid of algorithms, manuals and a plan of implementation, recording the time spent by the scanner and the route as well as the number of scans necessary for the generation of data. This step was developed to evaluate the results of the program based on the positions of the scanner that would obtain the best scans with the adjustment of the resolution according to the distance of the wall.

The calibration in this phase is done by positioning the tripod that will support the 3D scanner according to the manuals and algorithms guides. After the positioning, the tripod liming is done, verifying if the spherical bubble is in the plumb. Finally, the resolution and quality for the scans, in this case, of 1/4 and between 3x and 4x respectively, are defined in the scanner.

The algorithm is created using a MatLab´s graphical interface that facilitated the insertion of the data (see Figure 2).

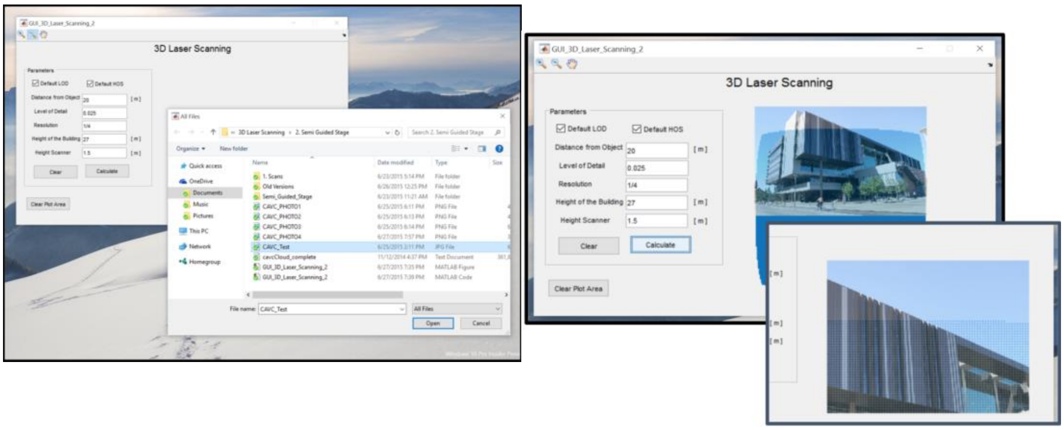

Figure 2. On the left is the algorithm user interface and on the right is the algorithm range.

The input data for the algorithm was collected through three mobile applications called EasyMeasure, CamMeasure and SmartMeasure, the first two for ios and the last for android. EasyMeasure provided the distance of the scanner to the object and CamMeasure the height of the scanner. SmartMeasure provided both data at once**.**

The scanning lasted 3 days due to the availability of the equipment. In the first series, 9 scans were performed and the process lasted 2 hours and 10 minutes for the entire process. In the second series, to be more precise, 8 scans were made lasting 1 hour and 37 minutes for the complete process.

The process of generating the digital models took about 1 week to be ready due to the size of the data, the average number of scans and the configuration of the computers used. The "Registration" process was repeated in the same way as in the first phase, which consisted in loading the scanner data to the computer (load scans), pre-processing them to prepare the points for preprocessing and performing the assembly of the scans (place scans). A manual process of data organization is done before, so the program automatically performs the "Registration" process.

In this step, it was evident the reduction of the number of scans in relation to the first step, although the data and processing time were similar.

Figures 3a and 3b show the number of scans around the building lower than the process presented in Figure 2. Also, It is viable to verify the 3D model of the building with the same quality after the registration process even with a lower number of scans.

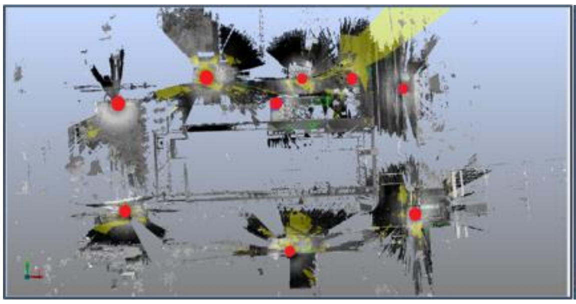

Figure 3a. Position of the scans.

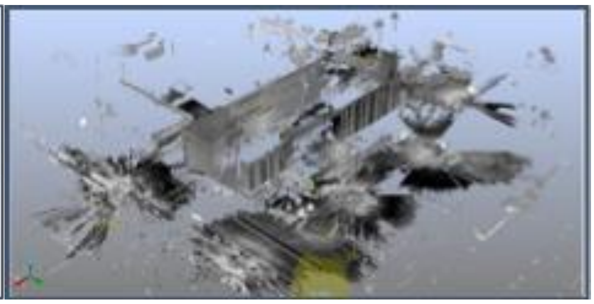

Figure3b. Model generated.

2.5. Guided Scans

This phase consists in performing the scanning process around the building with the aid of a precise algorithm, which will tell exactly the number of scans required in different resolutions and the position of the scanner in relation to the building. It will again timing the time spent by the scanner and on the path. This step was developed to evaluate the effectiveness of the algorithm capable of generating a scan map around the building.

The calibration in this phase is done by positioning the tripod that will support the 3D scanner with an accurate position algorithm that accurately specifies where the 3D scanner should be positioned and automatically generate the required resolution and quality. After the positioning, the tripod liming is done, verifying if the spherical bubble is in the plumb.
Figure 38 shows the scanning plane that must be performed to obtain the best efficiency.

The data were collected in 1 day. Six scans were performed and the process lasted 1 hours and 27 minutes. Another scan was made to be more precise with the same 6 positions in the same time of 1 hour and 27 minutes.

The process of generating the digital models took about 1 week to be ready due to the size of the data, despite the small number of scans and the configuration of the computers used. The "Registration" process was repeated in the same way as in the first and second phases, which consisted in loading the scanner data to the computer (load scans), preprocessing them to prepare the points for preprocessing and performing the assembly of the scans (place scans). This process was done automatically by the program but beforehand a manual data organization process was carried out.

At this stage it was possible to prove the efficiency of the algorithm. With only 6 scans in a time less than those mentioned in the previous steps, it was clear that this is the most efficient option.

In Figure 4a and 4b it is possible to visualise the number of scans around the building much lower than the process presented above. It is possible to verify the 3D model of the building with the same quality after the registration process even with a much lower number of scans.

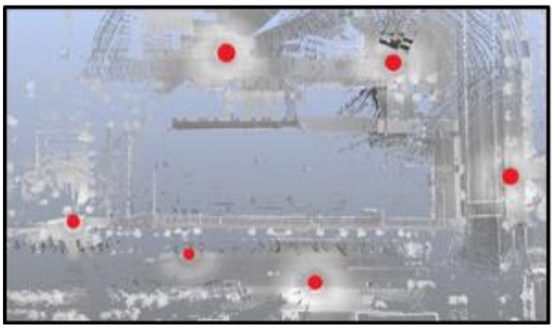

Figure 4a. Position of the scans

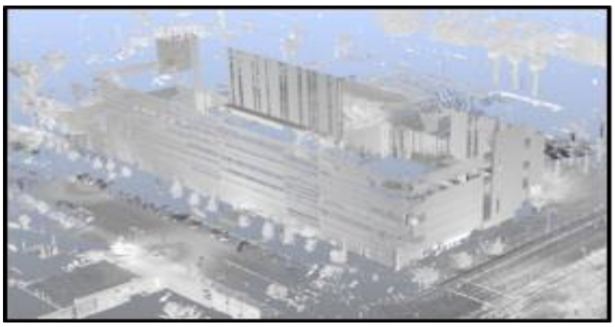

Figure 4b. Model generated

2.6. Comparison between the processes

The most important aspects of the study are that the algorithms play a significant role in the scanning process. As can be seen at table 1, it is evident its influence in reducing the phase-to-phase scanning time and saving time to the construction schedule.

Table 1. Comparison between the 3 different scanning processes

Sets	**Method**	**No. of Scans**	**Time (h)**
Non Guided	No Algorithms	14	2:34
		19	2:00
Semi Guided	Range Algorithm	9	2:10
		8	1:37
Guided	Range and Position Algorithm	6	1:27
		6	1:27

3. CONCLUSIONS

3D scanning is still the technology of the future even in developed countries. They have access to these innovations quickly. However, like all new technology, its adhesion depends on several external factors to be implemented, such as the cheapness of its components and programs. Algorithm

They range from forensic medicine to civil construction. Because of this, there are a large number of scanners and methods in their respective fields of application.

Although it has a high cost of implementation because it demands a very high performance equipment, needing computers that accompany this requirement, avoiding interferences between projects and being able to change them quickly and efficiently is the greatest benefit this technology can provide.

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Resilient safety culture: A modelling perspective

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Abstract

Resilience in organizational safety culture is what is needed in today's dynamic work environment. This resilience first needs to be identified, modelled and then quantified to be able to identify where the weakness lies in the safety culture. In this paper, resilient safety culture is identified using three sub systems and associated factors as gathered from the published literature. The three sub-systems are psychological, behavioural and managerial capabilities. The paper proposes adopting complex network theory to model the dynamic work environment. It argues that using this technique would allow for driving the relative probability for safety culture using the three sub-systems which in turn are inter-related using parallel and progressive relationships.

Keywords: resilient safety culture, complex network theory, quantification, modelling, risk

1. INTRODUCTION

1.1 Safety

Safety is defined as the absence of accidents where accident is an event which lead to unacceptable loss (Leveson, 2011). Safety is a system property and not component level property. In the past, the product designs were manageable as the components interactions were understood properly but now it is getting hard due to complexity in the system. This complexity has introduced new challenges. Since, there is no full control over the socio-technical system, complexity is not taken into consideration when designing the safety systems (Shirali, Motamedzade, Mohammadfam, Ebrahimipour, & Moghimbeigi, 2016). Previously, most systems employed conventional risk management techniques to deal with risks which were based on knowledge of previous experiences, failure reporting and risk assessments by computing historic data. But today, these are traced to organizational factors, functional performance variability and unexpected outcomes (Shirali, Shekari, & Angali, 2016).

There has been an evolution from past theories in safety management which contributed to the knowledge. Each stage was not left behind but was built upon which was already there. There has been five eras of safety management. First is the technological era, second is the behavioural and human factors, third is the socio-technical era, fourth is the cultural and fifth and latest is the resilience engineering era (Pillay, Borys, Else, & Tuck, 2010). There are various research papers which emphasise the causal link between risk and variability as a starting point of resilience. Primary risk areas is personal risks, risks due to errors committed , risks due to insidious accumulation of latent conditions within the maintenance, managerial or organizational spheres, risk due to third parties (Reason, 2016).

1.2. Organizational resilience

Resilience in the system is what is required to bounce back from any strain in the system (Tinmannsvik, Oien, & Storseth, 2009). Resilience is sometimes called resilience engineering or RE. Resilience engineering is recognized as other alternative to traditional approaches in safety management. One of the definitions of resilience engineering is "*intrinsic ability of a system to adapt its function before or* *after the mishaps so it can continue to work under both expected and unexpected conditions"* (Hollnagel, 2013). The challenge for health and safety is to draw up prevention strategies which adequately address complex, dynamic and unstable systems (Bergström, van Winsen, & Henriqson, 2015). The idea behind resilience engineering is that an organization must continually manage risks and create an anticipating, monitoring, responding and learning culture. Pillay et al. identified three dimensions of organizational resilience: cognitive, behavioural and contextual. Figure 1 shows the structure of organizational resilience.

Figure 1. Organizational resilience structure

Cognitive capabilities notices and interprets uncertain situations, analyses and formulate responses. Organizations with cognitive capabilities encourage ingenuity and develop new skills. Behavioural capabilities moves the organization forward that means it enables a firm to learn about the situation and fully utilize its resources. Firm having choices of different actions it can take and easily adopt to market shifts in unexpected situations. Contextual capabilities provides the setting for integrating cognitive and behavioural capabilities. It consists of connections and resources. This organizational resilience influences an organizational response to environmental change. It encourages the firm to develop varied repertoire of routines for responding to uncertainty and complexity in the system. It also encourages the firm to think about its environment such that it can improve its ability to determine the content and duration of change (Lengnick-Hall & Beck, 2005).

1.3. Safety culture

Safety culture is branched out of organizational culture (Trinh, Feng, & Jin, 2018.) Organizational culture is considered to be the "top-management business". A term used as observed in behavioural regularities when people interact, formal philosophy, rules of the game, organizational climate, embedded skills, habits of thinking paradigms (Choudhry, Fang, & Mohamed, 2007). Many studies have been done on safety culture but it has been seen that safety culture is not fully understood. Safety culture is divided into many sub-cultures as seen in figure 2. It shows the safety culture with other cultures in inter and intra-relationships (Reason, 2016). This can be due to focusing only on "just culture" and disregarding resilience aspect. The main drawback is the dynamic aspect of the culture is not taken into consideration interaction between people, technology and administration (Shirali, Shekari, et al., 2016).

Safety management, safety climate and safety culture are terms which are used interchangeably but they are all different. Safety climate is dependent on safety culture (Choudhry et al., 2007). Safety management is documented and formalized system of controlling against risk but the actual safety management system cannot reflect actual practice. That is where the term safety culture is used. It is the safety culture that influences the deployment of safety management resources, procedures which represent the actual work environment.

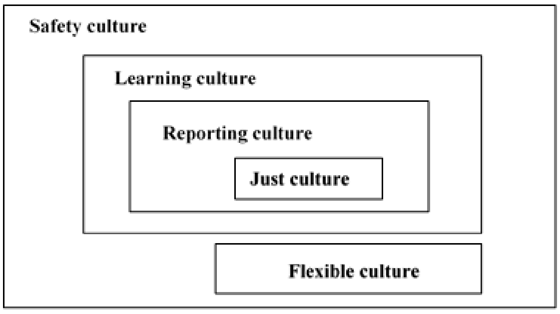

Figure 2. **Safety culture and its relationship with other culture types (Reason, 2016)**

Learning culture is how much does an organization respond to problems with denial versus modification (Hollnagel, 2013). It involves organizational learning, organizational memory, learning from accidents and disturbances, observations, investigations, risk analysis and research (R Akselsson, Koornneef, Stewart, & Ward, 2009). Reporting culture is subset of learning culture since learning from any incidents can't be done without good reporting. Reporting culture is cultivating an atmosphere where employees have confidence to report safety-related issues without fear of blame. Reporting culture brings about a just culture, which is motivation for reporting, user-friendly forms of reporting, good training, feedback from reports, a regular follow-up by management (R Akselsson et al., 2009). Just culture is an atmosphere of trust that workers are encouraged to report essential safety concerns and issues but also gross negligence, wilful violations, and destructive acts which are not tolerated. Flexible culture involves shifting from bureaucratic mode to a mode where knowledge, skills and abilities counts who leads the task in challenging situations and shifting back again when the challenges are gone (Roland Akselsson, Ek, Koornneef, Stewart, & Ward, 2009).

Safety culture is also defined into three groups: psychological aspect, which is about safety climate and how people feel, behavioural aspect which is what people feel and situational aspect talks about safety management system and what organization has as a structure (Roland Akselsson et al.,2009). The situational aspect deals with the structure of the organization, its policies, procedures, management systems, behavioural aspect is measured through peer observations, self-reporting and outcome measures. The psychological aspect is very critical and is measured by safety climate questionnaires to understand the employees' perception of safety. Figure 3 shows a safety culture model which recognize the presence of an interactive or reciprocal relationship between psychological, situational and behavioural factors (Cooper, 2000).

Understanding figure 2 and figure 3, it has be explained by some authors that psychological/ cognitive capabilities come under just culture, behavioural capabilities come under reporting culture, managerial/ contextual/ situational capabilities come under flexible and learning cultures (Cooper, 2000; Reason, 2016).

Figure 3. Safety culture structure as perceived by many authors

1.4. Resilient safety culture

Resilient safety culture is a new concept which has been proposed in order to cover the weaknesses of safety culture. It is a safety culture with resilience, learning, continuous improvements and cost effectiveness (Shirali, Shekari, et al., 2016). Resilient safety culture is based on three factors: 1) Psychological/cognitive capability 2) Behavioural capabilities and 3) Managerial/contextual capabilities to anticipate, monitor, respond and learn in order to manage risks in a resilient organization. The psychological/ cognitive resilience or capabilities of an organization that enables an organization to notice shifts, interpret unfamiliar situations, analyse options and figure out how to respond. Psychological resilience relate to sustaining pressures in a company environment. It is a personality trait. Behavioural resilience of an organization comprise of established behaviours and routines that enable an organization to learn more about the situation, implement new routines and fully use its resources. Managerial / contextual resilience is combination of interpersonal connections, resource stocks and supply lines that provide a foundation of quick actions (Lengnick-Hall, Beck, & Lengnick-Hall, 2011).

Analysing figures 1, 2, 3, it is found that "just culture" can only happen when there is "reporting" and "learning" cultures so it is subset of "behavioural" and "managerial capabilities" and is shown with special arrows as seen in figure 4. This figure is proposed by authors after understanding the current literature on organizational resilience, safety culture and resilient safety culture. This figure will be used in building up a resilient safety culture network model. This relationship justifies the accident causation model which explains the interactive relationship between psychological, situational and behavioural capabilities. The accident causation model are of three types-simple linear, complex linear and complex non-linear models. Examples of simple linear models is simple domino effect, Swiss cheese model for complex linear model and STAMP or FRAM for complex non-linear model.

Once we have identified a resilient safety culture model, we would like to measure this network model. Measuring resilient safety culture is through use of application of qualitative as well as quantitative data or their combination (Cooper, 2000). Complex network theory is used to quantify the resilience and use this new complex relationship between various cultures to understand this concept in more detail. It is used to account for the dynamics in the network.

Figure 4. The network of resilient safety culture

2. RESEARCH METHODOLOGY

2.1 Complex network theory

Complex network theory has been used in various fields and its examples are abundant specially for denoting network dynamics (Yang, Liu, Zhou, Li, & Sun, 2015). Many examples have tried to mimic the dynamic behaviours found in real world networks (Holme, Kim, Yoon, & Han, 2002). Complex network theory can be used to quantify the interactions of various components in a safety system. The structure and topology characters of the system strongly effects the dynamic behaviour of the system. There are three types of networks: regular, random and network in between that are scale free networks and small world networks (Chen, Zhang, & Cao, 2016).

Regular network is formed based on a rule that every node only connects to its neighbour's nodes. Random network is formed by randomly selecting several lines from connected ones (Barabási & Albert, 1999). Random networks assume that graph starts with fixed number of N vertices that are randomly connected without modifying N. Scale free network and small world networks are between regular and random networks. Both these networks are common to many real world complex networks. Scale free network does not have typical degree in the network. That means the degree distribution follows a power law which means hub nodes having high degree and secondary nodes having low degrees (Ji, Zhang, & Fan, 2014). Degree means number of link edges.

System engineering theory is used to model the resilient safety culture. The system contains different units, while units can group as a whole (Zhang & Wang, 2014). To model the resilient safety culture as a system, some modelling principles are followed. There are two relationships between factors: parallel and progressive. These two progressive and parallel relationships are shown in figure 5 and 6. The parallel relationship makes dependent factors together to make a superior factor as shown in figure 5. Factor A is on higher level than factors A_1, A_2, A_3 as information at A is based on information from A_1, A_2, and A3. The reliability probability of factor A is weighted by summation of probabilities of A_1, A_2 and A_3. In the progressive relationship as shown in figure 6, the factors happen to be in sequence order. As shown, factor B is on higher level than B_1, B_2, B_3, while B_2 happens behind B_1 and B_3 happen behind B_2. The reliability probability of B is the product of B_1, B_2 and B_3 probability (Chen et al., 2016).

Using figure 4, 5 and 6, we develop network model to quantify the whole system as well as for the subsets. We further break down the subsets of the resilient safety culture in more detail to find the dependent variables and factors. Figure 7, 8 and 9 shows the network models developed using the relationships defined. Let's look at each factor in detail.

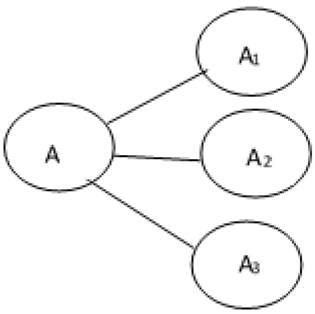

Figure 5. Parallel relation

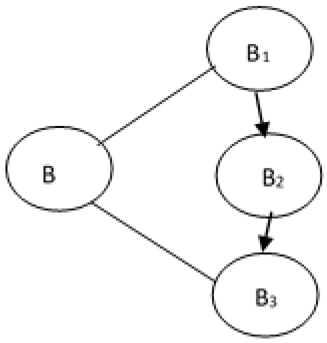

Figure 6. Progressive relation (Chen et al., 2016)

2.2. Psychological capabilities

Psychological/ cognitive capabilities of organizational resilience is based on constructive sense making and conceptual orientation (Akgün & Keskin, 2014; Lengnick-Hall & Beck, 2005). Figure 7 shows the network of psychological/ cognitive resilience of an organization. Organizations can foster a positive, constructive conceptual orientation through a strong sense of purpose, core value, a genuine vision and a deliberate use of language (Collins & Porras, 2005; Freeman, Hirschhorn, & Triad, 2003). Strong core values coupled with sense of purpose and identity encourage an organization to frame conditions in ways that enable problem solving and action rather than in ways that lead to either threat rigidity or dysfunctional escalation of commitment (Coutu, 2002.; Sutcliffe & Vogus, 2003). Constructive sense making enables firms and employees to interpret and provide meaning to unprecedented events. Collective sense making relies on language of organisation to construct meaning, describe situations and imply both understanding and emotion. It requires attitude that balances the contradictory forces of confidence and expertise against scepticism, caution and search for new information. Each situation is unique and contains features that may be subtle but that can be powerful in shaping consequences, relations and actions (Thomas, Clark, & Gioia, 1993; Weick, 1995). The mindset that enables a firm to move forward is blend of expertise, opportunism, creativity and decisiveness despite uncertainty.

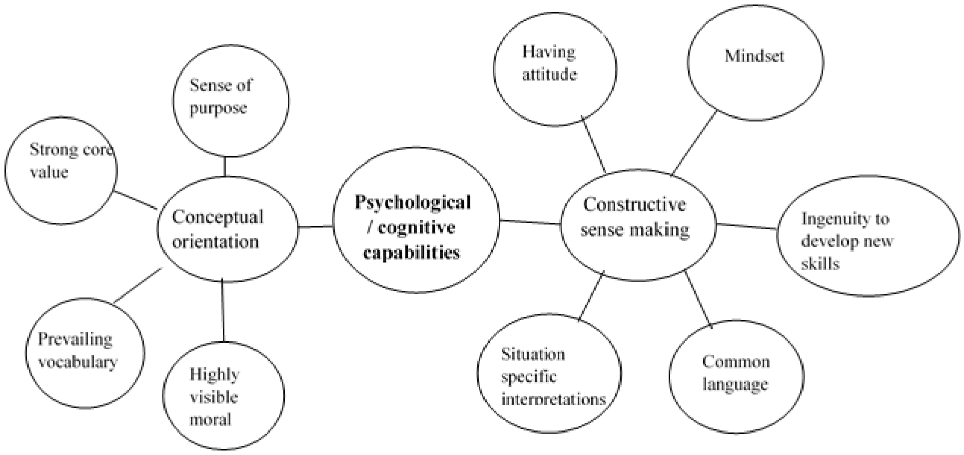

Figure 7. The network of cognitive capabilities of an organization

Cognitive foundations require a strong knowledge on reality and desire to question fundamental assumptions. The ability to conceptualize solutions which are novel and appropriate is desired (Lengnick-Hall et al., 2011).

2.3. Managerial capabilities

Managerial / contextual capabilities of an organizational resilience requires relationships within and outside an organization to facilitate effective responses to environmental complexities. It contains psychological safety, deep social capital, diffuse power and accountability and broad resource networks (Akgün & Keskin, 2014; Lengnick-Hall & Beck, 2005). Figure 8 shows the network of managerial resilience in an organization. Psychological safety is the degree to which people perceive their work is conductive to taking interpersonal risks. When people perceive psychological safety they are more willing to take these risks. Climate of psychological safety need to be established for organizational resilience (Edmondson, 1999). Deep social capital evolves from respectful interactions within the organizational community. Interactions which are rooted in trust, honesty and self-respect. These interactions build informal intimacy and creates collaborative sense making. It facilitates growth in intellectual capital. Also, it enhances resource exchange. It also eases cross functional collaboration between different kinds of people in an organization. It also enhances deep bonds beyond immediate transactions and creates long term partnerships. Finally, it creates network of support and resources (Adler & Kwon, 2000; Ireland, 2002; Weick, 1993).

Diffused power and accountability is another factor associated with creation of managerial resilience. Resilient organizations are not managed by hierarchical structures but by self-organization which create holographic structure where each part is small replica of the whole organization. Resilient organizations share decision making widely. Each replica has discretion and responsibility for attaining best organizational interests (Mallak, 1998; Morgan, 1999). Broad resource network is the main element in the managerial capabilities of resilient organization. Resilient individuals have ability to forge relationships with others likewise resilient firms share relationships with supplier and strategic alliances for sharing resources. Resources gained through the network sharing promotes an assortment of interpretations for alternative applications of these resources. This leads to innovation leading to cultivation of constructive sense making (Judge, Fryxell, & Dooley, 2000; Lengnick-Hall et al., 2011).

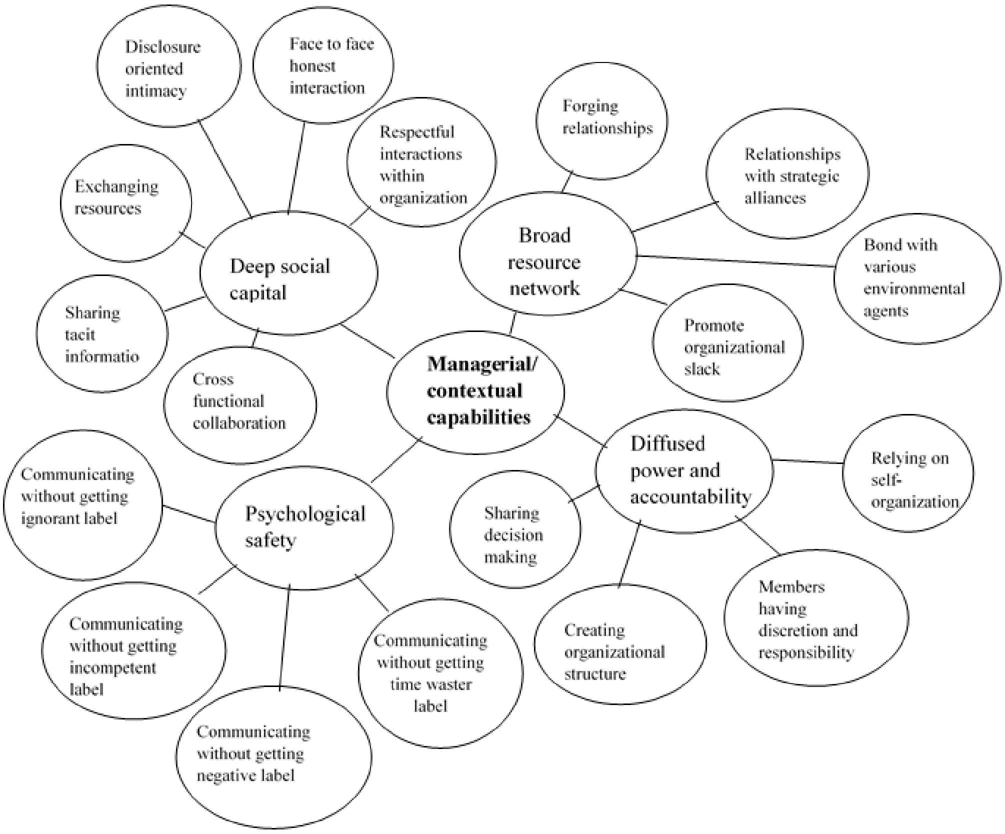

Figure 8. The network of contextual capabilities of an organization

2.4. Behavioural capabilities

Behavioural capabilities of organizational resilience is based on behaviour which helps get rid of any problems they face with their own ability and resources. Learned resourcefulness, ingenuity and bricolage are all the characteristics which are needed to cope with various challenges (Akgün & Keskin, 2014; Coutu, 2002). It can be developed using practiced resources fullness and counterintuitive agility along with useful habits and behavioural preparedness (Lengnick-Hall & Beck, 2005). The ability to follow dramatically different course of action from what is the norm is behavioural elements of organizational resilience. Figure 9 shows the behavioural resilience of an organization in a network form.

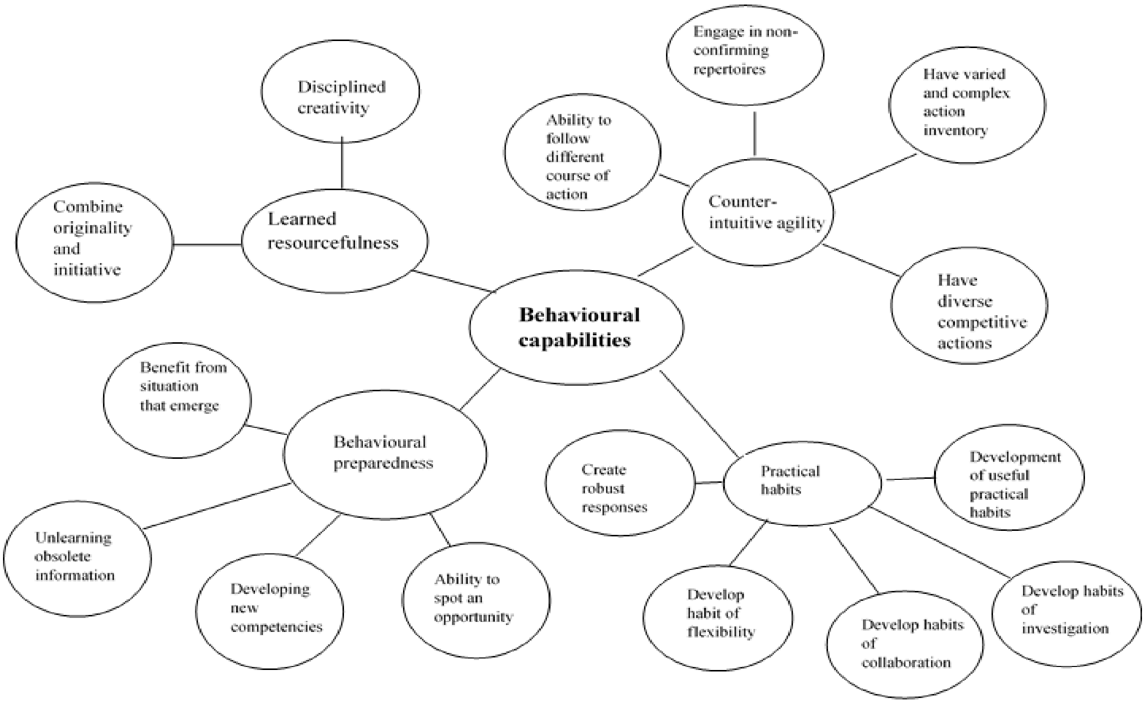

Figure 9. The network of behavioural capabilities of an organization

Behavioural resilience also relies on development of practical habits which are useful which provide first response to an unexpected threat. Organization which develop values that lead to habit of investigation as compared to assumption, routines of collaboration rather than antagonism and traditions of flexibility rather than rigidity. Behavioural preparedness helps bridge gap between divergent forces of learned resourcefulness and counterintuitive agility and convergent forces of useful habits. It also means organization learns from situations that emerge and unlearns obsolete information. Behavioural preparedness enables an organization to quickly spot an opportunity which others might miss. These organizations translate thoughts into actions (Ferrier, Smith, & Grimm, 1999; Miller & Chen, 1999).

It is seen that figures 7, 8 and 9 gives breakdown of sub-systems of resilient safety culture. An example is used to illustrate how the relative probabilities of these factors are calculated. Figure 10 shows a simplified example of behavioural capabilities (figure 9) network using complex network theory.

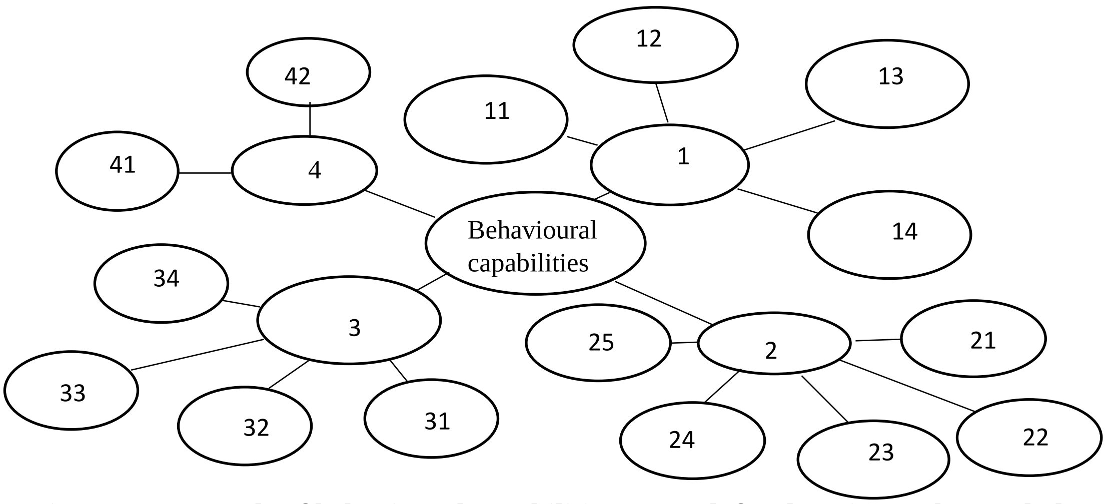

Figure 10. **Example of behavioural capabilities network for denoting nodes symbols**

Equation 1 shows the superior factor's probability which is calculated using summation of weighted inferior factors (Chen et al., 2016).

$$P = \sum_{i=1}^{n} a_i p_i \quad (1)$$

P is the relative probability of superior factors, a is the factor weight and p is the probability of that factor. The reliability probability of this sub-system is calculated as follows using equation 1. P is the total probability of this sub-system where as p_1 is the probability of the node 1 which is calculated using the equation 1 and 2 relationships using p_{11}, p_{12}, p_{13}, p_{14} likewise other probabilities like p_2, p_3, p_4 can be calculated. The weight of node 1 is a_1 whereas a_{11} is the weight for node 11. Equation 2 calculates the probability for parallel relationships which means happening together.

$$P = a_1p_1 + a_2p_2 + a_3p_3 + a_4p_4 \quad (2)$$

$$p_1 = a_{11}p_{11} + a_{12}p_{12} + a_{13}p_{13} + a_{14}p_{14}$$

$$p_2 = a_{21}p_{21} + a_{22}p_{22} + a_{23}p_{23} + a_{24}p_{24} + a_{25}p_{25}$$

$$p_3 = a_{31}p_{31} + a_{32}p_{32} + a_{33}p_{33} + a_{34}p_{34}$$

$$p_4 = a_{41}p_{41} + a_{42}p_{42}$$

Comparing figure 9 and 10, node 1 denotes "counterintuitive agility", node 11 denotes "ability to follow different course of action", node 12 denotes "engage in non-conforming repertoires", node 13 denotes "have varied and complex action inventory", node 14 denotes "have diverse competitive actions". Similarly other nodes are denoted.

By using this method, other two remaining sub system's relative probability can be calculated. So the relative probability of the whole system of resilient safety culture can be calculated using equation 3. Using equation 3, relative probability of the progression relationships is calculated which means factors happen in-sequence. Superior factor's probability is the product of inferior factors.

$$P = \prod_{i=1}^{3} p_i \quad (3)$$

3. CONCLUSIONS

Based on complex network theory, it can measure relative probability of the subsystems as well as the systems as a whole to find out how much resilient the safety culture is in an organization. The progressive and parallel relationships make a huge difference when calculating relative probabilities and it all depends on how the network is formed based on the relationships between the subsystems and factors. To balance this network, resources are allocated to those subsystems or variables where the weight is high, this helps resulting in enhanced resilience along with a balanced system. This approach gives the users to focus on weak areas of the safety culture in an organization which enhances the resilience.

4. FUTURE WORK

Future work will deal with empirical study for finding the reliability probability of an organizational resilient safety culture and compare it with other similar companies or units. It will also generate different networks based on which factors are prevalent for that particular organization. This is done by generating a survey related to the company and safety programs, collecting the data and analysing the results and providing recommendations for improving the safety culture by making it more resilient.

5. ACKNOWLEDGEMENTS

This paper was supported by funding from International post graduate research scholarship and post graduate research scholarship from Griffith University.

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Sustainable Construction Project Decision-Support tools: Integration of Life Cycle Sustainability Assessment and Multi-Criteria Decision Making

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Abstract

Even though the literature has explored avenues for reducing environmental impacts of the construction industry, there is still a lack of analysis that simultaneously examines environmental, social and economic aspects. One of the major reasons why this is not commonly attempted is due to challenges in deciding on appropriate weights to associate with all considered criteria, especially when trade-offs in the analysis exist. In addition, the impacts need to be assessed throughout the entire life cycle of the project, starting from the extraction of the raw materials used, to the stage of dismantling the building. To address this gap, this paper proposes a decision support system that integrates Life Cycle Sustainability Assessment (LCSA) with Multi Criteria Decision Making (MCDM). While LCSA is related to the evaluation of all impacts generated throughout the life cycle of the building, the MCDM approach is useful in helping to decide the best alternatives to adopt for a given project. A framework that describes the steps to be taken to integrate these approaches is presented.

Keywords: Life Cycle Sustainability Assessment, Multi Criteria Decision Making, Sustainable Construction.

1. INTRODUCTION

The construction sector is known to be an industry that consumes an exorbitant amount of resources, in addition to generating diverse environmental impacts (EEA, 2010). For this reason, in the last decade, professionals have been more concerned with creating more sustainable construction projects. However, sustainability is not only concerned with environmental issues, as it involves an interaction between a triple bottom line framework comprised of social, economic and environmental factors (Alhaddi, 2015).

Economic and social issues are crucial for sustainable development which also deserve special treatment (Sjostromand Bakens, 1999). In order to enhance the sustainability of construction, it is important to simultaneously account for all sustainability pillars in a fully harmonious way. In addition, it is imperative that the concern to minimise the impacts is related to the whole project life cycle, from the extraction and processing of the raw materials, to the final disposal of the project (or its elements). This gave rise to the life cycle analysis approaches, focusing on environmental, economic and social impacts throughout the various cycles involved in a project.

Since the late 1960s, researchers have been developing a basis for the current methods of life cycle analysis (Andrews et al., 2000). Initially, the impacts of interest were energy consumption, solid waste production, air and water pollutants (Andrews et al., 2000). Thus, the concept of Environmental Life Cycle Assessment (E-LCA) began to be implemented, usually referred to as simply as Life Cycle Assessment (LCA). Over time, the concepts of Life Cycle Costing (LCC) and Social Life Cycle Assessment (s-LCA) also emerged. LCC is defined as an assessment of all costs associated with the life cycle of a product linked to one of the actors in the product life cycle, such as the supplier, manufacturer or consumer (Ciroth et al., 2008). This assessment must be related to real money flows. On the other hand, s-LCA refers to a systematic method which accounts for all impacts borne by society throughout the life cycle of a product (Andrews et al., 2000). When the assessment covers all the environmental, social and economic impacts in the decision-making process, Life Cycle Sustainability Assessment (LCSA) approach is applicable.

When considering LCSA, the study becomes more extensive and consequently more complex, as new uncertainties arise and several stakeholders are involved (Clímaco and Valle, 2016). The need to analyse multiple factors when adopting the LCSA approach suggests the use of Multi Criteria Decision Analysis (MCDA). This methodology can be defined as a collection of formal approaches which seek to take into account several criteria to aid in decision making (Belton and Stewart, 2002). MCDA is particularly useful when different social, economic, and environmental indicators are contrasted (Motuzienė et al., 2016). Adopting MCDA on projects, it becomes possible to incorporate various perspectives when considering the impacts of decisions made.

2. Literature Review

2.1. Life Cycle Sustainability Assessment (LCSA)

In the 1990s, the International Standards Organization (ISO) published the first standard of LCA methodology: ISO 14040 – Principles and Framework (ISO, 2006). This approach has been widely applied in the construction sector since that time, as an important tool to evaluate the environmental impacts of construction materials in the different phases of the project life cycle (Fava, 2006).

In addition, a number of LCC and s-LCA approaches have been developed. Until then, however, the concepts and definitions related to the LCSA were not yet clearly presented. In 2003, a study presented a proposal to combine LCA with LCC and s-LCA, but the term LCSA was not used at the time (Klöpffer, 2003). The first time this term was used was in 2007, but the authors only analysed the impacts of climate change and resource depletion on their LCA, combining this analysis with an LCC, which does not completely meet the 'triple bottom line' model of sustainability (Guinée, 2016). In 2009, a study conducted by the Institute of Environmental Sciences, at Leiden University, presented a guideline for LCSA when implemented on general products (Zamagni et al., 2009). Even so, there is yet so little efforts conducted on building-based LCSA.

2.2. Multi-Criteria Decision Making (MCDM)

MCDM, also known as Multiple-criteria decision analysis (MCDA), is an approach used to aid in the decision-making process, incorporating information about the problem to perform the analysis of several alternatives or actions from different points of view (Jato-Espino et al., 2014). There are many studies on MCDM in various fields of knowledge, such as business, government and medicine, beyond the construction sector (Toloie-Eshlaghy et al., 2011). A recent paper presents an empirical application and comparison of six different MCDM approaches for the purpose of assessing sustainable housing affordability (Mulliner et al., 2016). This work evaluates the robustness of the methods and contrasts the resulting rankings.

There are different methods to support strategic decision making. One of them is the Displaced Ideal Method, developed in 1973. This method assumes that the attributes considered have a certain interdependence relation. When choosing a specific type of dependency and considering it as an anchor of the problem, the search for the solution is centred on the proximity of an alternative to the anchor elements, that is, the distance between the ideal alternative and the bad one (Zeleny, 1976).

3. RESEARCH METHODOLOGY

The incorporation of multi-criteria decision making into LCSA is challenging since there are no certain recommendations or best methods offered. It is believed that there will never be a single best approach to all kinds of multi-objective mathematical programming problems (Ignizio, 1983). For this study, the proven concepts about buildings, based on European Standards, will be used to develop a LCSA framework (EN 15643-1, 2010; EN 15643-2, 2011; EN 15643-3, 2012; EN 15643-4, 2012). In considering environmental, economic and social analysis as an optimization problem, the Displaced Ideal method (Zeleny, 1976) will be adopted as the MCDM method in the proposed framework.

To begin the analysis, the decision maker must have the prototype of the building. This would typically involve the three-dimensional (3-D) model developed as a Building Information Modelling (BIM) (Eastman, 2008); doing so significantly increases the performance and quality of the project. Utilising BIM makes it possible to gather environmental, economic and social data in the same model. It is important that, at this stage of project design, all construction materials and construction methods alternatives are listed. Having all the building data available in BIM, it is possible to start the analysis.

To begin the LCSA study, it is important to first define the goal and scope of the analysis clearly and accurately. At this level, the following information needs to be decided on: functional unit, system boundary, reference flows, assumptions and limitation of the study. The system boundary refers to the size of LCSA, and the choice of the system boundary can significantly affect the results of the study (Gaudreault et al., 2010). In this work, the use of a cradle-to-grave analysis is encouraged, i.e., going through all phases of the project life cycle. However, it is important that the practitioner analyses the need for each project to determine the boundaries of the study.

The purpose of the framework presented in this work is the comparison between different alternatives, from the environmental, economic and social perspectives. Therefore, the functional unit of the study will be considered as the whole building, while the reference flows will be the different alternatives of material bills to construct such a building. The impact categories to be considered should be chosen by the decision maker, analysing which are the most relevant to the target audience of the study. As the intention is to use an MCDM method to aid in decision making, each impact category shall be considered as an indicator identified by a single variable. To present an integrated framework, some indicators are chosen for the dimensions of the analysis: environmental, economic and social. Variables are defined for each of the parameters, where D_i refers to the dimension i, while X_j refers to the indicator j. The variables are presented in Table 1.

Table 1. Dimensions and indexes to be considered in the analysis

Dimensions ($\boldsymbol{D_i}$)	Indicators ($\boldsymbol{X_j}$)
(D1) Environmental	(X1) Climate Changes
	(X2) Resources depletion
	(X3) Acidification
(D2) Economic	(X4) Construction materials costs
	(X5) Operational water costs
	(X6) Operational energy costs
(D3) Social	(X7) Health and comfort
	(X8) Adaptability
	(X9) Noise

With all the data obtained and characterised, an MCDM method is used to weight the results found and thus enable the professional to choose the best alternative. The best alternative will be the choice that is the most sustainable, based on the 'triple bottom line' model of sustainability. The best alternative should be chosen in relation to each of the analysed dimensions. The anchor value, considered the ideal solution, is determined to be the maximum value of each one of the sets. Each alternative can be represented by a vector of *n* numbers, as follows:

$$X^K = (x_1^k, x_2^k, \ldots, x_n^k) \quad (1)$$

In this representation, the element x_j^k corresponds to the result obtained by the indicator *j* in the alternative *k*. In this way, the vector X^K includes all the information for each proposed alternative. As an example, suppose that one of the alternatives for the construction of the building, considered as Alternative 1, would be the use of the following list of materials: solid wood doors; 1.20m x 1.20m aluminium windows with tempered glass; enamelled ceramic floors; reinforced concrete slabs and walls made with ceramic blocks of 9cm x 19cm x 19cm. Considering this list of materials, all environmental, economic and social impacts should be calculated, based on previously defined indicators. Thus, the first vector of the study, related to Alternative 1, will be obtained in Equation 2.

$$X^1 = (x_1^1, x_2^1, \ldots, x_n^1) \quad (2)$$

Changes should be made with the purpose of examining each alternative building material within the project and thus analysing possible changes in the impacts generated. The other alternatives to be analysed may be a small variation in the list of materials already presented, such as the variation of the dimensions of doors and windows, or a large variation of all the materials used. Ideally, a sufficiently large number of vectors should be analysed so that a design decision can be made in a conscious and supportive way.

It is important to note that finding the minimum value among the alternatives is the same as finding the maximum value with negative sign (Petry et al., 2014). This relationship is important because some criteria can be determined by the maximum or by the minimum value. The anchor value is determined as the maximum value of each set, represented by:

$$x_i^+ = max_k\,(x_i^k) \quad (3)$$

In this way, the ideal value for the project will be obtained as follows:

$$u^+ = [x_1^+, x_2^+, \ldots, x_n^+) \quad (4)$$

Next, it is required to calculate how close each alternative is to the anchor value. The distance between the alternative u^+ and another alternative v can be calculated through the Euclidean distance, considering w_j as the importance value of indicator j, represented by:

$$d_E(u^+, v) = \sqrt{\sum_{j=1}^{n} w_j (u^+ - v)^2} \quad (5)$$

Thus, it is possible to present the sustainability indicators, chosen at the beginning of the study, from the Euclidean Distance and, therefore, it is easy to create a general ranking among the proposed alternatives, for analysis purposes. Although there is a ranking among project alternatives, qualitative and quantitative indicators are being analysed at the same time, which brings certain subjectivity to the analysis. The choice of the importance values w_j given to each variable is also subjective and must be aligned with the needs of the stakeholders and be consistent with what is expected of a sustainable project.

In order to illustrate what was proposed and to facilitate understanding, a framework is presented in Figure 1. It is worth remembering that the method chosen to aid in decision making can be changed, as long as there is an analysis of the entire project life cycle and the concern is to analyse the environmental, economic and social spheres.

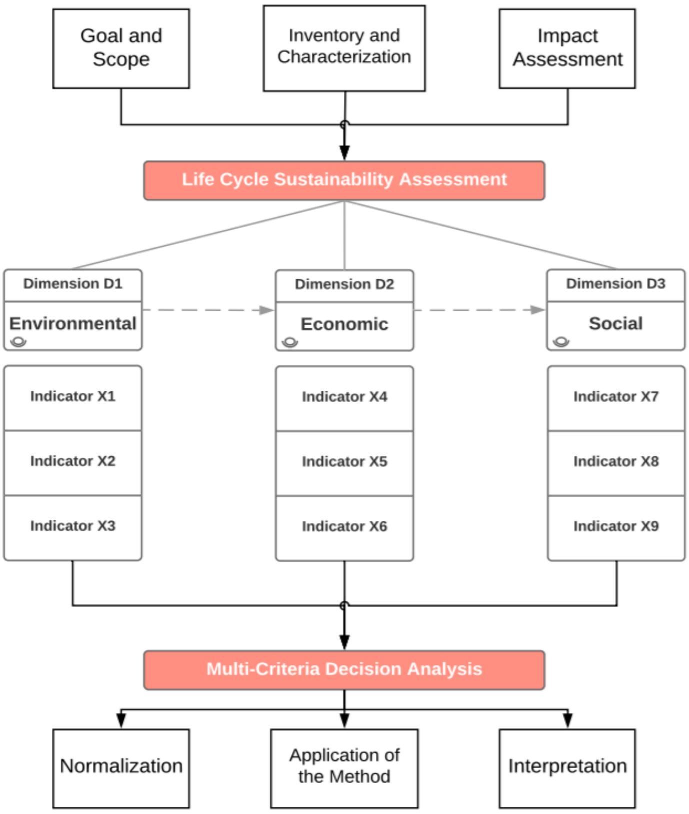

Figure 1. Framework of the proposed analysis

4. CHALLENGES AND WAY FORWARD

The utilisation of an integrated framework where LCSA and MCDM are combined presents several challenges to industry practitioners in construction. First, the definition of the indicators making up each sustainability attribute needs to be made in a manner that aligns with the sustainability objectives that stakeholders aim to achieve from the project. Second, the choice of the importance weights will be subjective since it will depend on the preferences of the decision maker and can thus vary from one decision maker to the next.

This study is still ongoing as it is known that the application of the method needs to be continually improved. It is a multidisciplinary tool, as it encompasses several areas of knowledge, as well as being a multi-criteria tool, since it is dedicated to several categories of impact at the same time. In this way, there is still great difficulty in obtaining all the data related to the building, covering the environmental, economic and social spheres. The future direction of this study is to explore the use of the proposed framework in real buildings, identifying effective ways of weighing the various impacts.

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Pre-fabricated Concrete System Analysis Applied to Social Housing

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Abstract

Construction companies in Brazil started to invest in new construction methods to meet the market demand for social housing, fuelled by national housing programs. The adoption rate of pre-fabricated concrete construction systems towards social housing still hasn't achieved the same scale as other construction systems. A more in-depth study on this construction method, focusing on project characteristics and its cost, is an opportunity to compare it with others, such as cast-in-place concrete wall system. This was done through a literature review on pre-fab construction and, the development of an application example, consisting of the architectural plans and a quantitative survey of its composition for the development of the budget and cost analysis on different project scales. With this study, it was possible to observe, through the results, that pre-fabricated construction, comprising concrete panel and hollow core slab elements, are a viable alternative for the execution of social housing projects.

Keywords: Pre-fabricated, Cast-in-place concrete wall system, Social housing, Budget, Cost analysis.

1. INTRODUCTION

To solve the population housing demand and maintain healthy economic growth, construction companies that take part national housing programs will have to continue seeking new ways to increase productivity on their construction operations: by adopting new construction methods and processes in the challenging context of high quality projects and limited profit margins (Berr & Formoso 2012). With this objective in mind, the construction industry has recently been inscreasingly adopting more rational construction methods when it comes to concrete structures, leaving the cast in place conventional practices aside for social housing projects (Klein & Maronezi 2013). Construction methods such as reinforced structural masonry and cast-in-place wall systems have had great appearance in construction job sites (Massuda & Misurelli 2009), however another solution that has the potential to produce in a satisfactory pace social housing projects with great resource efficiency is the pre-fabricated concrete system (Grande 2009).

Specifically when addressing the housing segment, pre-fabricated concrete wall panels has been the go to solution (Acker 2002; Peixoto 2015) when it comes to adopting industrial building systems. Even though, in Brazil, the implementation of concrete pre-fabricated structures have been mainly observed in shoppings, garage buildings, warehouses, commercial and residential projects (Serra, Ferreira & Pigozzo 2005), there's a study case, presented by this article, that implements the panel solution on a housing project. Its structure is composed by solid pre-fabricated wall panels, hollow core panels and hollow core slabs, connected between with reinforced grouted steal connections, resulting in a 4 story building (Jorge 2017).

In this article, an application example, composed of a 4-story housing building, is presented. An assessment on its project characteristics is made, analyzing: the architecture project: its design and dimension modularity; the pre-fabricated construction method implemented, step by step; and, finally, a cost assessment, making an estimate comparison between this method and a cast-in-place concrete wall system, both with the same architecture project.

Due to the very nature of industrial based construction, where its expected to be implemented on large scale projects (Frigieri Júnior 2011; Senden 2015), the cost assessment is made proportional to the scale factor of the project, where the the base building in this application is replicated in different quantities and how this affects the cost of the overall project.

1.1. Objective

Analyze the feasibility of the pre-fabricated concrete wall panel system for a social housing project based on a study case in Brazil, in the point of view of architecture project characteristics, structure execution and cost analysis. The latter will be based on a comparison of this system with the cast-in-place wall system on different scale magnitudes.

2. METHODOLOGY

The main reference used in this article is the graduation project "Comparative Cost Analysis Between Pre-Fabricated Concrete System and Cast-in-place Concrete Wall System" published by this article's author in 2017 at the Federal University of Rio de Janeiro. The framework adopted there is relayed here (see Figure 1).

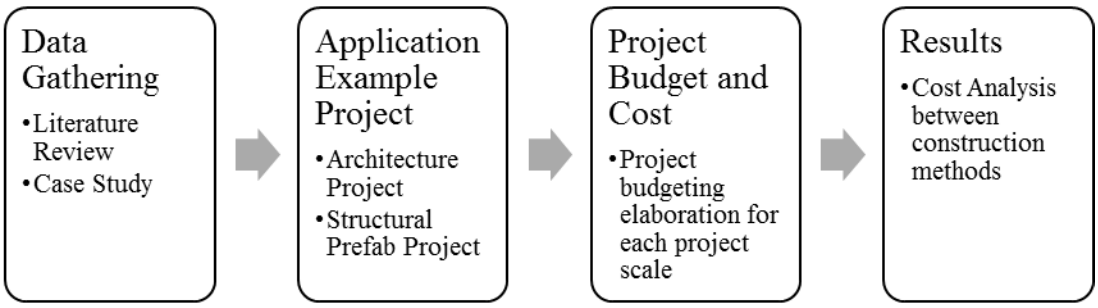

Figure 1 – Framework used in Jorge (2017).

As we can see, the first step was to gather as much information of construction projects that adopt pre-fabricated wall panel solutions. Since the project is based on the Brazilian construction industry, this was done by literature review of articles, thesis' and reports on this type of construction. The author also did an interview with a commercial representative of one main company that offers pre-fabricated concrete services for construction companies. This company displayed information about a social housing construction they executed which was adopted to the graduation project as a case study.

The next step was the elaboration of an Application Example Project, composed of two separate projects: an architecture project and a structural prefab project based upon it, with the pre-fabricated concrete elements (such as wall panels, floor slabs etc) displayed and quantified. The study case and the application example based upon it, illustrated in this article, is fine detailed at Jorge (2017). The graduation project also makes a deeper assessment on the cast-in-place concrete wall system. Since the focus of this article is mainly the analysis of the characteristics and project cost of a pre-fabricated system applied to housing, the cast-in-place solution is just used as a benchmark for reference on the cost analysis.

The purpose of the development of an application example was to quantify the many components and their respective quantities for a better budgeting process. This is the third step of the framework, Project Budget and Cost. All the items quantified had their price sought using a construction budgeting software called "Gerador de Preços" (Price Generator) by Cype Ingenieros. Although mapping the types and quantities of pre-fabricated concrete elements was necessary for the design of an authentic architecture project (for example, adhering to certain rulesets on dimension modularity of certain elements), pricing with this software is done per square meter (m²) of each element type, already considering the element materials (such as concrete, steel, etc), labor work and transportation. This is the main reason there isn't a specific formwork project made for the cast-in-place concrete wall system. For this solution, the same architecture project was used to calculate all the built vertical areas of the building. Not only does this prevents deviating the attention from the pre-fabricated study, but also having the same architecture project satisfy both construction method solutions makes the cost analysis study be done under one denominator.

Each extracted item from the Cype database is a composition of inputs, consisting of materials, equipments and labor. Each input has their average unit cost (as monetary cost per kilogram or square meter or per hour) and the performance of each respective input to compose the item composition.

In order to do the scalability of the project, the summary of compositions that comprises one building unit is nearly all multiplied and proportional by the number of buildings analyzed, except some fixed cost items in the project. For example, the pre-fabricated structure of one building unit was fixed per building unit, so, in this case, 5 building units comprises of 5 times the number of pre-fabricated structures. However, for the cast-in-place aluminium formwork, utilized to compare construction solutions, its quantity is fixed, regardless of building units, since it's reused for every building execution. Other items, such as job site components, transportation and waste management are also fixed in quantity. The software itself calculates a unit cost reduction due to the size of the construction footprint of your project. The application example comprises of cost analysis of: 1, 5, 10, 20, 35 and 50 building units, analyzing overall project cost, per building unit cost and the composition of price, divided into the categories: initial services, foundation, structure, coating, sealing, installations, roof, frames, waterproofing, waste management and final services.

The final step of the framework was to proceed with the cost comparative analysis between building systems. An estimated budget was made stem from the application example, without observing specific construction details. Each item composition was put into a spreadsheet with its corresponding unit cost. The project provided the quantity of each element and the final cost calculation is a sum of all compositions, proportional, also, to the quantity of Building Units analyzed. This was made for pre-fabricated concrete wall panel system (Prefab) and the cast-in-place concrete wall system (Cast-in-place). Note that construction elements that are not structurely related, such as installations, waterproofing, etc, were left unchanged in order to not influence the cost results. However, they were added regardless for the purpose of the elaboration of a full construction project.

3. APPLICATION EXAMPLE AND RESULTS

The application example was created with the same architecture and structural characteristics of the pre-fabricated concrete social house construction study case used at the graduation project mentioned earlier. The wall panel elements followed the same section dimension, with some modification on the length. The width and height of the hollow core floor slabs were also maintained. Hands on these dimensional modularities were analyzed before the concept of the architecture itself to facilitate, later, the creation of the pre-structural pre-fabricated layout. Modulation of the construction elements is very important for pre-fabricated projects, incentivizing savings due to less element variability and productivity in element production and execution at job sites (Acker 2002; Casagranda 2015).

Pre-fabricated concrete wall panels are part of a closure curtain system, normally already manufactured off site with the wall cladding done, different from reinforced masonry or cast-in-place concrete wall systems, ready to be assembled into place. They can function as structural components, such as the solid wall panels utilized on the project, and as closure components, such as the hollow core wall panels. An advantage of this system is the architecture flexibility: while the external walls are composed of these structural components, the interior of the floor is free to attend the architecture layout (Peixoto 2015). The internal divisions of the project are composed of dry wall panels, for optimal floorspace use and lighter loads on the hollow core floor slabs. We can view this in Figure 2: on the right, the architectural project of the application example shows all the internal division of apartments and rooms. While on the left, the pre-structural project shows no such divisions except the pre-fabricated panel wall system on the façades and central staircase core of the housing building.

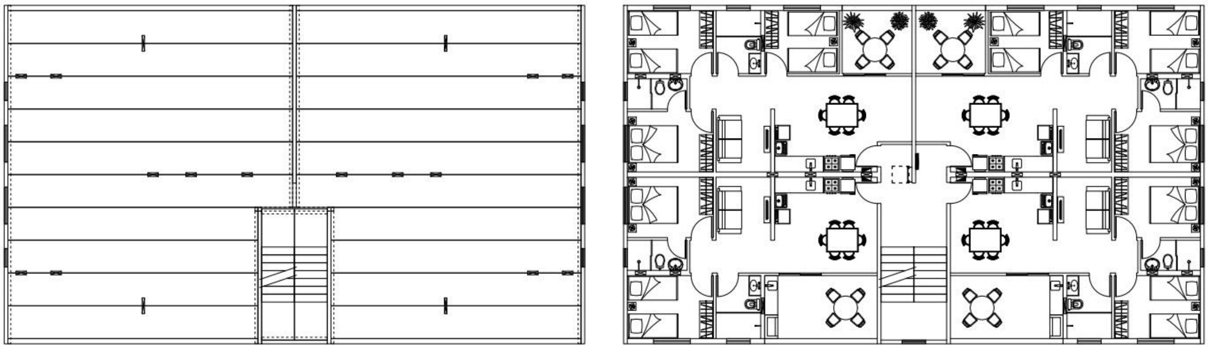

Figure 2 – Architecture reference floor plan of the application example on the right and the structural reference floor plan on the left (Jorge 2017).

In order to optimize the assembly of the constructed structure, an Assembly Plan needs to be done. This plan lays the sequence of components to be installed, also known as the Rigging Plan, that technically defines vertical transportation operations, combined with the Assembly Plan that dictates the job site layout: from receiving the elements in-site all the way to its final position (Leal 2015). The application example follows the same construction sequencing from the case study: (1) starting with the central staircase core and the lateral solid wall panels connected to the foundations; (2) hollow core wall panels and beams connecting the core with the lateral panels; (3) placement of hollow core floor slabs juxtaposed adjacentally, same orientation as the hollow core panels. This sequencing is repeated on remaining floors.

The architecture project, as seen in Table 1, is composed of 1 Building Unit (BU) of a Social Housing Project. This Building Unit is composed of 1 ground floor, with 4 apartment units, 3 reference floors with 4 apartment units each and a roof floor, with roof tiles and a water reservoir. In Table 2, the total constructed area per BU is shown: 1 BU equals 1425.45 m² of constructed footprint. Naturally, 5 BU's equals 5 times that of 1 BU and so on. Like previously mentioned, this constructed area is the same for the pre-fabricated concrete wall panel system and the cast-in-place concrete wall system.

Table 1 – Architecture project table, per Building Unit, with area types and quantities (Jorge 2017).

	FLOOR QUANTITY	2R APARTMENT QUANTITY	3R APARTMENT QUANTITY	TOTAL INTERIOR AREA (m²)	COMMON AREA - CORRIDOR (m²)	COMMON AREA - STAIRS (m²)
GROUND FLOOR	1	3	1	285.09	15.82	8.88
REFERENCE FLOOR	3	2	2	285.09	9.57	8.88
ROOF FLOOR	1	0	0	285.09	0	0

Table 2 – Total area built per building units quantity (Jorge 2017).

ARCHITECTURE PROJECT AREA CHART	
# of BUILDING UNITS	TOTAL AREA BUILT (m²)
1 unit	1425.45
5 units	7127.25
10 units	14254.50
20 units	28509.00

ARCHITECTURE PROJECT AREA CHART	
# of BUILDING UNITS	TOTAL AREA BUILT (m²)
35 units	49890.75
50 units	71272.50

Table 3 – Cost per square meter (m²) of each construction system corresponding to the number of BU (Jorge 2017).

M² VALUE PER CONSTRUCTION METHOD								
# of BU	PREFAB		%	# of BU	CAST-IN-PLACE		%	PREFAB / CAST-IN-PLACE (%)
1	R$	1,233.48	-	1	R$	2,796.04	-	44.1%
5	R$	1,115.28	-9.6%	5	R$	1,327.46	-52.5%	84.0%
10	R$	979.18	-12.2%	10	R$	1,021.92	-23.0%	95.8%
20	R$	975.41	-0.4%	20	R$	944.64	-7.6%	103.3%
35	R$	974.62	-0.1%	35	R$	911.42	-3.5%	106.9%
50	R$	974.26	0.0%	50	R$	899.41	-1.3%	108.3%

After doing a cost summary of each construction system, the final total value of the project was divided by the total area constructed, resulting in the cost per square meter. In Table 3, we can analyze that, in fact, the Prefab solution was very similar in cost to the Cast-in-place solution: somewhere between 10 to 20 Building Units (BU) their cost equalizes and, after that, the cast-in-place solution becomes a cheaper construction method. A natural decrease of cost is expected due to a lower cost per item in certain compositions of the budgeting process. More noticeably, this decrease is more drastic on the cast-in-place solution. The reason for this is the reutilization of the same aluminium formwork used for the execution of the concrete wall structures. This article considered only 1 set of aluminium formwork, so, naturally, the more BU's the spreader the investment made on them is across the project scale. This rapid decrease can visually be better appreciated on the graph of Figure 3.

Note that the results here are in the Brazilian currency, the Real (BRL), due to the location that this work was made, corresponding to local circumstances. In 2017, for reference, the currency pair Brazilian real and US Dollar (BRL/USD) was quoted at R$3,33.

Figure 3 – Total construction cost per BU per construction method in bars. Construction cost per square meter, BU and construction method displayed as graphical lines (Jorge 2017).

4. CONCLUSION

With the size increase of the construction project, the two construction methods reached values very similar to each other. In the Brazilian construction industry, cast-in-place systems are already adopted in large scale for social housing projects. The similarity of cost between these systems could potentially indicate the feasibility of adoption of a pre-fabricated concrete option, such as wall panel systems. However, this is only true, in this case, if the only criteria assessed is the project cost.

Although pre-fabricated systems do require greater planning and more detailed construction projects, it could bring advantages on later construction stages, such as smaller job site workforce, lower generation of waste and faster execution, setting stage for a more industrial and rational based construction practices. This article did not, however, bring to light some factors that could, in fact, increase the prefab construction cost, such as project typology (with a more complex architecture form), component logistics from the manufacturing stage to the job site and terrain characterization.

To increase the applicability of this result for the industry and scientific community, analyzing case studies of prefab implementation: budget and schedule following deviation, assessing what factors made this construction viable or not, etc, could grant a better analysis for stakeholders to choose this option over other construction methods available.

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The Role of Construction Project Managers (CPM) in Construction Health and Safety (H&S)

Construction project managers (CPMs) are in a unique position as project leaders to integrate H&S into the six stages of projects. Furthermore, the CPM identity of work records a range of H&S actions required throughout the six stages of projects. Given the afore mentioned, a study was conducted to determine perceptions and practices of CPMs relative to construction H&S.

A literature review was conducted of relevant literature relating to CPMs and construction H&S, which informed the development of the survey instrument in the form of a questionnaire, which was administered among a sample stratum consisting of registered CPMs.

The salient findings include that CPMs consider / refer to H&S primarily: during construction documentation and management, and tender documentation and procurement, in terms of project stages; during site inspections / discussions, site meetings, site handover, and preparing of project documentation in terms of occasions, and method of fixing, position of components, and specification in terms of design related aspects.

The study confirmed that CPMs consider / refer to H&S, there is more focus on H&S during procurement and construction, than design, and CPMs do understand and appreciate the need to integrate H&S into construction project management.

The study indicates a need for enhanced integration of H&S into the first three stages of projects, and the upstream design aspects such as concept design.

Keywords: Construction, Health and Safety, Project Managers.

1. INTRODUCTION

The Construction Industry Development Board (cidb) (2009) highlighted the considerable number of accidents, fatalities, and other injuries that occur in the South African construction industry in their report 'Construction Health & Safety Status & Recommendations'. The report cited the high-level of non-compliance with H&S legislative requirements, which the cidb contends is indicative of a deficiency of effective management and supervision of H&S on construction sites as well as planning from the inception / conception of projects within the context of project management.

Lingard and Rowlinson (2005) emphasise the importance of a multi-stakeholder approach to H&S and state that all parties to a project - clients, designers, specialist consultants, specialist subcontractors, and suppliers have a role to play in ensuring that H&S risks are controlled. The Australian Federal Safety Commissioner's best practice client H&S principles emphasise, inter alia, the inclusion of H&S as an integral aspect of project management, and that H&S should be afforded status equal to that afforded cost, quality, and time (Department of Education, Employment and Workplace Relations, 2008).

Given the differing interpretation of project management globally, it is important to define it within the context of South Africa, namely: "Construction project management is the management of projects within the built environment from conception to completion, including management of related professional services, and the CPM is the one point of responsibility in this regard." (South African Council for the Project and Construction Management Professions (SACPCMP), 2006). Therefore, CPMs manage design delivery, integrate design and construction, and manage the construction process indirectly.

The Construction Regulations, which constitute the primary regulations in terms of managing H&S in the South African construction industry, allocate a range of H&S responsibilities to clients, designers, quantity surveyors, principal contractors, and contractors (Republic of South Africa, 2014). Given the definition of construction project management and the requirements arising from the Construction Regulations, CPMs must ensure that H&S is integrated into the six stages of projects. Furthermore, integration implies that CPMs must ensure that H&S is a 'value' during projects.

Given the status of H&S in South African construction, the requirements of H&S legislation, and the CPM identity of work (IoW), a study was conducted, the aim of which was to evaluate the influence of CPMs on H&S. The objectives of the study were to determine, inter alia, the:

- importance of eight project parameters to respondents' practices;
- frequency at which respondents' practices consider / refer to H&S during the six stages of projects;
- frequency at which respondents' practices consider / refer to H&S on fourteen occasions, and
- frequency at which respondents' practices consider / refer to H&S relative to sixteen design related occasions.

2. REVIEW OF THE LITERATURE

2.1 Health and Safety legislation

In terms of the South African Construction Regulations (Republic of South Africa, 2014), clients are required to, inter alia, prepare an H&S specification based on their baseline risk assessment (BRA), which is then provided to designers. Designers in turn are required to, inter alia: consider the H&S specification; submit a report to the client before tender stage that includes all the relevant H&S information about the design that may affect the pricing of the work, the geotechnical-science aspects, and the loading that the structure is designed to withstand; inform the client of any known or anticipated dangers or hazards relating to the construction work, and make available all relevant information required for the safe execution of the work upon being designed or when the design is changed; modify the design or make use of substitute materials where the design necessitates the use of dangerous procedures or materials hazardous to H&S, and consider hazards relating to subsequent maintenance of the structure and make provision in the design for that work to be performed to minimise the risk. To mitigate design originated hazards, requires hazard identification and risk assessment (HIRA) and appropriate responses, which process should be structured and documented.

Thereafter, clients must include the H&S specification in the tender documentation, which in theory should have been revised to include any relevant H&S information included in the designer report. Thereafter, they must, inter alia: ensure that potential PCs have made provision for the cost of H&S in their tenders; ensure that the PC to be appointed has the necessary competencies and resources; ensure that every PC is registered for workers' compensation insurance cover and in good standing; discuss and negotiate with the PC the contents of the PC's H&S plan and thereafter approve it; take reasonable steps to ensure that each contractor's H&S plan is implemented and maintained; ensure that periodic H&S audits and documentation verification are conducted at agreed intervals, but at least once every 30 days; ensure that the H&S file is kept and maintained by the PC, and appoint a competent person in writing as an agent when a construction work permit is required. To mitigate design originated hazards, requires hazard identification and risk assessment (HIRA) and appropriate responses, which process should be structured and documented.

2.2 CPM Identity of Work (IoW)

In terms of H&S, the IoW (SACPCMP, 2006) is silent relative to stage 1 'project initiation and briefing'. The interventions with respect to stages 2 to 6 are as follows. Stage 2 'concept and feasibility': Advise the client regarding the requirement to appoint an H&S consultant. Stage 3 'design development': Facilitate any input from the design consultants required by CM regarding constructability. Stage 4 'tender documentation and procurement': Facilitate and monitor the preparation by the H&S consultant of the H&S Specification for the project. Stage 5 'construction documentation and management': Monitor the auditing of the contractor's H&S plan by the H&S consultant, and monitor the production of the H&S File by the H&S consultant and contractors. Stage 6 'project close out': Manage the finalisation of the H&S File for submission to the client.

3. RESEARCH

3.1 Research Method and Sample Stratum

A convenience sample survey consisting of CPMs was adopted for the national study, which entailed a self-administered questionnaire survey. The questionnaire was based upon a previous study conducted among engineers in South Africa to determine their perceptions and practices with respect to construction H&S (Smallwood, 2004). The questionnaire consisted of fourteen questions – thirteen closed ended, and one open-ended. Seven of the close ended questions were Likert scale type questions, and six were demographics related. 32 Responses were included in the analysis of the data, which entailed the computation of frequencies, and a measure of central tendency in the form of a mean score (MS), to enable the interpretation of percentage responses to Likert point scale type questions, and the ranking of variables.

3.2 Findings

Table 1 indicates the importance of five parameters to respondents' organisations on a scale of 1 (not important) to 5 (very important), and a mean score (MS) ranging between 1.00 and 5.00. It is notable that all the MSs are above the midpoint score of 3.00, which indicates that in general the respondents can be deemed to perceive the parameters as important. However, given that the MSs are all > 4.20 ≤ 5.00, the respondents can be deemed to perceive them to be between more than important to very important. Furthermore, it is notable that the traditional three project parameters, namely quality, time, and cost are perceived to be less important than public H&S and project H&S. However, quality management is critical in terms of assuring the structural integrity of permanent and temporary structures.

Table 1. Importance of eight project parameters to respondents' practices

Parameter	Response (%)						MS	Rank
	Un-sure	Not ……………………………Very						
		1	2	3	4	5		
Client satisfaction	0.0	0.0	0.0	0.0	12.5	87.5	4.88	1
Public H&S	0.0	0.0	0.0	3.1	9.4	87.5	4.84	2

Project H&S	0.0	0.0	0.0	3.1	15.6	81.3	4.78	3
Quality	0.0	0.0	0.0	6.3	9.4	84.4	4.78	4
Productivity (contractor)	0.0	0.0	3.1	0.0	25.0	71.9	4.66	5
Time	0.0	0.0	0.0	9.4	21.9	68.8	4.59	6
Cost	0.0	0.0	0.0	6.3	34.4	59.4	4.53	7
Environment	0.0	0.0	6.3	3.1	28.1	62.5	4.47	8

Table 2 indicates the frequency at which respondents' practices consider / refer to H&S during the six stages of projects in terms of a scale of never to always, and a MS ranging between 1.00 and 5.00. It is notable that all the MSs are above the midpoint score of 3.00, which indicates that in general H&S can be deemed to be considered / referred to during the six stages frequently as opposed to infrequently. However, it is notable that 3 / 6 (50%) of the MSs are > 4.20 ≤ 5.00, and thus H&S can be deemed to be considered / referred to between often to always / always. Construction documentation and management predominates with a MS of 4.91, followed by tender documentation and procurement, and design development. The frequency relative to the latter is notable as the opportunity to influence construction H&S is greater during the early than the latter stages.

Table 2. Frequency at which respondents' practices consider / refer to H&S during the six stages of projects

Stage	Response (%)						MS	Rank
	Unsure	Never	Rarely	Some-times	Often	Always		
Construction documentation and management (S5)	0.0	0.0	0.0	0.0	9.4	90.6	4.91	1
Tender documentation and procurement (S4)	0.0	0.0	0.0	6.3	21.9	71.9	4.66	2
Design development (S3)	0.0	0.0	3.1	18.8	21.9	56.3	4.31	3
Project close out (S6)	3.1	3.1	0.0	18.8	34.4	40.6	4.13	4
Concept and feasibility (S2)	0.0	3.1	15.6	15.6	28.1	37.5	3.81	5
Project initiation and briefing (S1)	0.0	9.4	18.8	18.8	15.6	37.5	3.53	6

Table 3 indicates the frequency at which respondents' practices consider / refer to H&S on fourteen occasions in terms of a scale of never to always, and a MS ranging between 1.00 and 5.00. It is notable that all the MSs are above the midpoint score of 3.00, which indicates that in general H&S can be deemed to be considered / referred on the fourteen occasions frequently as opposed to infrequently. However, it is notable that 9 / 14 (50%) of the MSs are > 4.20 ≤ 5.00, which indicates that H&S can be deemed to be considered / referred to between often to always / always. 2 / 14 (14.3%) are upstream (U), 4 / 14 (28.6%) are midstream (M), and 3 / 14 (21.4%) are downstream (D). It is notable that the top three ranked occasions are downstream. 5 / 14 (35.7%) of the MSs are > 3.40 ≤ 4.20. which indicates that H&S can be deemed to be considered / referred to between sometimes to often / often. It is notable that all are upstream.

Table 3. Frequency at which respondents' practices consider / refer to H&S on fourteen occasions

Occasion	Response (%)						MS	Rank
	Unsure	Never	Rarely	Some-times	Often	Always		
Site inspections / discussions (D)	0.0	0.0	0.0	0.0	9.4	90.6	4.91	1

Site meetings (D)	0.0	0.0	0.0	0.0	9.4	90.6	4.91	2
Site handover (D)	0.0	0.0	3.1	0.0	12.5	84.4	4.78	3
Preparing project documentation (M)	0.0	0.0	0.0	6.3	21.9	71.9	4.66	4
Evaluating tenders (M)	0.0	0.0	3.1	9.4	12.5	75.0	4.59	5
Constructability reviews (U)	0.0	0.0	3.1	9.4	18.8	68.8	4.53	6
Pre-tender meeting (M)	0.0	0.0	3.1	12.5	18.8	65.6	4.47	7
Pre-qualifying contractors (M)	0.0	0.0	9.4	6.3	18.8	65.6	4.41	8
Client meetings (U)	0.0	3.1	3.1	9.4	31.3	53.1	4.28	9
Detailed design (U)	3.1	0.0	6.3	18.8	31.3	40.6	4.10	10
Design (U)	0.0	0.0	6.3	28.1	18.8	46.9	4.06	11
Design coordination meetings (U)	0.0	0.0	9.4	25.0	31.3	34.4	3.91	12
Working drawings (U)	3.1	3.1	9.4	21.9	31.3	31.3	3.81	13
Deliberating project duration (U)	0.0	9.7	6.5	32.3	32.3	19.4	3.45	14

Table 4 indicates the frequency at which respondents' practices consider / refer to H&S relative to sixteen design related aspects in terms of a scale of never to always, and a MS ranging between 1.00 and 5.00. It is notable that all the MSs are above the midpoint score of 3.00, which indicates that in general H&S can be deemed to be considered / referred relative to the sixteen design related aspects frequently as opposed to infrequently. It is notable that 3 / 16 (18.8%) of the MSs are > 4.20 ≤ 5.00, which indicates that H&S can be deemed to be considered / referred to between often to always / always - method of fixing, position of components, and specification. The remaining 13 / 16 (81.3%) of the MSs are > 3.40 ≤ 4.20. which indicates that H&S can be deemed to be considered / referred to between sometimes to often / often. It is notable that design (general), and type of structural frame, ranked sixth and forth respectively, fall within this range as they have a major impact on H&S.

Table 4. Frequency at which respondents' practices consider / refer to H&S relative to sixteen design related occasions

Aspect	Response (%)						MS	Rank
	Unsure	Never	Rarely	Some-times	Often	Always		
Method of fixing	6.5	0.0	3.2	16.1	22.6	51.6	4.31	1
Position of components	6.3	0.0	3.1	12.5	34.4	43.8	4.27	2
Specification	0.0	0.0	9.4	9.4	31.3	50.0	4.22	3
Type of structural frame	3.1	0.0	0.0	21.9	34.4	40.6	4.19	4
Site location	3.1	0.0	12.5	9.4	21.9	53.1	4.19	5
Design (general)	3.1	0.0	6.3	15.6	34.4	40.6	4.13	6
Edge of materials	3.1	3.1	0.0	15.6	40.6	37.5	4.13	7
Plan layout	6.3	0.0	6.3	21.9	25.0	40.6	4.07	8
Elevations	6.3	0.0	9.4	15.6	28.1	40.6	4.07	9
Content of material	6.3	3.1	3.1	15.6	37.5	34.4	4.03	10
Mass of materials	0.0	6.3	0.0	18.8	40.6	34.4	3.97	11
Details	3.1	0.0	9.4	21.9	28.1	37.5	3.97	12
Finishes	3.1	0.0	12.5	12.5	40.6	31.3	3.94	13
Surface area of materials	6.3	6.3	9.4	12.5	37.5	28.1	3.77	14
Schedule	0.0	0.0	15.6	18.8	40.6	25.0	3.75	15
Texture of materials	3.2	6.5	12.9	19.4	32.3	25.8	3.60	16

4. CONCLUSIONS

Although client satisfaction was ranked first, public H&S, and project H&S were ranked second and third respectively, marginally ahead of quality, and ahead of time and cost. Therefore, it can be concluded that CPMs include H&S as a project value.

In terms of the frequency at which respondents' practices consider / refer to H&S during the six stages of projects, construction documentation and management (Stage 5) predominates followed by tender documentation and procurement (Stage 4), and design development (Stage 3). Concept and feasibility (Stage 2), and project initiation and briefing (Stage 1) were the stages when H&S was considered / referred to the ranked. Therefore, it can be concluded that CPMs focus on construction H&S more during the downstream and midstream stages than the upstream stages. However, given the frequency at which they consider / refer to design development (Stage 3), it can be concluded that CPMs understand and appreciate the role of design in construction H&S.

Given the frequency at which respondents' practices consider / refer to H&S during downstream and midstream occasions, namely site inspections / discussions (D), site meetings (D), site handover (D), preparing project documentation (M), evaluating tenders (M), pre-tender meeting (M), and pre-qualifying contractors (M), it can be concluded that CPMs focus on construction H&S more during during the downstream and midstream stages than the upstream stages. However, given the frequency at which they consider / refer to construction H&S during various upstream occasions, it can be concluded that CPMs understand and appreciate the role of client involvement and design in construction H&S.

The frequency at which respondents' practices consider / refer to H&S relative to sixteen design related aspects leads to the conclusion that CPMs understand and appreciate the role of design in construction H&S, and the opportunity to influence construction H&S during the early stages of projects.

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The Inclusion of Health and Safety (H&S) Preliminaries in Contract Documentation

The paper reports on a study conducted relative to the introduction of health and safety (H&S) preliminaries into contract documentation on building projects within South Africa, the objectives being to determine the: extent of financial provision for H&S by contractors; the causes of inadequate financial provision for H&S by contractors, and the need for the introduction of H&S preliminaries in contract documentation.

A literature review was conducted of relevant literature relating to financial provision for H&S, and interviews were conducted with quantity surveyors (QSs), general contractors (GCs), and representatives of the Association of South African Quantity Surveyors (ASAQS) (Eastern Cape Chapter), and the East Cape Master Builders Association (ECMBA) as part of an exploratory survey.

The salient findings include: the widely used forms of standard conditions of contract make limited reference to or mention of H&S; a preliminaries item predominates in terms of the manner which contract documents have facilitated / made financial provision for H&S; competitive tendering without reference to H&S does not marginalise H&S; detailed H&S preliminaries should be included in bills of quantities (BoQ), and GCs generally do not determine the percentage H&S constitutes of tender and project cost.

Conclusions include: the amended Construction Regulations 2014 have had an impact on H&S practices; financial provision for H&S is an issue in the industry, and there is major support for the inclusion of H&S preliminaries in the BoQ.

Recommendations include: a CHSA should preferably be appointed at the first stage of projects; detailed H&S preliminaries should be included in BoQ, and employer and professional should inform their members of their responsibilities with respect to the Construction Regulations 2014.

Keywords: Construction, Financial, Health and Safety, Provision.

1. INTRODUCTION

The considerable number of accidents, fatalities, and other injuries that occur in the South African construction industry was highlighted in the Construction Industry Development Board (cidb) (2009) report 'Construction Health & Safety Status & Recommendations'. The report cited the high-level of non-compliance with H&S legislative requirements, which the cidb contends is indicative of a deficiency of effective management and supervision of H&S on construction sites as well as planning from the inception / conception of projects within the context of project management. Financial provision for H&S certainly falls within the ambit of planning within the context of project management.

The cidb (2009) also refer to Smallwood's 2004 findings that the total cost of accidents (COA) could have been between 4.3% and 5.4%, based upon the value of construction work completed in South Africa. The key issue relative to the COA is that ultimately, clients incur the COA as the COA is included in contractors' cost structures in the form of indirect costs, as contractors do not disaggregate costs when preparing tenders.

Given the aforementioned, a study 'The introduction of H&S preliminaries in the Eastern Cape province' was conducted among GCs and QSs to determine perceptions, problems, and practices, and the potential value of introducing H&S preliminaries in order to assist contractors in terms of making adequate financial provision for H&S.

2. REVIEW OF THE LITERATURE

2.1 H&S Legislation and Regulations

In terms of the Construction Regulations (Republic of South Africa, 2014), clients must provide designers with an H&S specification, and the designers must submit a report to the client before the client provides the H&S specification to the principal contractor (PC) when the project goes out to tender. The 'designer' report should include, inter alia, all relevant H&S information with respect to the design of the relevant structure that may affect the pricing of the construction work. Furthermore, the client must ensure that the PC has made adequate financial allowance for H&S, and the PC similarly with respect to potential subcontractors.

2.2 Standard Contract Documentation

The most widely used form of contract for construction in South Africa is the Joint Building Contracts Committee (JBCC) Principal Building Agreement, the latest addition being Edition 6.1 – March 2014. Other forms of contracts include the General Conditions of Contract (GCC), International Federation of Consulting Engineers (FIDIC) and the New Engineering Contract (NEC). The GCC does not make any explicit reference to H&S, other than 'reporting of accidents'. The FIDIC and NEC contracts originated overseas, and therefore provide conflicting clauses in terms of the H&S legislation in South Africa.

The model preliminaries as presented by the JBCC makes provision for a single item, which states that contractors need to comply with the Construction Regulations and the Occupational Health and Safety Act. It gives the contractor the opportunity to price this 'consolidated' or single item to ensure compliance with the abovementioned and in terms of the H&S specification provided by the employer. According to Smallwood and Emuze (2014), scope exists for the standard forms of contract to include more direct reference to construction H&S.

2.3 Form of financial provision for H&S

Wells and Hawkins (2009) state that to avoid misunderstanding of what is required and to facilitate the checking of contractors' financial provision for H&S, it is recommend that H&S items that can be separately priced be listed as prime cost items, provisional sums, or the use of another form of pricing mechanism. A study conducted by Smallwood and Emuze (2014) determined the concurrence with a range of statements in terms of a mean score between 1.00 and 5.00 to be: Contract document enabled financial provision for H&S promotes H&S (4.36); A detailed H&S section should be included in the Preliminaries (4.27), and A provisional sum should be provided for H&S in the preliminaries (3.64).

3. RESEARCH

3.1 Research Method and Sample Stratum

The qualitative component of the study was designed to target four sample strata, with a view to informing the primary study, which was quantitative in nature. The sample strata were quantity surveyors (QSs) who are members of the Association of South African Quantity Surveyors (ASAQS) Eastern Cape (EC) Chapter, and general contractor (GC) members of the East Cape Master Builders Association (ECMBA), and a representative from each of the ASAQS and ECMBA.

3.2 Findings

The gender composition of the respondents was: 100% of the GCs were male; 75% of the QSs were male, and 25% female; the ASAQS representative was female, and the ECMBA representative was male.

All the respondents were ≥ 35 years of age. 25% of the QSs were ≥ 55 < 65 years of age, and 75% were ≥ 65 years of age. 60% of the GCs were ≥ 45 < 55 years, and 40% were ≥ 55 < 65 years. The one representative was ≥ 35 < 45 years, and the other was ≥ 45 < 55 years.

75% of QSs possessed an Honours degree or higher. 40% of GCs possessed a National Diploma, 20% a Post-Graduate Diploma, and 40% an Honours Degree. 50% of the representatives possessed a Post-Graduate Diploma, and 50% an Honours Degree.

100% of the respondents have more than 18 years of work experience in the construction industry.

As an introductory question, all interviewees were required to indicate the importance of H&S to their organisation on a scale of 1 (not) and 5 (very). A mean score (MS) between 1.00 and 5.00 was computed based upon the percentage responses to the scale. The resultant MSs are: ASAQS (3.00); ECMBA (5.00); GCs (5.00), and QSs (4.00) (Table 1).

Table 1. **Importance of Health & Safety (H&S) to firm or association**

Stakeholder	**Ranking / Respondent No.**					**MS**
	1	**2**	**3**	**4**	**5**	
ASAQS (EC)	3					3.00
ECMBA	5					5.00
GC	5	5	5	5	5	5.00
QS	5	4	2	5		4.00

Respondents were asked whether the amended Construction Regulations of 2014 had impacted on the practice of their discipline. 75% of QSs stated that they had made changes to the method of producing a Bill of Quantities (BoQ) in terms of the Construction Regulations of 2014. One (25%) QS stated that they encourage clients to appoint a Construction H&S Agent (CHSA) due to their limited knowledge of H&S and the new legislation. One (25%) respondent provided an example of a BoQ that includes H&S items as a separate section in response to the changes of the Construction Regulations 2014. The latter is notable as clients are required to ensure that principal contractors have made adequate financial allowance for H&S. One (25%) respondent stated that they ensure an H&S Specification is attached to the contract documentation as an addendum and that they include the ASAQS 'model description' for H&S.

80% of GCs stated that they had made changes to the methods of executing a project. Changes included: correct safety lines and harnesses; method of transporting of workers; employing of registered H&S Officers; training of employees; changes to the SHEQ management system, and scaffold training. 20% of GCs stated that they were undertaking projects that were beyond the requirements of the Construction Regulations, and therefore no changes were required. 20% stated: "Unfortunately, a company with my size cannot afford to employ a H&S officer, do that is a very grey area."

The ASAQS representative stated that they (ASAQS) have not made any changes in terms of H&S to documents and information available to members, apart from one clause in the Preliminaries.

The ECMBA representative stated that they (ECMBA) have made changes to all their documents in terms of the amended Construction Regulations 2014, including the national H&S audit system and H&S Manual.

Table 2 indicates the percentage H&S constitutes of project value. The extent of 'unsure' response is notable – both associations, and 50% of QSs. Both 'aware' QSs stated the percentage as 2-5%. The GC responses include 0.5% (20%), 1-2% (40%), 3.5% (20%), and 6-8% (20%).

Table 2. Percentage H&S constitutes of project value

Stakeholder	Percentage range (%) / Respondent No.				
	1	2	3	4	5
ASAQS (EC)	Unsure				
ECMBA	Unsure				
GC	0.5	1-2	1-2	3.5	6-8
QS	2-5	2-5	Unsure	Unsure	

In terms of the provision made in the BoQ or by firms for H&S, the ASAQS makes provision for H&S in the 'model' preliminaries by providing a single item stating that contractors need to comply with the H&S specification as well as the H&S related legislation. All QSs stated that the only provision made in the BoQ is a one clause item in the preliminaries. They also stated that a H&S specification is attached as an addendum to the BoQ. 80% of GCs make provision for H&S by interpreting the H&S specification and creating a 'spreadsheet' of H&S related items. The total amount is then inserted in the preliminaries section of the BoQ under the H&S item. 20% of GCs allowed a set amount for H&S, but state that they do not allow for H&S items such as sheltered eating areas, and changing facilities on site.

Respondents were required to indicate whether contractors experience difficulty in pricing H&S. 75% of QSs responded in the affirmative, and 25% in the negative. It is notable that 80% of GCs stated that they do not experience difficulty when pricing H&S. The other GC stated that their firm experiences difficulty when pricing H&S due to each project being different with different requirements. Both associations agree that contractors experience difficulty when pricing H&S. The ECMBA stated that the H&S specification is not always attached to the BoQ at tender stage, and that smaller inexperienced contractors struggle to interpret the specification and therefore struggle to price for H&S.

GCs were asked how competitive tendering affects financial provision for H&S. The responses are recorded below:

- "It doesn't, but that is in the view of my company as we do not take shortcuts with H&S."
- "It doesn't, it is such a small percentage."
- "We never cut H&S to be more competitive. You cannot really say if it affects competitive tendering as we cannot see a break-down of other tenderer's P&G."
- "In my opinion, it is the last thing that should be 'cut'."
- "I do not see that H&S is a deciding factor as to whether or not you get awarded the project."

The ASAQS and QSs were asked what steps are taken by the client to ensure contractors have made adequate financial provision for H&S. The ASAQS representative stated that they do not provide any methods or documents that allow the client to ensure contractors have made adequate financial provision for H&S. All the QSs stated that the client cannot take any steps to ensure the contractor has made adequate financial provision for H&S. One QS (25%) stated that the contractor has to comply, whether he has made adequate financial provision for H&S or not, and another (25%) QS stated that the client does not have the knowledge to determine whether the contractor has made adequate financial provision for H&S, or not. 50% of QSs stated that as QSs they cannot determine if the amount allowed by the contractor is adequate, as they do not have the necessary experience and knowledge regarding H&S.

With respect to whether an H&S preliminaries section should be introduced, the ASAQS and the ECMBA representatives were both in favour thereof, and 75% of the QSs, and 80% of the GCs were. Items that were suggested for inclusion in such a section are presented in Table 3 below. Most of the items have substantial cost implications, and the inclusion of facilities items in the form of sheltered eating areas, shower facilities, and WCs is notable.

Table 2. Items to be included in an H&S preliminaries section

Item
Design of temporary works
Full-time H&S Officer
Geographical issues
H&S Audits
H&S file
Medicals
PPE
Scaffolding
Seasonal climatic issues
Sheltered eating areas
Shower facilities
Special scaffolding
Suspended scaffolding
SWPs and method statements
WCs

Interviewees were given the opportunity to record their comments regarding the introduction of H&S preliminaries. There responses are recorded verbatim.

The ASAQS representative commented: “We would like to see more than one item in the preliminaries. This would be beneficial for cost control.” The ECMBA representative in turn commented: “It has to involve contractors and the QS profession in order to put this document together. The JBCC committee should discuss and implement this type of document.”

The GCs’ comments are as follows:

- “I am against constant changes to contract documentation, so writing a whole new section of H&S preliminaries is not an option.”
- “It levels the playing field, and everyone will know what is required of them in terms of H&S.”
- “I feel the way forward is getting a standard H&S section in the preliminaries. I think it has to come into effect, whether the contractor then chooses to price an item in this section or not, is up to him. At least then the QS can see what the contractor has allowed for in terms of H&S.”
- “Consumables shouldn’t be quantified, as you will never be able to say how many hard hats, etc. each project will have.”

The QSs’ comments are as follows:

- “The H&S agent should be introduced at design stage in order to assist the quantity surveyor with regard to H&S related items.”
- “I feel there is a resistance to introducing this document and people are in denial. I believe there is no possibility of denying the urgency of such a document.”
- “It has possibly been taken too far, with the cost of certain items such as medicals being far too much, and it is possibly a money-making scheme.”

4. CONCLUSIONS

H&S is important to the respondents, which leads to the conclusion that they are committed thereto. This is reinforced by their initial selection as being likely to provide insight relative to H&S, and their willingness to be interviewed.

Given that respondents had made changes to their H&S practices it can be concluded that the amended Construction Regulations 2014 have had an impact.

The degree of uncertainty with respect to the percentage H&S constitutes of project value, and the percentage ranges stated, indicates that this aspect is an issue. The latter is reinforced by the extent to which contractors experience difficulty in pricing H&S, albeit to a lesser extent in the case of GCs.

Although competitive tendering was not perceived to negatively impact financial provision for H&S, there was major support for the inclusion of H&S preliminaries in the BoQ based on a project specific H&S specification provided by the client, and contributed to by designers. This indicates that the general status quo in the form of providing a single item in the preliminaries stating that contractors need to comply with the H&S specification as well as the H&S related legislation, is inadequate and inappropriate.

5. RECOMMENDATIONS

A CHSA should preferably be appointed at the first stage (project initiation and briefing), or at the latest, the third stage (design development) of a project to assist designers with respect to mitigating hazards, and the QS in terms of interpreting the H&S specification, and compiling contract documentation, particularly when compiling H&S items for the BoQ.

The relevant associations, and more specifically, the JBCC Committee need to consider the inclusion of H&S preliminaries to keep abreast with regulations relating to H&S. The ASAQS and MBAs, should inform members of their responsibilities with respect to the Construction Regulations 2014.

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Life-cycle assessment of buildings, the pathway to achieve sustainable development goals: A review

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ABSTRACT

Seventeen sustainable development goals (SDGs) are set in the 2030 Agenda for Sustainable Development by General Assembly of the United Nations in 2015 for making human-being environment liveable, resilient and sustainable. With the manner of sustainable development, three major development elements, which are social, economic and environmental development, are adopted in these goals. These elements need to be synchronised and harmonised by governments with international and national legislation system.

Many activities in the construction industry form environmental impacts such as greenhouse gas emissions, construction waste from resources utilisation and energy consumption during project phases of production, construction, demolition, recycling of building products. These activities relate directly or indirectly to achieve the sustainable development goals such as project workers and building occupants health, water and energy consumption goals. The meaning of green building intersects 11 goals of 17 sustainable development goals. Green building definition covers all the concerns of building design during its life-cycle in term of building's indoor comfort, responsibility of resource consumption and production, sustainable economic growth, and environmental health.

This review paper summarises and organises the literature on sustainable development goals, life-cycle assessment in green building carried out for life-cycle environmental assessment of construction projects and buildings related industry. The review shows the intersection between sustainable development goals and life-cycle assessment, as well as how to achieve these goals via the life-cycle assessment pathway.

Keywords: Sustainable development goals, Life-cycle assessment, Green building, Greenhouse-gas emissions

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I. INTRODUCTION

The marking of January 1st, 2016 is a critical milestone in the global environmental protection practice as the United Nations Sustainable Development Goals (SDGs) were brought into force (General Assembly, 2015). These goals are developed from Millennium Development Goals (MDGs) which state a challenge for human-kind to separate sustainable economic development from social and environmental problems. The concept of green-building is believed to able to contribute to the success of these goals. However, there is a quite far distance from theoretical concepts to practical activities.

In this paper, the characteristics of the goals will be discussed in terms of the comparison with the previous MDGs and the interception with the definition of green-building. From these discussion, the definition analysis of life-cycle GHG emissions assessment in the context of Australia is also examined in the paper.

II. LITERATURE REVIEW

2.1 Intersection between sustainable development goals and green building conception

The awareness about sustainable development was raised in the report of the World Commission on Environment and Development in 1987, which states that "Humanity has the ability to make development sustainable - to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). Sustainable development goals (SDGs) are set in the 2030 Agenda for Sustainable Development by the General Assembly of the United Nations in 2015 (General Assembly, 2015). Seventeen goals are set for making human-being environment livable, resilient and sustainable. These SDGs replace the previous Millennium Development Goals (MDGs) to reinforce the integration of three sustainable pillars which are social, economic and environmental development (Biermann et al., 2017). However, there are also many challenges to keep creating wealth and prosperity for society along with protecting environmental resources.

First, the correlation between international legislation system and national laws is not so strong due to the reason that there is no legal obligation to bind governments to commit SDGs by their national law and regulations system (Kim, 2016). This is one of SDGs' characteristics that is different from other environmental goals which are preserved in legal binders such as the ozone layer's protection. The other distinguished nature of SDGs with previous MDGs is addressing both industrialised and developing countries (Sachs, 2012). The term of sustainability turns all developed countries back to developing countries because these countries must reform their structure with more sustainable development approaches.

Also, SDGs is not only related to development like MDGs. With the manner of sustainable development, three major development elements, which are social, economic and environmental development, are adopted in these goals. These elements need to be synchronised and harmonised by governments with international and national legislation system. Although there are 169 targets are set to implement these SDGs, many of them are qualitative and give a big room for governments to pursue the goals on their pathways. Moreover, even when the targets are quantitative, their nonbinding character still allows governments to choose how they interpret and implement the goals.

Many activities in the construction industry form environmental impacts such as greenhouse gas emissions, construction waste from resources utilisation and energy consumption during project phases of production, construction, demolition, recycling of building products. These activities relate directly or indirectly to achieve the SDGs such as project workers and building occupants health, water and energy consumption goals. The primary energy source in the building industry nowadays still depends on fossil fuels which are threatening the global environment by polluting air, water and food systems (Allen et al., 2017). The meaning of green-building is using technological innovation and utilisation to decrease the amount of energy consumption and polluting emissions by reducing materials, water consumption during a building's life-cycle. This concept intersects 11 goals of 17 SDGs, which are represented in Figure 2-1. Green-building definition covers all the concerns of building design during its life-cycle in term of building's indoor comfort, the responsibility of resource consumption and production, sustainable economic growth, and environmental health.

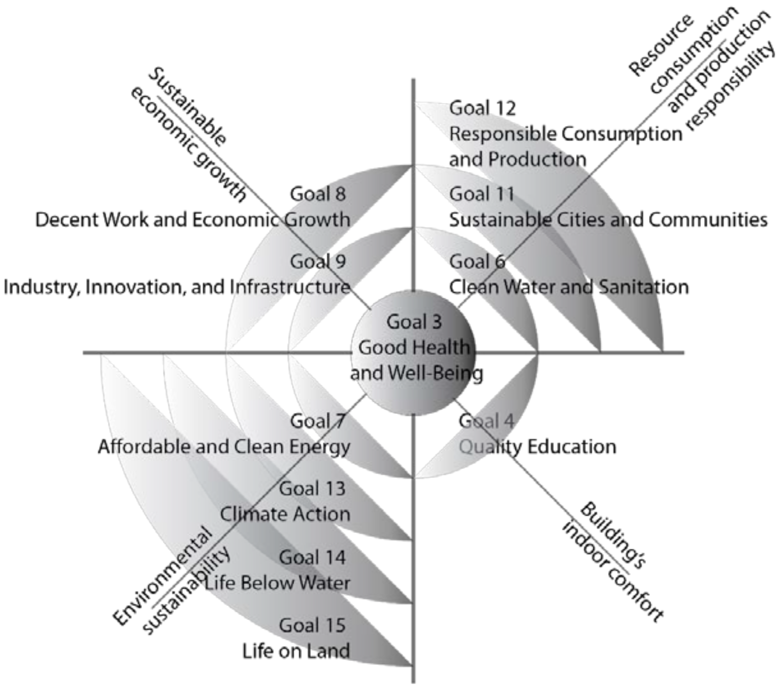

Figure 2-1. Intersection between green-building conception and SDGs

The fundamental aspects of building's healthy indoor comfort are interpreted via ventilation air quality, water quality, acoustic and lighting quality. Green-building aims to improve the occupant's health and well-being which satisfies SDG 3: Good health and well-being. However, the information related to these facets are still not well educated, so that the quality of education for the building's indoor health needs to be innovated to improve the building's comfort as well. Many green-building standards such as LEEDS, BREAM, or the Green-Star imply on improving the building's indoor comfort as well as occupant's health. Along with achieving SDG 4: Quality Education, the public's awareness about green development can be raised, and practitioners can optimise the green-building characteristics of their projects based on these sustainable frameworks.

Emission footprints are mostly from the construction and manufacturing areas, raise the necessity of materials use, resources and energy consumption management during the building lifetime. As the targets in SDG 6, 11 and 12, green-building conception also indicates sustainable resource deployment, clean water and hygiene management which consolidates into sustainable cities and communities. From that social sustainability consequence, economic development will be fostered by creating a stable labour market, employing innovative technologies in the industry to meet SDG 8 and 9 which encourage sustainable economic growth. Both social and economic targets then combine with environmental sustainability goals to protect habitats underwater as well as on land and address the impacts of climate change.

Interchanging with these SDGs, many definitions of green-building have been developed. However, they both have a similar point that this is the practice using incentives and processes to mitigate significant impacts on the economy, society and environment in the project's life (Bon-Gang & See, 2012; Olubunmi et al., 2016). Throughout the lifetime of a green-building, the efficiency of material production, construction site operation, water, energy utilisation is improved and the impacts on the built environment and human physical, mental health is reduced by more effective design, construction, operation, destruction and recycling processes.

One of the standard definitions of green-building is from the US Environmental Protection Agency (2015). It recognises the initiatives of building structures and utilising effective processes in all phases in a building's lifetime. The practice elaborates and completes the economic, comfortable and durable concerns related to the conventional building design. In this definition, a green-building is recognised as a sustainable and/or high-performance building. American Society of Heating Refrigerating and Air-Conditioning Engineers (2006) defined a green-building as a project operates with high performance in considering in the building's life-cycle. Natural resources utilisation is minimised and alternated by renewable construction materials, water, land and energy resources. Reducing the impacts of emissions that produced from these resources relates directly to alter global warming and climate change phenomenon or to improve the quality of building environment including indoor condition, occupants comfort. Green design also considers the demolition and recycling phases in the building life. Solid and liquid waste management plans are included in the green-building design to minimise adverse effects from the project. However, this definition discusses the fundamental of the whole life and whole building analysis on environmental issues but not much on economic and social matters.

2.2 Life-cycle GHG-emission assessment in the Australian context

Green-building Council Australia identifies a green-building is the practices during its life-cycle that reduce its environmental impacts. In this definition, green-buildings promote the building efficiency to enhance better performance and reduce its life-cycle cost significantly. Useful resources utilisation and healthy environment developing are some significant points to construct a sustainable place for living and working as well. The sustainable indicators of a green-building are illustrated in Table 2-1, indicating environmental, economic and social indicators. These indicators are developed into categories that meet the needs of sustainable purpose. While environmental indicators include all concerns related to human well-being, natural resources and the environment, the social and economic indicators synthesise population density, quality of human habitat, macro and microeconomic aspects (Henderson, 1994; Briassoulis, 2001; Dammann & Elle, 2006; Lawn, 2006; United Nations, 2007)

Table 2-1 Sustainable indicators of green-buildings

Social category	Economic category	Environmental category
Population, density, growth rate	Gross domestic product per capita	Global warming potential
Urban/rural migration	Investment share over GDP	Acidification potential
Assessible public services percentage	Inflation rate	Nutrient pollution potential
Quality of living environment (acoustic, thermal, lighting comfort, security)	Labour productivity and unit labour costs	Photochemical ozone formation potential
Efficient living space	The diversity of casual and permanent employment	Human toxicity potential
Lifespan and mortality rate	The adaptable capacity of the building	Depletion of fuel and heavy metal resources
	Life-cycle cost	Waste disposal and recycling

Green-buildings continuously offer sufficient benefits to its occupants and for relevant parties. The community recognition and perceived benefits of green-buildings are becoming popular (Mahbub et al., 2012). The economic and social benefit can be recognised via the global trend which helps to increase the efficiency and of employment markets, strengthening the economy (Buckley & Logan, 2016). Sustainable practices and community sense towards green-building development also are the essential reasons for social benefits. The occupant's health and working performance rally due to the improvement of green-building's environment. The better indoor environment is created, the higher positive social impacts are developed (Allen et al., 2017). For economic aspect, green-building is also estimated to account for creating more jobs and saving more efficient water and energy consumption. These lead to lower construction and operation cost for building tenants as well as increase asset value for building investors (Hamilton, 2015; Molenbroek et al., 2015). The most apparent benefit of green-building is the positive impact contribution to nature. Greenhouse gas emissions reduction is projected to 84 Giga-tones of CO_2-equivalent by 2050 by saving energy more than 50% through measures like energy efficiency, renewable energy utilisation (Dean et al., 2016). In Australia, the report of Green Building Council of Australia (2013) shows that certified green-buildings help to produce lower 62% of greenhouse gas emissions in comparison with typical buildings.

III. CONCLUSION

The paper has discussed the intersection between the concepts of SDGs and green-building. During the lifetime of a green-building, all facets relating to resources consumption, occupants comfort, economic growth and environmental well-being are addressed in 11 goals over 17 SDGs.

The paper suggests that the information on good health and well-being of the buildings, which is mentioned in SDG 3 (Good health and well-being) should need more improved education to satisfy the goals in SDG 4 (Quality education). Regarding resource consumption, there are three SDG 6 (Clean

Water and Sanitation), SDG 11 (Sustainable cities and communities) and SDG 12 (Responsible consumption and production) involved with developing an ecological approach to managing material resources, water using in the sustainable construction projects. Energy consumption of a green-building is typically lower than a traditional building. This reduction of using energy leads to the decrease of toxic pollutants as well as greenhouse gas emissions released to the environment. The fewer energy utilisation also helps green-buildings contribute to the sustainable economic growth and ignites the ability of innovation in the construction field.

IV. Acknowledgements

The authors wish to acknowledge the financial support from the Australian Research Council (ARC) Discovery Project under grant number DP150101015.

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TIME BAR PROVISIONS IN UAE: A CRITICAL STUDY OF ITS INTERPRETATIONS UNDER UAE CIVIL CODE

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Abstract

UAE is primarily a Civil Law jurisdiction where the legislations are formulated into a number of major codes.

The primary source of law pertinent to construction operations was identified as the Law of Civil Transactions of the State of the United Arab Emirates specifically, Sections 1 to 4 which contains twenty-four articles relating to Muqawala, Articles 872 to 896.

Albeit UAE is Civil Law jurisdiction, it was found that the majority of the conditions of contracts used in UAE are tailored by common law principles as they were heavily based on the FIDIC conditions of contracts.

Hence, the research was carried out to identify the areas of inoperability and ambiguities in interpreting the Conditions of Contracts used in UAE, particularly relates to the Time bar provisions under the UAE Civil Code.

This research takes the form of 'what is law' rather than expository nature which attempts to explain legal doctrines. Hence, this research takes the form of a doctrinal research.

Doctrinal research is not simply a case of finding the correct legislation and the relevant cases and making a statement of the law which is objective verifiable. It is a process of selecting and weighting materials taking into account hierarchy and authority as well as understanding social context and interpretation. For this reason, it can be argued that doctrinal research is qualitative, thus, forming this a qualitative research.

The UAE Civil Code does not address, recognize or reject time bar provisions of a contract under an express provision. However, good faith principle (article 246), causing disproportionate harm (article 106) and unjust enrichment (article 318 and 319) may act strongly against the contractual notice regime. Therefore, it is been suggested that "in the UAE a failure to adhere to a contract's notice provision will not necessarily, of itself, restrict claims from being pursued.

***Key Words**: UAE Civil Code, Time Bar Provisions, Construction Contracts UAE, Construction Law.*

1. INTRODUCTION

UAE is primarily a civil law jurisdiction, which is heavily derived from the Egyptian legal system and French and Roman law. The Shari'ah law, which is the embodiment of the Islamic law, is the corner stone of the formation of the UAE law (Tarbuck and Lester, 2009).

When it comes to the construction contracts in UAE, the majority of Contracts are often based on the International Federation of Consulting Engineers (Federation in Ternationale des ingenieurs-conseils (FIDIC) conditions of contracts.

Albeit the FIDIC has attempted to reconcile the needs of both Common law and Civil law systems and to be compatible with the jurisdiction of any country, the FIDIC contracts are highly underpinned with the common law principles (Bunni, 2006).

Saadoon (2007) claims that '*lawyers who have trained in civil law jurisdictions in the Middle East often do not appreciate the English legal concepts underpinning those [FIDIC] conditions".*

Therefore, it suggests that the applications of the provisions in conditions of contracts in UAE may face difficulties when it is interpreted under governing law of UAE.

Hence, the aim of this research is to explore the law applicable to construction contracts, particularly relating to time bar provisions, and critically review its applications into the currently used conditions of contracts in UAE, in order to enhance the understanding of inoperability of such conditions.

2. RESEARCH METHODOLOGY

Aim of this research is to identify and explore construction law in UAE in context with conditions of contract used in UAE in order to identify the intolerabilities of such conditions. It is therefore, this research takes the form of 'what is law' rather than expository nature which attempts to explain legal doctrines. Hence, unarguably, this research takes the form of a doctrinal research.

However, due to the relatively new and unexplored nature of UAE construction law, the applications and interpretations of law is compared with legal doctrines with English Law. It is therefore, international and comparative legal research method is also adopted to perform this study.

2.1. Research strategy

In theory, two main type of research strategies can be found namely, Qualitative and Quantitative research.

Naom (2007) claims that qualitative research is '*subjective*' in nature whereas quantitative research is *'objective'* in nature. He further adds; "*qualitative research emphasizes meanings, experience and description and so on. Qualitative researchers on the other hand believe that social facts exist independently of people's perception"*. Hence, the quantitative researches are observable and measurable in nature.

Nevertheless, the doctrinal research cannot be categorised as qualitative simply because it is non-numerical.

The doctrinal research can be categorized as quantitative if the same result can found regardless of who was carrying out the research. Dobinson and Johns (2007) describes doctrinal research as though it was equivalent to quantitative research or at least does not catergotise it as qualitative research.

They also claim that the characterisation of doctrinal research as not being qualitative is interesting because it reveals the established paradigm of legal research: that there is somehow an objective approach to finding the law.

They further argue that ultimately, law may be knowable, but it is not necessarily predictable. Doctrinal research is not simply a case of finding the correct legislation and the relevant cases and making a statement of the law which is objective verifiable. It is a process of selecting and weighting materials taking into account hierarchy and authority as well as understanding social context and interpretation. For this reason, it can be argued that doctrinal research is qualitative.
Accordingly, this research is also takes the form of a qualitative research.

3. TIME-BAR PROVISIONS

In order for the time-bar clauses to be valid, it is the view that the clauses must stipulate that the contractor’s entitlement for extension of time shall be subject to the notification served within a specified time period of the possibility of additional time and cost.

According to *Bremer Handelgesellschaft mbH v Vanden Avenne Izegem nv HL 1978,* the House of Lords said that a notice provision was unlikely to be a condition precedent unless it stated a specific time for delivery of the notice and said clearly that the rights would be lost in the event that the notice was not given.

It can be seen that the notice provision is often interacting with the prevention principle when it comes to granting the extension of time claims in construction contracts.

Prevention principle states that if the acts or omission of one party to a contract have hindered the other party from completing its obligations within the stipulated time, the party responsible for the impediment cannot insist the other party to honour its obligation under the contract.

In *Holme v Guppy (1838) 3 M.& W. 387* Justice Park J stated that: “*There are clear authorities that if a party be prevented, by refusal of the other contracting party, form completing the contract until the time limited, he is not liable in law for that default*.”

The question that arises is whether the operation of the prevention principle is subject to the procedural act such as a serving of a notice pursuant the contract.

3.1. English law akin to time-bar provisions

According to *Gaymark v Walter Construction (1999) 16 BCL 499,* it is suggested that the prevention principle must override the principle of condition precedent. In this case, it was found by the Supreme Court that albeit the contractor had failed in serving the notice, the employer was responsible at least for some of the delays and therefore, the right to claim liquidated damages was lost and time was set at large.

Lal (2007) suggests that: *“The employer may not always know he has caused delay: indeed, the employer allocates the risk of delays, their identification and assessment to the contractor. It is unfair and may encourage poor project management to allow the contractor to simply miss notice requirements and assert his right to EOT at times (only) suitable for him.”*

Therefore, in order to resolve the tension between the time-bar provisions and the prevention principle, he further suggested the following approaches:

1. "*The prevention principle is a rule of construction and not a rule of law, so that express terms… can simply exclude its operation; or*
2. *The prevention principle does not apply, because the 'proximate cause' of the contractor's loss is not the employer but the contractor's own failures to operate the contractual machinery, so there is no 'act of prevention'*."

This view was also presented by Cole in *Turner Corporation Ltd (Receiver and Manager Appointed) v Austotel Pty Ltd (1997) 13 B.C.L 378*. "*…claim that the act of prevention which would have entitled it to an extension of the time for Practical Completion resulted in its inability to complete by that time. A party to a contract cannot rely upon preventing conduct of the other party where it failed to exercise a contractual right which would have negated the affect [sic] of the preventing conduct*."

However, despite the contradicting views, it can be seen through the case laws that the English law has taken a much strict approach towards the failure to adhere to time bar provisions.

This tendency of English Courts can be illustrated through *WW Gear Construction Ltd v McGee Group Ltd [2010] EWHC 1460*, where the judge noted that the "*requirement to make a timely application in writing is a pre-condition to the recovery of loss and/or expense (under the contract)*".

Therefore, it was held that the Contractor has no entitlement to recover such loss or expense unless and until it has made such an application.

In the Australian case of *Gaymark Investments v Walter Construction Group (1999) Adj.L.R. 12/20*, the contractor's failure to adhere to the notice provisions results in losing his rights to claim for extension of time. However, it was also found that if there was an act of prevention, the employer could not claim liquidated damages for the delay that they had caused.

However, the English courts have doubted whether this represents the law of England. Jackson J in *Multiplex Constructions (UK) Ltd v Honeywell Control Systems [2007] BLR 167 TCC* argued that "*contractual terms requiring a contractor to give prompt notice of delay serve a valuable purpose; such notice enables matters to be investigated while they are still current… If Gaymark is good law, then a contractor could disregard with impunity any provision making proper notice a condition precedent. At his option the contractor could set time at large*"

Similarly, in the Scottish case of *Education 4 Ayrshire v South Ayrshire Council [2009] CSOH 146*, Lord Glennie found that: "*The same factors which point to the clause being a condition precedent also point to the need for any notice served in accordance with the clause to comply strictly with its terms"*.

Where parties have laid down in clear terms what has to be done by one of them if he is to claim certain relief, the court should be slow to relieve that party from the consequences of failure.

3.2. Time Bar Provisions in UAE

UAE has a civil law jurisdiction and is therefore, the primary source of law and is statutory in nature. Over the years, the federal government and individual emirates have enacted several laws that are relative to the construction industry, which, wholly or partly, apply to the construction industry.

Nonetheless, there is currently no federal or emirate-level construction law, specifically for construction contracts. The primary source of law that is pertinent to construction operations could be identified as the Law of Civil Transactions of the State of the United Arab Emirates (the Civil Code) and it was enacted by the federal government pursuant to Federal Law No. 5 of 1985 on 29 March 1986.

In Civil Code Book Two, Part 1 of Chapter 3, Sections 1 to 4 contains twenty-four articles relating to muqawala which is in Arabic, meaning "*contract to make a thing or to perform a task*". These twenty-four Articles, Articles 872 to 896 of the Civil Code are the basis on which the construction contracts are currently regulated in the UAE.

The UAE Civil Code does not address, recognize or reject time bar provisions of a contract under an express provision. However, good faith principle (article 246), causing disproportionate harm (article 106) and unjust enrichment (article 318 and 319) may act strongly against the contractual notice regime.

Article 246 of the UAE Civil Code provides:

1) "*The contract must be performed in accordance with its contents, and in a manner consistent with the requirements of good faith.*
2) *The contract shall not be restricted to an obligation upon the contracting party to do that which is (expressly) contained in it, but shall also embrace that which is appurtenant to it by virtue of the law, custom, and the nature of the transaction*"

in addition, following provisions may also be applicable.

Article 318:

"*No person may take the property of another without lawful case, if he takes it he must return it.*"

Article 319:

1) *"Any person who acquires the property of another person without any disposition entitling his so to do must return it if that property still exists, or similar property or the value thereof if it no longer exists, unless the law otherwise provides.*
2) *If the property of any person leaves his possession without his so intending and by unavoidable process merges with the property of another person in such a way that it cannot be separated therefrom without causing harm to one of the owners, the property of the lesser value shall be regarded as part of the property of the greater value after paying the value thereof, and if (the two parts) are of equal value then the property shall be sold and the proceeds distributed, unless there is an agreement or a provision of law to the contrary."*

Tolson and Glover (2008) found that in the construction industry, an increasing tendency can be seen to include time bar and notice provisions which are intended to have the effect of disallowing the contractor claim that might otherwise be legally recognizable. The general provisions of these clauses is that the contractor will lose all rights and entitlements to cost and extensions of time for a specific claim if a notice is not issued strictly in accordance with the specific provision.

More or less a similar provision is found under both Nakheel and Road and Transport Authority (RTA) Conditions of Contract which are closely following the FIDIC Conditions of Contracts.

Nakheel Conditions of Contract: Clause 44.2 Contractor to Provide Notification and Detailed Particulars
"Provided that the Employer Representative shall not make any determination unless the Contractor has:

a) *within 7 days after such event has first arisen notified the Employer Representative with a copy to the Employer, and*
b) *within 21 days after such notification submitted to the Employer Representative detailed particulars of any extension of time to which he may consider himself entitled in order that such submission may be investigated at the time.*

Such detailed particulars shall include reference to the programme submitted to the Employer Representative pursuant to Clause 14 and shall clearly set out the basis and justification for extension of time to which the Contractor is of the opinion that he is entitled to receive.

If the Contractor fails to give notification of delay as required by paragraph (a) above, the Time for Completion shall not be extended, the Contractor shall not be entitled to additional payment, and the

Employer shall be discharged from all liability in connection with the claim. If the Contractor gives notification of delay as required by paragraph (a) above but fails to submit detailed particulars of any extension of time to which he may consider himself entitled as required by paragraph (b) above, any extension of time and/or additional payment shall take account of the extent (if any) to which the failure has prevented or prejudiced proper investigation of the claim"

3.3. Operation of Time-bar provisions under UAE Civil Code

It can be observed that there are no specific provisions provided under the UAE Civil Code which addresses the issues relating to the time-bar provisions. However, pursuant to Articles 258 and 259 of the Civil Code, it states that the parties' intention must be upheld when it is clearly defined and without ambiguities.

Furthermore, Article 886(1) of the UAE Civil Code which can be interpreted as condition precedent states that:

"…if it appears … it is necessary for the execution of the plan, …, substantially to exceed the quantities on the itemized list, the contractor must immediately notify the employer thereof, …, and if he does not do so he shall lose his right to recover the excess cost over and above the value of the itemized lst."

Article 886(2) of the UAE Civil Code stretched the importance of the specified notice as it gives the employer a right to withdraw from the contract if the exceeded quantities are significant. It is therefore, such notice that would alert the employer of the possible financial consequences and allow the employer to avoid this by withdrawing from the contract after compensation to the contractor. Hence, such a condition aims to protect the employer's and the contractor's interests.

The UAE Civil Code Article 246, stipulates that "*the contract must be performed in accordance with its contents, and in a manner consistent with the requirements of good faith*."

Notice provisions aim to protect the employer from losses and provides an early opportunity to mitigate that harm, so that a contractor who denies this right and breaches the contract could be considered as a party who performs in bad faith.

On the contrary, if the employer who caused the delay and is well aware that it could result a delay or extra money, but is trying to deny the claim simply due to the reason that the contractor has failed to comply with the notice provision, it could be argued that the employer is acting on bad faith.

In addition, if the delay is caused by the engineer, such as engineer's instructions, or the delays that would be obvious to the engineer as he is on-site and therefore should be aware of the site condition and day to day events on the site, it could be argued that it is unfair to not consider such a claim because of the slight delay of the submission or noncompliance of a notice provision. In such case, it could be argued that the engineer is acting in bad faith.

Article 318 and 319 of the UAE Civil Code recognise that unjust enrichment is unlawful. If a contractor's claim is rejected simply due to the reason that the contractor has failed to comply with the notice provision it could be argued that the employer is getting unjustly enriched by benefiting from additional work while avoiding the payment by relying on a procedural technicality.

Furthermore, Article 106 of the UAE Civil Code provides that the exercise of right shall be unlawful if, the interests desired are disproportionate to the harm that will be suffered by the other party. It can therefore be argued that the financial losses to the contractor is largely disproportionate to his failure of simple procedural compliance according to the contract. This argument can be further strengthened if the delays or additional money was known to the employer or was caused by the employer.

Nevertheless, it must be noted that Article 886(2) of the UAE Civil Code addresses a particular circumstance and does not address the claims for delay or additional money in general and does not cover for all the event that may occur throughout the life of the project.

Considering the above and the other provisions of the UAE Civil Code, David Thomas QC, cited in Marican (2013), also claims that it has long been suggested that legal systems in the Middle East may not enforce such provisions. Further consideration should be given to Sharia law as the Sharia is a main source of legislation in the UAE.

Harley and others v Smith and another [2010] EWCA Civ 78 in UK explored limitation periods in Sharia law. Although this was not a construction case, the court considered the concept of time limitation under the Saudi employment law, which in this case was one year.

The court consulted two experts on Islamic law – Professor Adnan Amkhan, an Honorary Fellow at the University of Edinburgh, whose primary expertise is in Islamic law, and Mr Alissa, an attorney licensed to practice in the KSA.

In the judgment, both experts concluded in a joint statement as follows:
"*Unlike modern Arab legal systems, Sharia does not recognise the concept of time limitation…"*

4. CONCLUSION

In exploring the law applicable to the construction contracts, it was found that there is currently no federal or emirate-¬level construction law, specifically for construction contracts. The primary source of law pertinent to construction operations was identified as the Law of Civil Transactions of the State of the United Arab Emirates (the Civil Code) was enacted by the federal government pursuant to Federal Law No. 5 of 1985 on 29 March 1986 specifically, Sections 1 to 4 which contains twenty-four Articles.

These twenty-four Articles, Articles 872 to 896 of the Civil Code are the basis on which the construction contracts are currently regulated in the UAE.

It was observed that the UAE Civil Code does not address, recognize or reject time bar provisions of a contract under an express provision. However, good faith principle (article 246), causing disproportionate harm (article 106) and unjust enrichment (article 318 and 319) may act strongly against the contractual notice regime.

Hence it can be safely argued that in the UAE, a failure to serve a notice would not necessarily restrict the Contractor's entitlement, particularly when the delay is caused by the employer.

In light of the above findings of this research, it was found that that the time bar provisions are not enforceable, particularly when the delay is caused by the employer, under the UAE Civil Code, even though they exist in currently used conditions of contracts in UAE.

Hence, it is recommended that a regulatory body must be formed in order to oversee the construction industry and the currently used conditions of contracts in UAE must be reviewed and amended according to the governing law of the country.

The findings and recommendations of this research may have limited applications due the relatively new and unexplored nature of UAE construction law, limited resources/ authorities available and the nonexistence of juris president in UAE Civil Law.

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The impact of the decline of Oil prices in construction industry growth in Kuwait

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Abstract

Since peaking at $128.14 in March 2012, the oil price has fallen dramatically, hitting a low of $29 in February 2016; a decline of 75 percent. This research will investigate the effect of the dramatic decline in oil prices over a short period, specifically 2013-2016. Government expenditure in fiscal years 2014/15 and 2015/16 remained largely unaffected, however starting 2016/2017; many government agencies started scraping major new projects, while strategic projects remained untouched. It is expected, that oil price movements do have a material impact on economic and capital expenditure in the construction industry. This research will study the impact on the components of the construction industry and the project finance activity. The research will focus on the impact on financial instructions in financing projects, and secondly the impact on the supply and demand of major construction materials for the next five years 2016-2020. The research has the objective of studying the impact of oil prices in future construction activity over the period of the next five years.

Keywords:

Construction Management, oil prices, construction industry, forecasting

1. INTRODUCTION

Kuwait's economy is heavily reliant on oil. In 2013, for instance, the hydrocarbon industry accounted for 55.9 percent of total output and 93.6 percent of government revenue. Changes in the oil price will most certainly have a material impact on gross domestic product or GDP. All the same, in 2013, government and private sector consumption expenditure represented only 41 percent of GDP, with net exports and fixed capital formation accounting for the remaining 45 percent and 14 percent respectively. Many experts anticipated that the recent decline in the oil price does not therefore necessarily imply less consumption in the domestic economy (Institute of Banking Studies 2015).

Economic activity in the nonoil sector has continued to expand see Table 1. Nonhydrocarbon growth slowed from 5 percent to an estimated 3½ percent in 2015, as higher uncertainty weighed on consumption. The main risk to the outlook stems from a further sustained decline in oil prices. Slow project implementation, more volatile global financial conditions and spillovers from heightened regional security risks could also affect economic prospects (IMF 2017).

Kuwait is considered an oil-dependent country; and while Kuwait and other GCC countries are projected to grow by 3.7% in 2016 and 2017. While this rate is considered high compared to other emerging markets, they remain below the region's average growth rate of 5.8% between 2000 and 2011. The reason for the slowdown is the decline in oil prices. While rising government expenditure, coupled with falling oil prices have influenced the GCC region, not all markets have reacted in this same pattern. Despite similarities in economic structures, the countries differ in terms of economic size, population, levels of diversification and fiscal break-even prices. Kuwait non-oil GDP growth is expected to rise to 3 percent in 2017 and 4 percent thereafter as indicated in a recent International Monetary Fund report about. Kuwait Government had recently adopted Kuwait Development Plan that will support gradual recovery in real non-oil GDP growth to 3 percent in 2017 and 4 percent thereafter.

Table 1. Kuwait: Selected Economic Indicators, 2013–2021

			Est.	Proj.					
	2013	2014	2015	2016	2017	2018	2019	2020	2021
Oil and gas sector									
Total oil and gas exports (billions of U.S. dollars)	108.6	97.6	48.8	45.0	54.0	57.8	60.4	63.7	66.5
Average oil export price (U.S. dollars/barrel)	105.4	98.0	51.9	44.0	51.9	54.4	55.9	57.8	59.3
Crude oil production (millions of barrels/day)	2.93	2.87	2.86	2.97	3.03	3.09	3.15	3.22	3.28
	(Annual percentage change, unless otherwise indicated)								
National accounts and prices									
Nominal GDP (market prices, in billions of Kuwaiti dinar)	49.4	46.3	34.3	33.8	38.2	41.1	43.9	47.1	50.4
Nominal GDP (market prices, in billions of U.S. dollars)	174.2	162.7	114.1	111.3	125.8	135.3	144.6	155.2	166.0
Real GDP [1]	0.4	0.6	1.2	3.6	2.6	2.6	2.8	2.8	2.9
Real oil GDP	-1.8	-2.1	-0.3	3.9	2.0	2.0	2.0	2.0	2.0
Real non-oil GDP	4.0	5.0	3.5	3.2	3.5	3.5	4.0	4.0	4.0
CPI inflation (average)	2.7	2.9	3.2	3.4	4.5	3.6	3.4	3.4	3.4

Source IMF Special report on Kuwait (2017)

2. RESEARCH OBJECTIVES AND IMPORTANCE

This research will examine the effects of lower oil prices on the Kuwaiti economy and on the construction industry. No existing or current research investigated the impact of current events or addressed the potential impact on the economy and government expenditure on construction activities. Specifically, the research will forecast the impact for the next five years 2016-2020.

The stated objectives of this research are to investigate the extent to which:

1. Lower oil prices could lead to a freeze or reduction in government spending on the construction sector.
2. Lower oil prices could lead to lower spending by the private sector and construction material suppliers.
3. Lower oil prices could lead to lower growth in deposits, which in turn could lead to slower construction growth.

Thus, the objectives will project a range of possible economic outcomes for fiscal year 2015/16 given different potential average oil prices. The methodology stated in this proposal will enforce fulfilling these objectives. The methodology, which will be focused on structured interviews, will look at the likely impact of lower oil prices on loan growth, loan quality, and deposit funding in relation to the construction industry.

Construction industry activities play a very important rule for the state of Kuwait's private sector and people of Kuwait. The importance of this research comes to fact that lower oil prices will lead to a freeze or reduction in government spending and that lower oil prices lead to lower spending in the private sector. Another importance that research could bring is the effect of low oil prices on material prices and how that can it affect the people.

3. KUWAIT CONSTRUCTION INDUSTRY

The Kuwaiti construction industry will continue to expand in real terms over the forecast period (2016–2020), with investments in infrastructure construction, healthcare, industry, educational facilities and housing projects continuing to drive growth. "Growth will also be driven by the country's Vision 2035, under which the Government aims to develop the country's road, rail, airport and related infrastructure.

As for construction activities, and because of this depression in oil price, there will be a delay in both the decision-making of governments and reduced investment commitment in the awarding of project contracts. A low energy cost has a direct correlation with low commodity prices resulting in increased investment in the energy and industrial sectors of the economy. Despite plunging oil prices and projected contraction in the GCC economy, all countries, with the exception of Oman, are predicted to show current account surpluses in 2015. This coupled with huge financial reserves and overseas assets to fall back on, means GCC Governments will continue to invest strongly in the important projects within the education, residential, infrastructure, hospitals, and utility sectors of the economy, meaning a continued demand for construction. Among the most resilient of the GCC states, Kuwait is in the strongest position, owing to their low fiscal breakeven oil price of $53 and $78 per barrel respectively, on top of their relatively large reserves.

As for project financing by Kuwait banks, the oil price movements do have a material impact on system-wide bank deposits. All the same, ‘excess' funding among the Kuwaiti banks suggests that slower deposit growth, caused by lower oil prices, should have little effect on the provision of credit. Many financial institutions will be tested too if their exits particular risk to loan book quality from the recent decline in the oil price.

The methodology that was adopted in this research is typical. It involves the following steps:

1. ***Literature review*. A**n adequate review of the current literature or previous research that studied the impact of oil prices on construction growth will be collected. The proposed research will be correlated with current reports and studies that centered on other economic sectors.
2. ***Data Collection.*** A Data collection were targeted toward price movements of basic construction materials such as steel, cement, etc. from 2007 to 2017. Also date collected were collected in terms of number of contracts signed and number of cancelled projects that were planned to be tendered during the period of oil prices decline.
3. ***Analysis of information collected.*** After collecting the needed information from the experts, data will be analyzed using a simplistic statistically method, such as M.S.Excel, do determine trends that research investigator will base his writing the report. Specialized statistical software such as SPSS was considered in analyzing data collected.

4. ***Writing report***. The final report will be written, after writing a preliminary manuscript and discusses with a related conference, to get more feedback to finalize the report. Once the final report is written, a journal paper will be written and send to journal (not yet identified) for possible publications.

4. RESULTS AND FURTHER INVESTIGATION

4.1 Data Collection

Data collected from many local and international agencies. These data collected for the period from 2007 to 20017. These data were regarding the following:

1. Steel prices in Kuwait for a 14 mm diameter. These prices were collected from historical data from three general contractors who working in construction industry in Kuwait, and two steel vendors. Figure 1 shows steel prices for such period

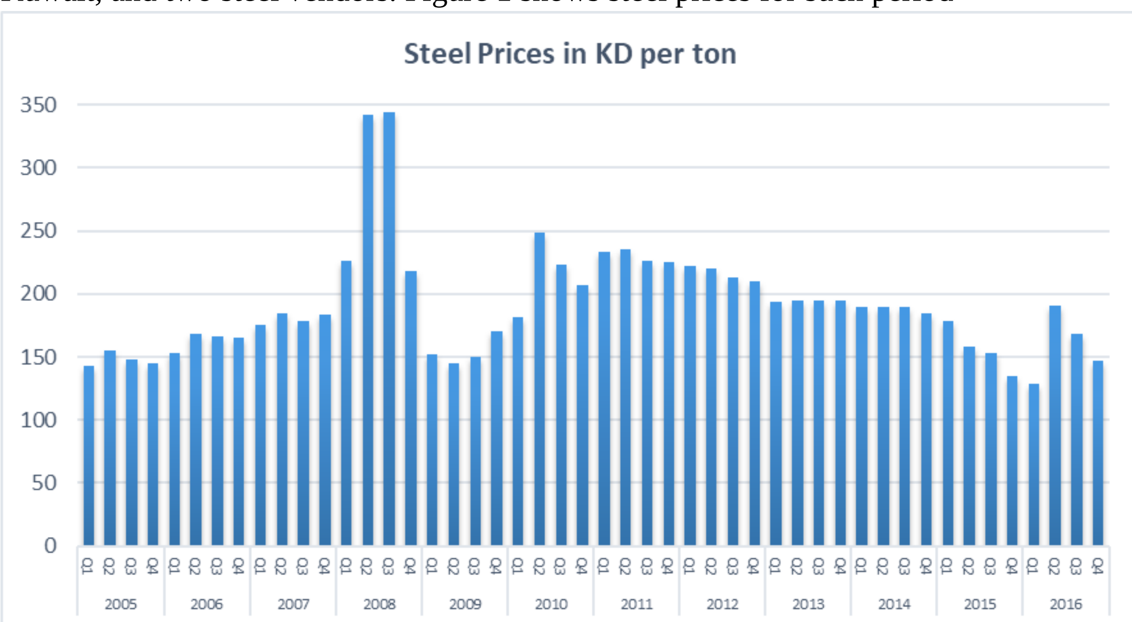

Figure 1 Steel prices in KD for period from 2005-2016

2. Cement prices in Kuwait for ordinary Portland cement bag 50 kg. These prices were collected from three general contractors working in construction industry in Kuwait. These prices varies from 1.1 to 1.2 KD/bag.

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3. GDP values. These values were collected from Kuwait central bank web site and Kuwaiti central statistical bureau publications. Figure 2 shows GDP values in thousands $ dollars in period from 2005 till 2017.

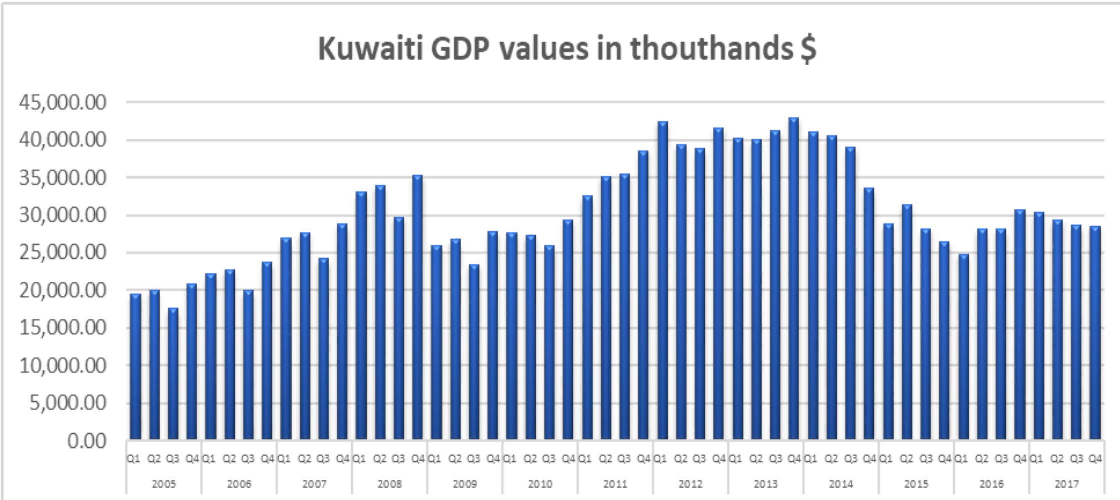

Figure 2 Kuwaiti GDP values 2005-2017 *source: Kuwait Central Bureau and KCB*

4. Kuwaiti crude oil prices. These prices were collected from Kuwait Central Bureau and Statista. Figure 3 shows Kuwaiti oil crude oil prices for this period.

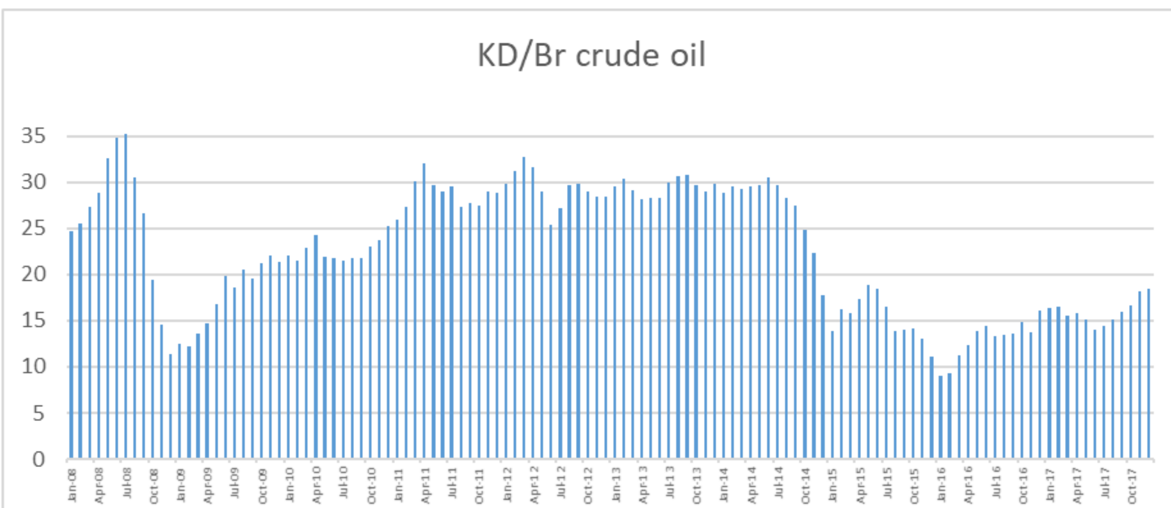

Figure 3 Kuwaiti crude oil price (KD/Br) – *source: Kuwait Central Bureau and Statista*

5. Number and values for awarded and cancelled contracts. These numbers were collected from Ministry of Public Works (MPW) documents. MPW is the ministry which is responsible for governmental construction projects in Kuwait. Table XX shows numbers and value of contract awarded for MPW from 2007 to 2017

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Table 2 MPW contracts awarded from 2007-2017 – *Source MPW documents*

year	buildings projects		maintenance projects		infrastructure projects		big projects		total	
	no	value (KD)	no	value (KD)	no	value (KD)	no	value (KD)	no	value (KD)
2007	9	107,318,575	26	52,357,134	7	102,949,550	1	117,719,887	43	380,345,146
2008	14	203,249,133	23	34,736,402	6	36,934,993	1	14,232,750	44	289,153,278
2009	16	395,063,845	24	46,576,004	13	174,904,507	0	0	53	616,544,356
2010	15	189,343,314	29	62,167,648	22	474,146,640	1	328,013,000	67	1,053,670,602
2011	3	64,557,338	14	15,722,214	12	348,356,023	0	0	29	428,635,575
2012	4	19,965,171	34	36,039,739	11	841,073,685	0	0	49	897,078,595
2013	6	50,886,558	24	33,407,103	7	33,468,900	0	0	37	117,762,561
2014	3	69,682,189	14	20,269,545	15	245,305,190	0	0	32	335,256,924
2015	8	69,759,710	9	8,561,564	5	129,768,666	0	0	22	208,089,940
2016	5	277,482,789	24	38,731,209	13	662,420,719	1	929,077,051	43	1,907,711,768
2017	3	73,366,160	10	29,974,768	13	531,823,522	0	0	26	635,164,450
	86	1,520,674,782	231	378,543,329	124	3,581,152,395	4	1,389,042,688	445	6,869,413,194

4.2 Correlation values

Correlation value is calculated by statistical analysis software "SPSS 24". Table 3 shows Pearson correlation values for steel prices, Kuwaiti crude oil prices, GDP values, cement prices, values of awarded and cancelled contracts for the period from 2007-2017. The correlation coefficient can range from −1 to +1. The larger the absolute value of the coefficient, the stronger the relationship between the variables. In Pearson correlation, an absolute value of 1 indicates a perfect linear relationship. A correlation close to 0 indicates no linear relationship between the variables. As shown in Table 3, Pearson correlation values between table variables are non-significant. It means that there is no significant for linear relationship between these variables.

Table 3 shows that there is strong correlation between oil price, steel price and GDP value for this period of time.

		steel prices	oil price	GDP	cement price	Contract award.	contract cancelled
steel prices	Pearson Correlation	1	0.561	0.541	0.255	-0.208	0.046
	Sig. (2-tailed)		0.058	0.070	0.423	0.565	0.899
oil price	Pearson Correlation	0.561	1	0.536	0.480	-0.458	0.265
	Sig. (2-tailed)	0.058		0.059	0.097	0.156	0.430

GDP	Pearson Correlation	0.541	0.536	1	-0.296	-0.294	0.286
	Sig. (2-tailed)	0.070	0.059		0.326	0.380	0.395
cement price	Pearson Correlation	0.255	0.480	-0.296	1	-0.334	0.028
	Sig. (2-tailed)	0.423	0.097	0.326		0.316	0.935
contract award.	Pearson Correlation	-0.208	-0.458	-0.294	-0.334	1	0.016
	Sig. (2-tailed)	0.565	0.156	0.380	0.316		0.964
contract cancelled	Pearson Correlation	0.046	0.265	0.286	0.028	0.016	1
	Sig. (2-tailed)	0.899	0.430	0.395	0.935	0.964	

Table 4 shows the Pearson correlation values for the same variables for the period of oil prices declining from 2013-2017. The significant result of this table can be extracted that, the correlation values for steel price, oil price and GDP values are significantly correlated, which mean there is a linear relationships between these values. It is also worth mentioning, that before 2013, there was weak or no significant relationships between those values.

Table 4 Pearson correlation values for the period from 2013-2017

		steel prices	**oil price**	**GDP**	**cement price**	**contract award.**	**contract cancelled**
steel prices	Pearson Correlation	1	.987*	.995**	0.534	-0.534	0.448
	Sig. (2-tailed)		0.013	0.005	0.466	0.466	0.552
oil price	Pearson Correlation	.987*	1	.996**	0.660	-0.654	0.502
	Sig. (2-tailed)	0.013		0.000	0.225	0.231	0.389
GDP	Pearson Correlation	.995**	.996**	1	0.647	-0.605	0.463
	Sig. (2-tailed)	0.005	0.000		0.238	0.279	0.432
cement price	Pearson Correlation	0.534	0.660	0.647	1	-0.751	0.414
	Sig. (2-tailed)	0.466	0.225	0.238		0.144	0.489
contract award.	Pearson Correlation	-0.534	-0.654	-0.605	-0.751	1	-0.248
	Sig. (2-tailed)	0.466	0.231	0.279	0.144		0.688

contract cancelled	Pearson Correlation	0.448	0.502	0.463	0.414	-0.248	1
	Sig. (2-tailed)	0.552	0.389	0.432	0.489	0.688	
***. Correlation is significant at the 0.05 level (2-tailed).**							
****. Correlation is significant at the 0.01 level (2-tailed).**							

4.3 Regression analysis

As shown in Table 4, the linear relationship between Oil Price and GDP value is significantly correlated. By using SPSS 24, the regression values between oil price and GDP value for Kuwait for the oil price declining period can be calculated. Table 5 shows the regression coefficient between oil price and Kuwaiti GDP value

Table 5 shows the regression coefficient between oil price and Kuwaiti GDP value

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	66481.655	3547.163		18.742	.000
	oil price	987.682	50.389	.996	19.601	.000

Figure >> regression coefficient between oil price and Kuwaiti GDP value

The model for predicting GDP values for the period of declining oil price can be calculated as the following equation:

GDP value in thousands $ = 66481.655 + 987.682 oil price in KD

The model for predicting GDP values for the period of declining oil prices can be calculated as the following equation:

GDP value in thousands $ = 66481.655 + 987.682 oil price in KD

This equation can be used for predicting GDP value for the coming years if the situation of declined prices continues. The research is into further Analysis that will be conducted after this preliminary result, as the second phase is data verification with experts in construction industry and cost engineers.

Acknowledgement

The author acknowledges the support Research Administration – Kuwait University for funding and sponsorship of this research through research EV02/16

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Revolutionizing urban energy planning: A roadmap towards city-level energy modeling in Australia

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Abstract

30 to 70 percent of a city's energy is consumed by its buildings. The current building energy simulation platforms are restricted at the individual building level, while city policymakers and urban planners need to consider energy issues of a much larger scope at the region and city level. Due to the technical complexity and high requirement of data, there is no commercialised city-level energy modelling platforms or applications in the world to date. Drawing on the recent development of CityBES which is still at the trial stage in USA, this study proposes a roadmap for developing a city-level energy modelling platform for Australia. This study proposes that the existing databases of NABERS and NatHERS rating systems could be utilised to develop the prototype of the platform. The platform needs to integrate the functionality of geographical information system such as ArcGIS, energy simulation engines such as EnergyPlus, and cloud computing capability to simulate the energy consumption of all buildings in different regions in a city under different scenarios. City policymakers and urban planners could use this platform to see how much energy could be saved in different regions under different intervention or policy incentive strategies, thereby scientifically backing up the planning and decision making of energy use and development in regions. This platform will, therefore, fundamentally revolutionize the current approach of urban energy planning.

Keywords: Energy modeling; cities; CityBES; Australia

1. INTRODUCTION

Studies have shown that 30% to 70% of urban energy is consumed by buildings (Chen et al., 2017). Therefore, the key strategy for cities to mitigate global warming and reduce greenhouse gas emissions is not only to construct new energy-efficient buildings, but also to transform existing buildings. Planning a building's retrofit strategy is complex as it requires a thorough understanding of the building's operating model, physical characteristics, and energy status. City managers are always faced with even greater challenges as they need to consider the energy retrofit of existing buildings at a regional level. To meet this challenge, a city energy simulation platform is needed to simulate the effectiveness of different retrofit strategies on the energy performance of existing buildings at the regional level. In this case, CityBES was developed by Lawrence Berkeley National Laboratory in the United States. Even though it is still at a development, CityBES has demonstrated the power and effectiveness of a city energy simulation platform (Hong et al., 2016). Until now there is no commercialized city energy simulation platform available in Australia. This study aims to investigate the technical features of the CityBES developed in America and explore the possibility of developing a similar platform for Australia. A roadmap toward city-level energy modeling in Australia was proposed.

2. CITYBES

Developed by Lawrence Berkeley National Laboratories, CityBES is a city-level energy simulation platform. CityBES could be understood from 3 perspectives, namely the data used, the algorithm and software and the use cases. Regarding the data used, CityBES mainly uses weather data, building stock data, GIS data and data on building technology and utility (Chen & Hong, 2018). Regarding the algorithms and software, CityBES was developed by integrating the functions of EnergyPlus, OpenStudio and CityGML. Regarding the use cases, CityBES has various functions such as for energy benchmarking, urban energy planning, energy retrofit analysis and building operation optimization. CBES includes a prototype building database of 16 climate zone office and retail buildings as defined by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers). It also has a comprehensive ECM database containing cost and performance data for 82 ECMs. In the ECM database, the technical specifications and modeling methods of each ECM are described in detail. One can even see the number of inventions and the payback period for each ECM, which helps decision making. These ECMs can be selected as input data and used by EnergyPlus.

First, CityBES can access the city's GIS dataset and generate building inventory data using the international standard CityGML or GeoJSON format. Then, CityBES calculates the solar shading effect by modeling the surrounding buildings and detecting the shared wall to calculate the shading surface. At the same time, the default weather file is automatically inserted into the simulation process based on the GIS location of the building. After that, CityBES analyses the energy-saving potential of urban building renovation methods, gradually moving from small towns to entire cities. Since the partitioning method greatly affects the accuracy of the energy simulation, a new pixel-based algorithm was invented to automatically create hotspots for different building footprints. Finally, based on the selected performance metrics, the user can color code the 3D view of the building on CityBES to obtain performance results. Users can also download hourly load profiles or annual retrofit results for each building. The workflows of CityBES are shown in Figure 1, with Figure 2 demonstrating the screen of CityBES.

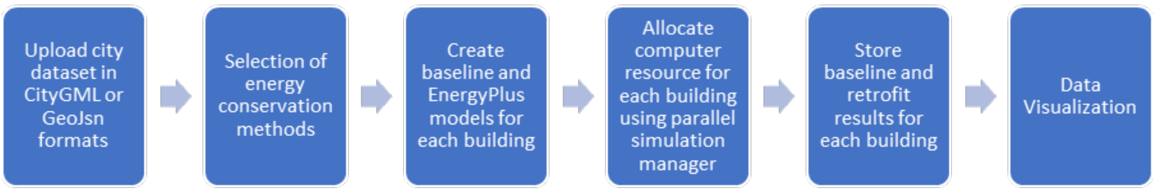

Figure 1. Procedure of CityBES

Figure 2. Screenshot of CityBES for illustrative purpose

3. A ROADMAP FOR CITY-LEVEL ENERGY MODELING IN AUSTRALIA

To develop such a city-level energy modeling for Australia, six categories of data are needed, including city GIS data, building geometry, building operational energy data for model calibration, energy conservation measures, cost data, and climate data. Australia has various organisations which could potentially become the data sources for these categories of data. For instance, regarding the city GIS data, building type and building height, various organisations could become the data sources, such as the Geoscience Australia. Similarly, regarding the building geometry and building system data, the existing NABERS rating system and NatHERS could become the potential data sources. Table 1 summarizes the required data to develop the city-level energy modelling for Australia and the potential data sources. Table 1 shows that, to enable such a system, various organizations need to collaborate with each other to share the data they owned.

Table 1. Required data to develop a city-level energy modeling platform in Australia

Data Category	Potential data sources	URLs
City GIS data including GIS-based building footprint, year built, building type, building height, number of stories, etc.	• Gov Pond • Geoscience Australia • PMSA-Geospace • Australia Urban Research Infrastructure Network	http://www.govpond.org/index.php http://www.ga.gov.au/ https://www.geoscape.com.au/ https://portal.aurin.org.au/
Building geometry (e.g. internal zoning) and building systems (e.g. HVAC systems)	• National Australian Built Environment Rating System (NABERS) • Nationwide House Energy Rating Scheme (NatHERS) • Green Star	https://www.nabers.gov.au/ http://www.nathers.gov.au/ https://new.gbca.org.au/
Building operational energy data for model calibration	• National Australian Built Environment Rating System (NABERS) • CSIRO-Energy Use Data Model • Baseline Energy Consumption and Greenhouse Gas Emissions - In Commercial Buildings in Australia	https://www.nabers.gov.au/ https://www.csiro.au/en/Research/EF/Areas/Electricity-grids-and-systems/Economic-modelling/Energy-Use-Data-Model https://www.energy.gov.au/publications/baseline-energy-consumption-and-greenhouse-gas-emissions-commercial-buildings-australia
Energy conservation measures	• Australia's guide to environmentally sustainable homes • Existing building survival strategy	http://www.yourhome.gov.au/ https://www.propertycouncil.com.au/
Cost data	• Rawlinsons Construction Cost Guide	https://www.rawlhouse.com.au/
Bureau of Meteorology	• Weather data	http://www.bom.gov.au/climate/data/

Figure. 3 further elaborates the process of developing city-level energy modeling for Australia. This paper proposes that there are six key stakeholders in the development process, namely the PSMA Australia Limited, Green Star, AURIN, NatHERS, NABERS, and CSIRO. These stakeholders need to share three key categories of data, including City GIS data, building geometry and system data, and building operational energy data. These organizations have already established several initiatives that could potentially contribute to the development of city-level energy modeling for Australia. For instance, CSIRO has initiated the energy use data model project, which aims to not only capture measured energy consumption data but also key demographic and technology facets of Australian occupants. Similarly, PSMA Australia Limited is in the process of developing Geospace, which provides the footprints of 15 million buildings across 7.6 million km^2. Once these projects are completed and established, the data provided by these projects could be used to develop the city-level energy modelling platform. Policies play a significant role in sustainable construction innovations (Chang et al., 2016; Zhao et al., 2016). To facilitate the corporation among these stakeholders, relevant policies need to be issued.

City-level energy modeling could also be significantly facilitated by the installation of smart meters in households. A smart meter is a device that digitally records electrical energy consumption data and sends it to an energy provider to monitor and form a bill. Smart meters record energy consumption on an hourly or longer rate and report it at least once a day. The smart meter enables two-way communication between the meter and the supplier. With this meter, energy usage data can be recorded and managed. In fact, according to Australian energy regulators, smart meters are being promoted throughout Australia. With the growing popularity of smart meters, building energy management will become increasingly data-driven in the future. The energy consumption data provided by smart meters could significantly contribute to the development of city-level energy modeling. Once developed, the city-level energy modelling platform could also draw data from building information modeling (BIM) tools, to become BIM-supported platform (Lu et al., 2017).

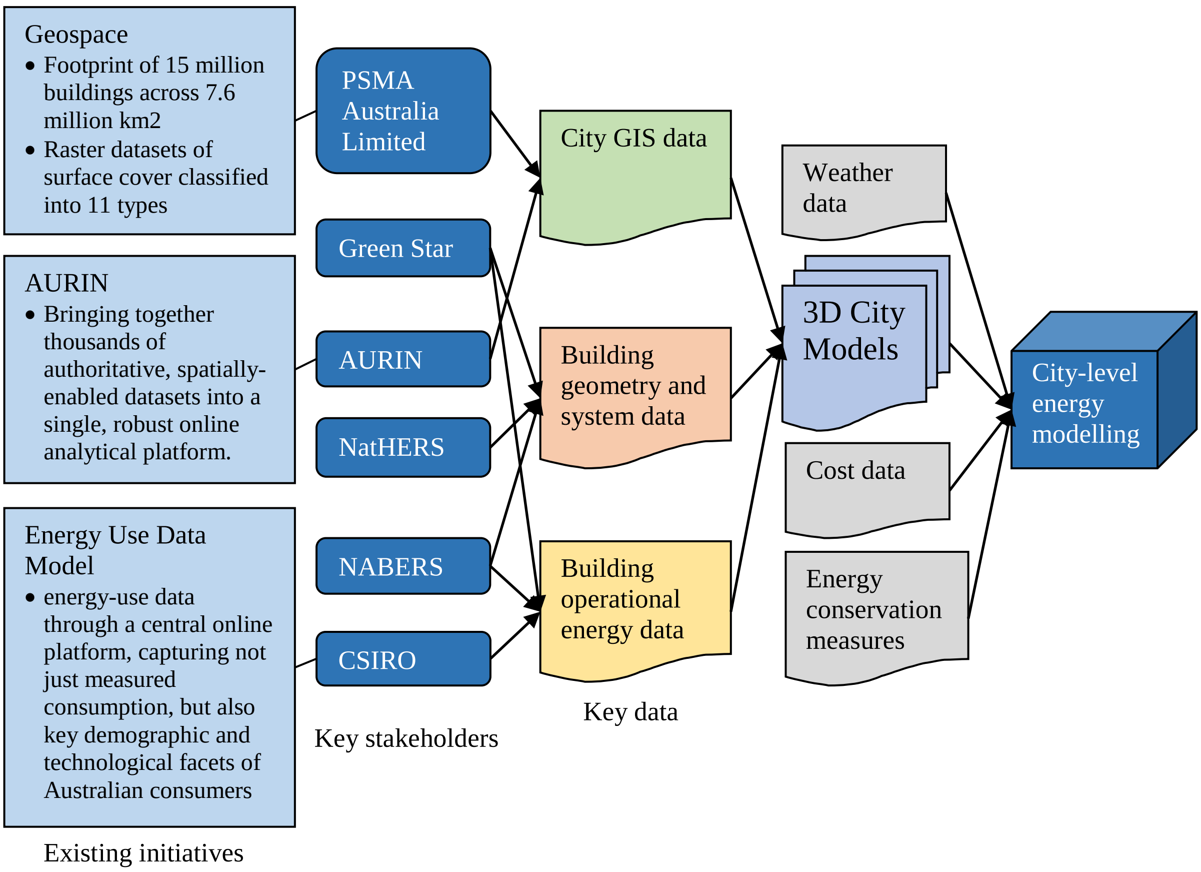

Figure 3. Roadmap for developing a city-level energy modeling platform in Australia

4. CONCLUSION

City level energy modeling could be used by urban planners, utility companies and policy makers to better understand energy consumption at the regional level. By drawing on the experience of the development of CityBES in USA, this paper explores the possibility of developing a city-level energy modeling platform for Australia. This study proposes that six key stakeholders need to collaborate to provide six categories of data. The key categories of data include city GIS data, building geometry and system data, and building operational energy data. Data about whether, cost and energy conservation measures also need to be used in developing the city-level energy modeling platform. The platform could be used for various purposes. For instance, by simulating the effects of different energy conservation measures, the city-level energy modeling platform could demonstrate which measure is the most effective in reducing energy consumption at a regional level. Similarly, the platform could show the solar potential at the regional level as well. This could facilitate the development of renewable energy and the improvement in energy efficiency in the built environment. This study provides a useful reference for urban planner, energy planners, policy makers and scholars in building energy research in Australia.

5. ACKNOWLEDGMENTS

This study was supported by the 2018 faculty research fund from Bond University. The authors would like to thank Guisen Huang, who compiled the existing publications on CityBES for the authors.

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Modelling Hospitals Functional Performance Using MICMAC Analysis: A Resilience Perspective

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Abstract
Hospitals are one of the critical healthcare infrastructure and contribute to the societies by providing various healthcare services. Any interruption in hospital's functions can pose a significant impact on the local community. Improving resilience of hospitals' functional performance (HFP) is therefore very critical so that interruption in their service can be minimised. While many authors offered different approaches for achieving resilience in HFP and reducing vulnerabilities, little attention is given towards understanding the interaction between various hospital performance metrics. By understanding the linkages, it is possible to enhance the HFP efficiently. In this paper, first, metrics and sub-metrics related to HFP was identified by which the resilience of HFP can be measured. Second, the list of HFP metrics and their relative sub-metrics was narrowed down to those elements that a group of experts collectively believed contribute the most to HFP's resilience. Finally, by conducting structural and MICMAC analysis, via identification of the direct and indirect influences of chosen metrics, their influence on the overall HFP resilience was identified and discussed.

Keywords: Hospital Functional Performance, Resilience, MICMAC.

1. INTRODUCTION

Hospitals are part of healthcare facilities which plays a central part in providing social wellbeing, enhancing the local and national economy and dealing with the impacts of disastrous events on society dwellers (Achour and Price, 2010). Hospitals' functions are tied to their physical structure and organisational performance as well as availability of supply and services which are being provided by the Critical Infrastructure (CI) (Arboleda, 2006). In other words, Hospital Functional Performance (HFP) can be impacted by the range of internal and external issues such as increase in the healthcare demands beyond the hospital's capacity, disruption of service of their critical infrastructure (CIs) (e.g. power, water supply) leading to reduction in its capacity, disruption in staffing, etc. HFP refers to the capability of the hospital to perform its critical functions and therefore, its resilience refers to the extent of system's adaptive capacity to absorb stress and maintain its critical tasks. Resilience of HFP is an emerging concept which analyses key features of hospital operational aspects with an aim of enhancing HFP while under stress (Zhong et al., 2014, Mahmoudi and Mohamed, 2018).

HPF depends on factors such as 1) the extent of vulnerability of structural and non-structural components, 2) their critical infrastructure (CI) networks, 3) the potential impacts of events on facilities' occupants, including disruption to staffing, and 4) the role of their external stakeholders and public policies to absorb and response to the adverse impacts. Several studies have been aimed at identifying critical factors for increasing resilience of HFP (a good summary can be found in Mahmoudi and Mohamed, 2018). However, they fell short in addressing the potential inter-relationship between these resilience factors. To address this research gap, in their previous work, authors have developed a Functional Resilience Index (FRI) through which various aspects of resilience of HFP can be evaluated internally and externally. This paper uses empirical data collected from stakeholders of hospitals in the South East Queensland and identifies interrelationship between resilience factors (direct and indirect relationships) and chalk out the critical metrics and activities that contribute the most to the overall resilience of HFP.

2. METHOD

FRI developed by the authors in their earlier work (Mahmoudi & Mohamed 2018) is generated by creating a list of relevant indicators from the literature and identifying most relevant one from the list by a focus group discussion from stakeholders of a hospital. The purpose of conducting the focus group was to identify internal and external metrics needed to evaluate the resilience of HFP. Each identified metric had one or more sub-metrics to facilitate the evaluation. The identified Sub-metrics reflect the critical few sub-metrics by which the metric can be defined. Based on the outcome of the focus group and what has been reflected in the literature, the top eight internal metrics and those sub-metrics representing them were selected for further MICMAC analysis. The aim of using the application of MICMAC is to describe the system and quantify the relationships among the selected sub-metrics (Godet, 2006; Onyango, 2016).

2.1. Structural Analysis Using MICMAC

It is called the Matrice d'Impacts Croisés Multiplication Appliquée á un Classeement (cross-impact matrix multiplication applied to classification) is abbreviated as MICMAC, is a tool structuring idea by using matrix through which of the system's constituent components can be combined. This approach is based on the multiplication properties of metrics (Scholl, 1999) focusing on the essential elements of the system and their relative influence and dependence. In other words, by performing MICMAC analysis allows decision-makers to identify key variables for the system's evaluation via the identification of the existing bidirectional relationships among variables. In the current paper, after identification of the critical metrics and their essential sub-metrics representing HFP resilience, MICMAC analysis was performed to clarify the role of each sub-metrics in the resilience of HFP. The MICMAC model development is following a multi-phase process involving main steps as;

1. Identify relevant variables: the aim of this stage is to finalising those variables via which the resilience of HFP can be represented and measured. The list of metrics was presented by Mahmoudi and Mohamed (2018) finalised via conducting a focus-group (Figure 1).
2. Build the causal relationship between variables: the outcome of this phase is a Structural Analysis Matrix (SAM) in which pair-wise direct relationships among variables are obtained. If there is none, one puts 0. If there is, one must ask if this relationship of direct influence is low (1), medium (2) high (3). To develop the SAM, n x n-1 questions, for n variables, were asked in 1-on-1 interviews with the focus-group participants.
3. Identify key variables: this step is mainly about identifying key variables and factors that are essential to the resilience of the HFP. At this stage, the SAM was compared to the indirect classification by the hierarchy of variables in the various classifications.

MICMAC Analysis follows the steps below to draw the comparison between the Matrix of the Direct Influence and Indirect Influence as;

1. *The Direct Influence/Dependency matrix (MDI)* – the MDI classifies the extent of influence and dependence of the direct interrelationships among various metrics. The strength of their influence is presented in the total number of MDI rows and the extent of their dependence is shown in the total number of their columns.
2. *The Indirect Influence/Dependency matric (MII)* – the MII is derived from MDI, through getting enhanced in power via number (designated as 'n') of successive iterations. Like the MDI, the MII, the sum of columns represents the extent of instability of those metrics while the sum of rows shows the extent of the power that metrics, indirectly, have on other metrics and therefore, the overall HFP.

3. *Influence (Power)/Dependence Comparison of MDI and MII* – this step, highlights the order of metrics based on the extent of their dependence on the impact of the performance of the other metrics, in both MDI and MII.
4. *The Map of displacements is shown in Figure 2* – the objective of performing MICMAC analysis is to analyse the driver power and dependence power of variables.

In the current paper, the MICMAC software (MICMAC, 2018) was used to cumulate the rows and the columns for each element and therefore, developing MDI, MII and their graphs, comparison of influence and dependence and the map of displacement.

3. RESULTS, DISCUSSION AND CONCLUSION

The presented list of metrics by Mahmoudi & Mohamed (2018) ranked by experts by conducting the focus group for identifying the essential metrics needed to evaluate the resilience of HFP. Each identified metric had one or more sub-metrics to facilitate the evaluation. The identified Sub-metrics reflect the critical few sub-metrics by which the metric can be defined. Based on the outcome of the focus group and what has been reflected in the literature, the top eight internal metrics were selected for further MICMAC analysis (presented in Figure 1).

After confirmation of HFP's most important metrics and sub-metrics, MICMAC analysis was performed to highlight the role of each sub-metrics in the system and relative to other sub-metrics. As it is explained in the previous section, via one-on-one interviews with the experts, their collective view on potential relationships was obtained and consequently MDI and MII were developed. Based on the MDI and MII the most powerful direct and indirect influence graphs of sub-metrics are illustrated in Figure 2 and Figure 3. It can be observed that sub-metrics of LS, SP, TD and OP impose the most direct and indirect influence on the other system's components and meanwhile, SC and RD are the most dependent variables of the system. In other words,

Based on the developed MDI and MII, the sums of each row and column was calculated. Based on the calculation of the total influence and dependence of each system's sub-metrics, the Map of displacements (shown in Figure 4) was developed in which it is possible to compare the influence of each sub-metrics on each other and HFP – the the objective of performing MICMAC analysis is to analyse the driver power and dependence power of variables. By developing the diagram of the driver power–dependence and using reachability matrix, the objectives or criteria can be classified into four categories as follows (presented in Figure 4):

i. *Autonomous variable:* The only Autonomous metric in the system is PM. This metric has weak influence and dependence. It is relatively disconnected from the system, with which it has few strong links. Although the direct influence/dependence of PM, after considering the indirect matrix, it moves into the next quadrant.
ii. *Depending variables:* there are two metrics of CM and RD in this quadrant which means both metrics are having little influence on the overall system's performance, yet they are sensitive to changes of influential variables of the system. While these is no significant displacement between their direct and indirect influence on the system, PM becomes more dependent and moves into this quadrant after considering variables' indirect influence on the system.

Metrics	Rank	Sub-Metrics	Description
Facility Safety Design and Construction	*3*	*Redundancy (RD)*	Having redundant systems enhance the resilience if the systems are independent
			Availability of the alternative emergency energy and facilities for backup
Maintenance	*6*	*Preventive Maintenance (PM)*	Revising, maintaining and renewing technical features in compliance with new regulations, periodically
		Corrective Maintenance (CM)	The activities being carried out in order to repair the damages, and recover the function.
			Analysis of cause of the failure and taking corrective course of action
Hospital Infrastructural Safety and Vulnerability	*5*	*Hospital Safety Standard and Procedures (SP)*	Mechanisms for identification of risks and vulnerabilities (e.g. hospital vulnerability assessment, risk assessments)
			The effectiveness of the safety standards withstanding disasters
Disaster Leadership and Cooperation	*1*	*Leadership (LS)*	Establishment of committee for top-down transmit of situation awareness to the staff
		Disaster Cooperation (DC)	Establishing crisis cooperation mechanism within hospital
			Cooperation with community facilities, and external stakeholders
Disaster Plans	*2*	*Operating Procedures to Execute the Plan (OP)*	Having protocols to initiate the plan to guarantee staff and equipment in place immediately
			To what extent the plan can be executed
			Are there any different responsive procedures for different disaster levels and phases
Emergency Staff Capability	*4*	*Constitution of Emergency Group (CG)*	Staff composition of emergency expert group for different types of events
			Staff composition of emergency expatriate team for different types of events
Emergency Training and Drills	*8*	*Emergency Training and Drills (TD)*	Training for different types of events
			The percentage of trained staff
			The content of training and what to include
			The frequency of training
			Are there different incident types for drills
			Different methods for implementing drills
			The frequency of drills
Emergency Critical Care Capability	*7*	*Disaster Surge Capacity (SC)*	Surge capacity of emergency beds
			Surge capacity of emergency resources
			Surge capacity of emergency staff (strategies for emergency staff)

Figure 1. The most influential performance metrics for achieving HFP resilience

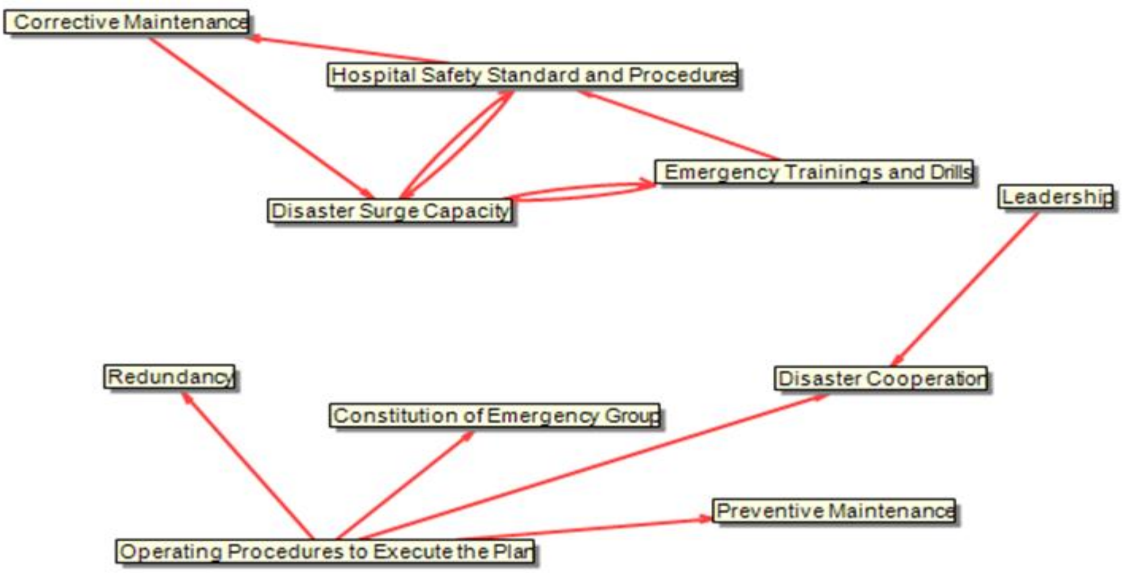

Figure 2. Direct Influence Graph

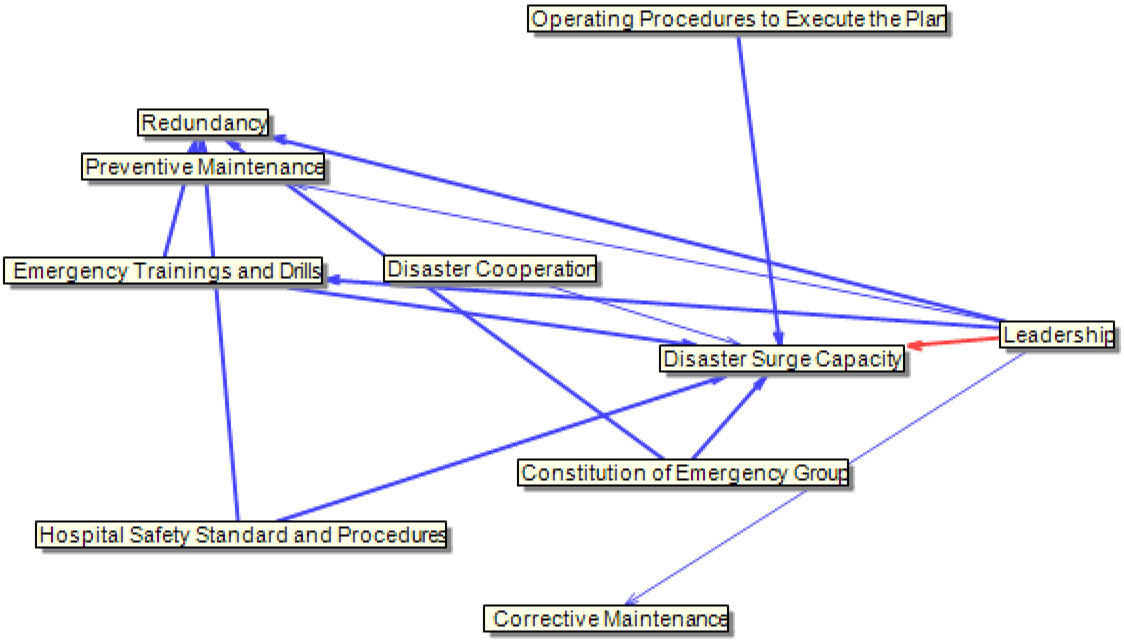

Figure 3. Indirect Influence Graph

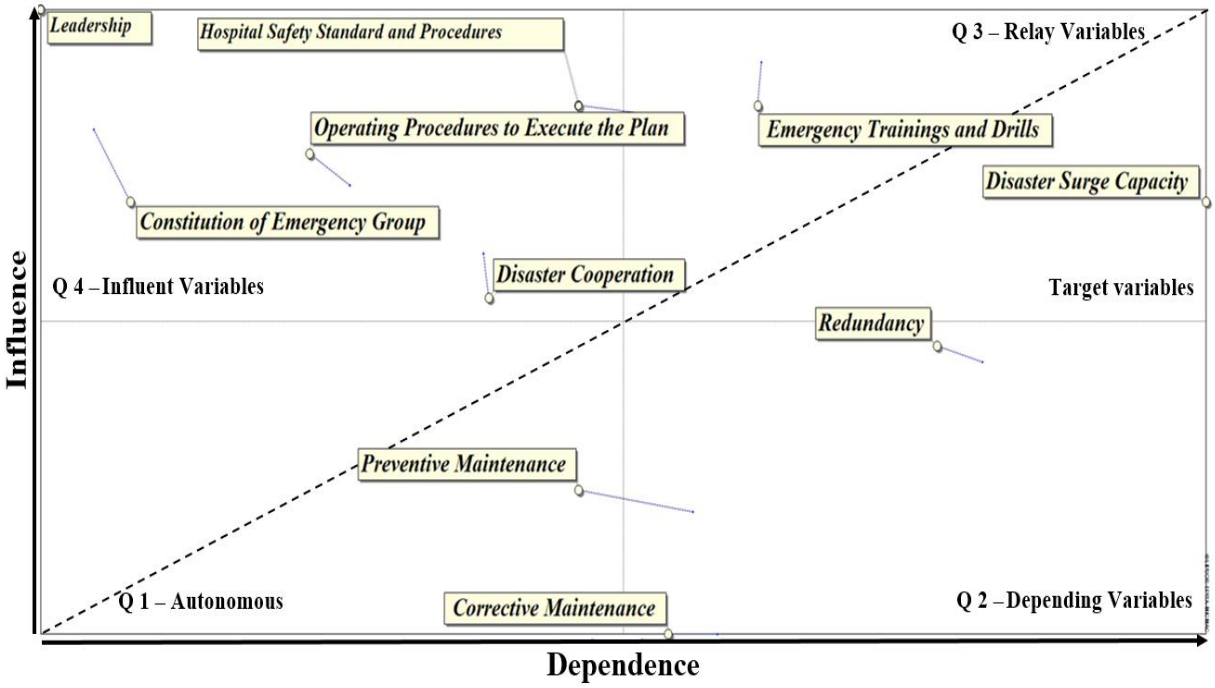

Figure 4. Map of Displacement

iii. *Relay Variables:* there are two relay metrics of SC and TD. These metrics have strong driver power and strong dependence power; therefore, their impact not only can influence other variables, also affecting themselves. While these metrics can instable the system, some of these metrics can be specifically targeted to improve system's performance as;

Target variables: these variables are relatively more dependent than influent. Therefore, they can represent the actions that can be conducted to develop certain objectives for the system to achieve. In Figure 4 third quadrant, metrics under the diagonal SC is the metric that can be assumed to be the evolution of the system and be aimed to enhance the resiliency of HFP.

iv. *Influent Variables:* there are five metrics of LD, CG, SP, OP, and DC in this category. These have strong driver power but weak dependence power. These metrics are key factor of inertia or movement in the system due to the extent of their influence. It can be assumed that the system itself has no influence on these metrics and all together they can have direct and indirect impact on the overall HFP. For the SP which was displaced after the analysis of the MII, it can be assumed that it is more influential rather than dependent due to the extent of its influence drive and having no change in its displacement ranking.

The results of the MICMAC analysis indicate that the most influential and least dependent performance sub-metrics in the HFP are Leadership, Emergency Training and Drills and Hospital Safety Standards and Procedures, and the most dependent and less influential metrics are Redundancy and Disaster Surge Capacity. Therefore, by enhancing the most influential metrics it is possible to target the improvement in the performance of system's surge capacity and redundancy. In total the application of MICMAC analysis, provided an insight into different aspects and dimensions of achieving resilience of HFP based on experts' collective view to the subject matter. The structural analysis has been built on the collective opinion of a group of experts' through which the variables and the interrelationships among them have been identified. Thus, the current paper provided a perspective for looking at the reality of achieving/enhancing HFP due to the subjective nature of structural analysis. Moreover, the outcome of MICMAC indicates what has been perceived as the reality of HFP among the selected group of experts, as much as the system under study.

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Life cycle assessment methods of road infrastructures – insights from past studies

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Abstract

Transportation sector has been considered to have the highest contribution to environmental issues. Road infrastructures play a vital role in everyone's daily life and is therefore encouraged for more environmental friendly and sustainable practices. Objectively and accurately quantifying the sustainability of road infrastructures is the first step towards the reduction of environmental impacts. As such, a large number of life cycle assessment (LCA) studies have been conducted over last two decades. However, existing studies are found to be inconsistent in terms of function unit selection system boundary definition and impact categories evaluated. It is therefore necessary to further the standardisation of the implementation of the LCA approach in road projects to improve utility of this approach. This paper presents some preliminary results of a critical review of existing studies that apply LCA to roads evaluation. The research shows that there is a lack of standardised procedure for conducting LCA on road infrastructures. Specifically, there are inconsistencies in functional unit and system boundary definition when defining goal and scope, limited report on data sources when compiling life cycle inventories, missing impact assessment phase or divergent impact categories selection during life cycle impact assessment and a lack of sensitivity and uncertainty analysis when interpret assessment results. Therefore, further standardising the implementation of the LCA approach in roads evaluation has been recommended for future studies.

Keywords: Life cycle assessment (LCA), roads, sustainable development, green infrastructure

1. INTRODUCTION

The concept of sustainable development has been recognised worldwide since it was mentioned in the 1987 Brundtland Report (World Commission on Environment and Development, 1987). According to IPCC (2014), the buildings and transport sectors together contributed to 60% of global energy use and 32.7% of total GHG emissions in 2010. As such, infrastructure has been recognised to be crucial to achieve sustainability. Road infrastructures play a vital role in everyone's daily life and is therefore considered as important for achieving sustainability.

To integrate sustainability into infrastructure projects, several rating systems were designed worldwide. CEEQUAL in the UK, Infrastructure Sustainability (IS) in Australia and Envision in the US are widely recognised sustainable infrastructure rating systems (Diaz-Sarachaga et al., 2016). They all concentrate on environmental considerations which occupy 62.6%, 70.48% and 71.46% of total points, respectively (Diaz-Sarachaga et al., 2016). Among these environmental concerns, carbon performance-related metrics contribute 4.1% to CEEQUAL (48 metrics in total), 10% to IS (15 metrics in total) and 7.59% to Envision (14 metrics in total). Reducing carbon emissions is therefore vital to achieve any award of the sustainable infrastructure rating systems.

Estimating and analysing emissions is the first step to reduce the environmental impacts of a product or process (Sandanayake et al., 2017). As such, LCA has been widely adopted to evaluate road construction and maintenance. Despite the large number of LCA studies in road evaluation, the existing studies are also found to be inconsistent in terms of function unit selection, system boundary definition and impact categories evaluated (Inyim et al., 2016). It is therefore critical to further the standardisation of the implementation of the LCA approach in road projects to improve utility of the approach. This study aims to evaluate the current development and implementation of LCA in road projects and identify the limitations of current evaluation steps.

2. RESEARCH METHOD

A comprehensive literature review is conducted adopting a seven-step approach as Thomé et al. (2016) suggested. First, the research aims and the expected outcomes are defined, as aforementioned. The second step is to defined search strategies. The Web of Science database is selected for primary data collection and Scopus considered for cross-checking, which were representative for their coverage and quality. During the search, keywords of ("life cycle assessment" or "LCA") AND ("road" or "pavement") are used to identify articles that contain such keywords in the article's title, abstract or keywords section. It has also been decided that only peer-reviewed journal papers will be selected based on quality considerations. The following two steps are data collection and quality evaluation, following the strategies defined in the previous step. As a result, 82 peer-reviewed journal papers that aim to apply LCA to road assessment are retrieved.

The fifth and sixth steps include data analysis and interpretation, followed by the last one which refers to results presentation. Content analysis, which is commonly adopted and recommended as the best fit for analysing textual data, is adopted (Erlingsson and Brysiewicz, 2017). According to Erlingsson and Brysiewicz (2017)'s guide to doing content analysis, a typical content analysis often includes four steps, namely, 1) getting familiar with the content through reading and re-reading processes, 2) dividing up the texts into meaning units and condensing the units into short versions; 3) coding the condensed meaning units and; 4) sorting the codes into categories or themes according to the research questions or objectives. The codes for this study include: year, author, journal, location, functional unit, system boundary, life cycle assessment method, selected database, impact category, major findings and future needs. This paper only presents some preliminary findings as part of the literature review has been conducted.

3. FINDINGS AND DISCUSSION

According to ISO 14044 (2006), a LCA usually comprises four steps, namely goal and scope definition, life cycle inventory compilation, life cycle impact assessment and life cycle interpretation of results. Interpretation can be very subjective and varied from different studies, therefore this study only considers sensitivity and uncertainty analysis which is required in interpretation stage.

3.1. Goal and scope definition

3.1.1. Functional unit (FU)

There are several various ways of describing a FU for a road. This is probably due to a lack of standardised procedures to follow or parameters to consider when defining a FU in the ISO 14044. For complex systems such as roads, the definition is therefore hard.

Among the 82 retrieved papers, 59 (72.0%) used road length, such as kilometre, lane-kilometre and lane-mile (e.g. Cass and Mukherjee, 2011). 10 (12.2%) used area such as square metre as their FUs where their scopes were focused on the surface or wearing course of the pavement (e.g. Hassan, 2010). Another FU used was the whole project, which was usually used when deciding a strategy (e.g. road closure scheme during rehabilitation) for a given road project (e.g. Hanson and Noland, 2015). Others also used volume (e.g. cubic metre, cubic yard) to deal with the impacts of earthworks or recycling of materials (e.g. Capony et al., 2013).

However, a lane mile, or a square metre cannot be used as a standard FU (Cass and Mukherjee, 2011). It was pointed out by AzariJafari et al. (2016) that road functions could not be appropriately reflected if the FU did not take roadway classification, lane width and number of lanes into account. However, such information were rarely fully stated when defining FUs in existing studies. In addition, the missing consideration of condition of pavement is also a shortfall in existing FU definition. Unlike other products or service, the conditions of a pavement often deteriorate over the long service life and therefore directly influence the function of a road. Thus a FU that captures the changeable condition and performance of the pavement is required.

3.1.2. System boundary

Generally, there are six phases during a road's life cycle, namely materials extraction and production, transportation of materials, construction, use, maintenance and repair (M&R) and end-of-life (EOL) phases. Materials extraction and production usually includes the processes needed to manufacture the road materials, from the acquisition of raw materials to the final production of materials (i.e. mixing plant operations). The construction stage includes all preservation and construction activities, such as the combustion of fuels of paving equipment. For rehabilitation projects, the traffic delay caused by construction activities should also be included in this phase (Celauro et al., 2015). The transportation of materials from manufacturing plants to construction sites is often integrated into the construction stage (e.g. Zhang et al., 2010) and in some cases treated as a separate one (e.g. Hassan, 2010). The use stage is not well defined, but often includes the fuel combustion and emissions from vehicular activities (Yu and Lu, 2012). M & R stage focuses on maintenance treatment of roads, including routine maintenance, preservation and rehabilitation (Torres-Machi et al., 2018). In addition, EOL stage usually considers the demolition of roads and the transport, recycling and final disposal of wastes (Celauro et al., 2015). Among the 82 papers, 79 (96.3%) considered materials extraction and production phase, 52 (63.41%) included transportation of materials, and 70 (85.37%) evaluated the environmental impacts of construction phase. However, only 24 (29.27%) considered use phase, 9 of which only gave limited consideration; 48 (58.54%) took into account M & R stage and 26 (31.71%) included EOL stage in the system boundary.

3.2. Life cycle inventory (LCI)

3.2.1. LCI data sources

The International EPD® System categories data to three kinds for the LCI phase, that is, primary data, secondary data and tertiary data. Primary data refers to first-hand data usually obtained by on-site surveys and field investigations; secondary data can be obtained in the literature, including published articles, annual environmental reports and commercial databases and; tertiary data is often available through statistical averages (Moretti et al., 2017). In existing studies, 10 (12.20%) used primary data such as field investigation (e.g. Cass and Mukherjee, 2011) and self-developed local or regional database (e.g. Al-Qadi et al., 2015). Because of the hardship of obtaining first-hand data, over half (49, 59.76%) used secondary data, including published literature, authorised reports (e.g. reports from EPA) and commercial databases (e.g. Ecoinvent mostly applied, U.S. LCI databases, etc). Some of the aforementioned papers used both primary and secondary data (e.g. Giani et al., 2015). Others (30, 36.59%) did not report the data source, which may result in high uncertainty in the LCI results.

3.2.2. LCA Tools

The selection of LCA tools is usually related to the adopted LCI method. Most of the papers that adopted a process-based LCA method chose SimaPro or GaBi software, especially SimaPro (Giani et al., 2015; Vidal et al., 2013). SimaPro and GaBi were both developed 25 years ago, created by PRé Sustainability Company and Thinkstep Company, respectively. For EIO-LCA, the most used tools were PaLATE and EIO-LCA model. PaLATE is short for The Pavement Life-cycle Assessment Tool for Environmental and Economic Effects, specially designed to assess environmental and economic impacts of pavement and roads. Economic Input-Output Life Cycle Assessment (EIO-LCA) model is an online tool designed by the Green Design Institute at Carnegie Mellon University, aiming to make EIO-LCA method fast, easy and free. For Hybrid LCA, however, there is no widely used tool yet.

3.3. Life cycle impact assessment (LCIA)

3.3.1. LCIA methods

Generally, there are two main schools of impact analysis methods (Van den Heede and De Belie, 2012). The first school is a damage oriented method representative by Eco-indicator 99, which focuses on the endpoint (where actual environmental effects or damages occur) environmental damages such as damage to human health, damage to ecosystem quality and damage to mineral and fossil resources. The second one is considered to be a problem oriented method or midpoint method, representative by CML 2001 developed by the Institute of Environmental Sciences, Leiden University. There are also methods that combine the two methods, such as ReCiPe. In existing literature, only 13 (15.9%) reported their method of impact assessment. 12 adopted a midpoint method, among which 2 applied both the ReCiPe midpoint method and ReCiPe endpoint method (Vidal et al., 2013). The other 1 used BEES impact assessment model, which is not typical midpoint or endpoint method.

3.3.2. Impact categories

Selecting impact categories is a mandatory element of LCIA (ISO 14044, 2006). However, it is noted that there is a lack of a standardised way of reporting the results. A few of the studies only gave simple quantification of the outputs and left out the impact assessment step. For example, Yu and Lu (2012) considered energy consumption and GHG emissions such as CO_2, CH_4, N_2O, VOC, NO_X, CO, PM_{10}, SO_x without conducting further impact assessment. Such omission of the impact assessment step can bring in difficulty in decision-making process since pure estimation of gas emissions is not able to provide intuitive information (Inyim et al., 2016).

Other studies, although interpreted the emissions calculation results to impact assessment, selected extremely varied impact categories and only a few reported the impact assessment method, which makes it hard to conduct cross comparison between different studies. Among these studies, energy consumption and GHG emissions are most consistently used assessment metrics. Other widely used categories also indicate special cares for ecosystem and human health while little consideration have been given to natural resources such as land use. It should also be noted that few authors explained the reasons for choosing certain impact categories, making it hard to tell whether the selection was consistent with their goal and scope.

3.4. Sensitivity and uncertainty analysis

Sensitivity analysis is a compulsory element in a LCA study (ISO 14044, 2006). The aim is to evaluate the reliability of the final results through quantifying the extent to which the results are affected by uncertainties coming from data, allocation methods or LCIA calculation. Therefore, uncertainty analysis is often used as a supplementary and is supposed to quantify uncertainty such as model imprecision, input uncertainty and data variability (ISO 14044, 2006). However, most of current studies neglected such procedure. Only 29 (35.4%) conducted a sensitivity analysis, usually on the effects of transport management and traffic growth (e.g. Yu and Lu, 2012; Batouli et al., 2017); 15 (17.1%) studies conducted an uncertainty analysis. It should also be pointed out that only a few conducted the analysis according to the requirement of ISO 14044 (2006). Some implemented a sensitivity analysis without clearly reporting the results (Wang et al., 2012), some others implemented a separate uncertainty analysis or utilised a sensitivity analysis to address the uncertainty (e.g. Giani et al., 2015; Wang et al., 2012). Interestingly, this misunderstanding does not necessarily mean a failure in fulfilling the aim of sensitivity check. This may suggest a need for a clearer definition of the differences and relations between sensitivity analysis and uncertainty analysis.

4. CONCLUSION

The analysis on the existing LCA application studies on roads reveals a lack of standardised procedure of conducting LCA in road infrastructures, which includes:

- **Goal and scope:**
  - o Inconsistent selection and definition of FU. This is mainly due to a lack of standardised procedure of defining a FU and the complexity of road conditions.
  - o Inconsistent selection of system boundary. Specifically, there are limited studies on use and M & R phases and most studies fail to consider EOL stage.

- **LCI:**
    - Limited report of data source, which may result in high uncertainty in final results.
- **LCIA:**
    - Lack of standardised LCIA procedure. This includes missing impact assessment phase and an inconsistency of choosing impact categories, resulting in the difficulty of conducting comparisons across existing work.
- **Life cycle interpretation:**
    - Lack of sensitivity and uncertainty analysis. The lack of sensitivity and uncertainty considerations indicates high uncertainties on the reliability of the results concluded by existing publications.

It can be concluded that there is a need to further standardise the procedure of applying the LCA approach in road infrastructures evaluation, and it will be conducted in future work. In addition, this study only focuses on existing studies that apply LCA in roads while omit others which aim to improve the approach or develop tools to better adapt the LCA approach to roads assessment. Therefore, there will be another paper dealing with the modelling development subsequently.

5. ACKNOWLEDGMENTS

This research was funded by the Australian Research Council Discovery Early Career Researcher Award (Project No. DE170101502) by the Australian Government.

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The diversity of CSR practices in various international construction markets

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Abstract
With business activities expanding across traditional national borders, new business models are desired for companies operating in overseas markets. Such business models aim at not only profit-making, but also involving corporate social responsibility (CSR) to enhance their 'soft power'. The primary aim of this research is to analyse the diversity of CSR practices in various host countries, with a focus on international construction. It is hypothesised that the diversity of CSR practices measured by entropy is positively related to the developing levels of host markets, measured by Human Development Index (HDI). Content analysis is firstly adopted to extract data for the 56 selected host countries. Regression model is then applied to test the hypothesis, which is confirmed by this research. Our findings suggest that the contexts where companies embed play an important role in the conduction of CSR practices. The expectations of stakeholders and compliance pressure in the developed countries may be higher than those in the less developed countries. The international construction companies need to take the expectations of various stakeholders in the host markets into account to make their CSR strategies and conduct their CSR practices properly.

Keywords: Diversity of CSR practices, host markets, international construction markets

1. INTRODUCTION

As the consequences of globalisation, traditional barriers are lowered for business activities expanding over national borders, and new social networks with mutual dependences are created, which lead to emerging new responsibilities (Scherer and Palazzo, 2008). The world's development challenges are spotlighted when business activities are involved in the global agenda. United Nations (UN) states in their website that "over the next fifteen years, with these new Goals (Sustainable Development Goals) that universally apply to all, countries will mobilise efforts to end all forms of poverty, fight inequalities and tackle climate change, while ensuring that no one is left behind" (UN, 2016). New business models are thus required for companies operating in the overseas markets, which include not only profit-making, but also respect for the environment, policies on safety, health and well-being of the workforce. International construction companies (ICCs), as individual companies, need to advance their ways to minimise negative impacts and maximise positive effects on society, which desires to involve corporate social responsibility (CSR) agenda in their operations in the host markets. CSR here refers to "companies not only care about the profits but also integrate social and environmental concerns in their business operations and their interaction with their stakeholders" (Communities, 2001). Host markets here refer to the markets (countries) where ICCs conduct business except for their domestic markets.

The host markets offer the outside environment for ICCs to conduct business as well as CSR practices. Drawn from the macro perspective of institutional theory (e.g. DiMaggio and Powell, 1983; Kostova et al., 2008), the socially acceptable patterns of organisational structures and actions are determined by the institutional environment embedded. Oliver (1991) points out that institutional theory offers several unique insights into organisation-environment relations and how organisations react to the institutional environment. More than merely suggesting the action as a reaction to the pressures of the external environment, Wooten and Hoffman (2008) state that institutional theory also asks questions about how social choices are shaped, mediated and channelled by the institutional environment. Many researchers propose the question -*Under what conditions are corporations more likely to act in socially responsible ways than not* to explore the macro-institutional pressures from the companies' embedded environment on corporate engagement in CSR, and use these to demonstrate how CSR varies in particular contexts (e.g. Campbell, 2007; Jackson and Rathert, 2017). They illustrate the influence of such things as health of the economy (Campbell, 2007), connection to the global economy (Baughn et al., 2007), the rise of non-profit organisations (NGOs) (Doh and Guay, 2006), communication and education (Campbell, 2006) on corporate engagement with CSR activities.

CSR, as a part of a company's corporate strategy to behave responsibly and to engage with all the stakeholders in the business and with the general public. It may be seen as a response to pressure from outside stakeholders who may be adversely affected by company practices, or as a pro-active attempt by firms to pre-empt these pressures and enhance the reputation and value of the corporation (Jackson and Apostolakou, 2010). Expectations of stakeholders will not be the same in all different countries (Hillman and Wan, 2005; Mahmood and Humphrey, 2013). CSR has become a strongly institutionalised feature of the contemporary corporate landscape and is a way to gain legitimacy. Especially for construction firms, the projects of which are literally "grounded" in a local environment in the host markets- a building, a bridge, a water plant, or a pipeline is attached to a specific location. Once the site is chosen, it is difficult- and always costly- to relocate (Scott, 2011). It is thus necessary for ICCs to take local conditions into account and conform to social norms and values of the markets wherein they operate. For example, they take more initiatives related to local communities to establish the good relationship with local people.

The primary aim of this research is to analyse the diversity of CSR practices in various host markets conducted by ICCs, thus to examine the outside environment where ICCs are more likely to act in socially responsible ways. As reviewed and discussed above, host markets play an important role in the conduction of CSR practices. Economic development and economic transition can guide stakeholders' perceptions of CSR practices (Wang and Juslin, 2011). In less-developed markets, societal needs are generated to settle the basic livelihood and basic human rights, while in developed markets, expectations of stakeholders would vary as they may desire to concentrate on various social and environmental issues. Therefore, the hypothesis is *H: The diversity of CSR practices is positively affected by the developing levels of host markets*. To test the hypothesis, this paper is structured as follows: following introduction section, the research methods section provides a detailed description of the data and research methods; the third section presents the analysis and results; and discussions and conclusions are presented in the last section.

2. RESEARCH METHODS

To achieve the research aim and test the hypothesis, content analysis is firstly adopted to extract data for the analysis. Afterwards, measurements for two variables are presented: the independent variable- the developing level of the host country, and the dependent variable- the diversity of CSR practices. The regression model is then applied to test the hypothesis.

2.1 Extracting data by using content analysis

Data for the content analysis are from the CSR/sustainability reports of ICCs. The choice of ICCs was determined by referencing to the top international contractors lists compiled by *Engineering News-Record (ENR)* and GRI's Sustainability Disclosure Database. Some of the ICCs were excluded due to the lack of CSR /sustainability reports. Therefore, there remain 68 ICCs to collect their CSR reports. CSR/sustainability reports of the 68 ICCs over the seven years (2011-2017) were retrieved from their websites or the GRI's Database. Not all the ICCs disclose their CSR reports every year. Totally, 369 CSR/sustainability reports are collected for the content analysis.

For the content analysis, an analytic framework is developed to guide the analysis (see Table 1). Human decoding is conducted first. A total of 50 CSR reports from eight ICCs are chosen to be interpreted with the assistance of qualitative data analysis software *NVivo Pro 11*. Texts are firstly coded according to the host country names. Then, coded texts are classified into the six categories based on the analytical framework. Given the large volume of reports to be analysed, an innovative approach of text mining is developed to assist human coding approach. Similar to the process of human decoding, texts are firstly extracted according to the country names. Keywords are identified to stand for each category (see Table 1). Latent semantic analysis (LSA) is used to calculate the similarity scores between keywords and extracted texts, thus to get a score for each sub-category.

When the score of one sub-category is higher, it is assumed that the texts are more likely related to that sub-category. This process is implemented on top of a well-known LSA software *genism* in *Python 3.6.5*. By doing this, each text would get six scores based on six categories in the analytical framework.

Table 1: The analytical framework for decoding CSR reports

Code	Category	Sub-category	Keywords
EC	Economic	EC1- Job creation; EC2-Supply chain responsibility	job creation; supply chain
LA	Labour practice	LA1- Training and education; LA2-Occupational Health and Safety	training; health; safety; occupational
PR	Product responsibility	PR1- Quality of products	quality
SO	Local community involvement	SO1- Local community communication; SO2-Donation; SO3-Disaster relief; SO4-Poverty caring; SO5-Medical caring; SO6-Youth and education	community; donation; disaster; poverty; hunger; disease; medical; disability; children; student; sport
HR	Human rights	HR1-Non-discrimination	discrimination
EN	Environmental	EN1-Energy and carbon emission; EN2-Biodiversity conservation; EN3-Waste management	carbon emission; biodiversity; ecosystem waste

Certainly, the inter-rater reliability test is conducted before the text mining results can be accepted for further analyses. In other words, the text mining results are validated and improved based on the results of the human coding approach. We thus get the improved text mining results as the final results of the content analysis. In total, the results present 1138 items with each item expressing the CSR practices indicated in 6 categories by one ICC in one host country.

2.2 Sample and data

Data of various host markets are from the results of the content analysis. There are 56 host countries chosen from the results of the content analysis as the sample for the following analysis (shown in Table 2). In some host markets, only few ICCs conduct CSR practices, therefore, they are excluded during the sample selection. There remain 825 items for the analysis. Drawn from the results of the content analysis, each ICC only has one item in one specific host country. The amount of ICCs who conduct CSR practices in each host countries could be counted (represented with N0). Similarly, the amount of ICCs who conduct CSR practices in each category for each host country (Ni, i=1,2,…, 6) could also be counted and shown in Table 2. Taking the United Kingdom in Table 2 as the example, there are 36 ICCs implementing their CSR practices in the United Kingdom (N0=36), of which, 17 ICCs implement EC practices (N1=17), 22 ICCs implement EN practices (N2=22), *etc*.

Table 2: An excerpt of sampled host countries

No.	Host countries	The amount of ICCs conducting CSR practices (N0)	The amount of ICCs conducting CSR practices in each category (Ni)					
			EC (N1)	EN (N2)	LA (N3)	HR (N4)	PR (N5)	SO (N6)
1	United Kingdom	**36**	17	22	23	2	13	18
2	India	**31**	10	6	19	1	7	18
3	China	**28**	6	15	13	0	11	13
4	Singapore	**27**	6	8	22	0	11	16
5	Australia	**27**	9	14	20	2	11	15
…	…	**…**	…	…	…	…	…	…
Total	56	**825**						

Notes: EC, EN, LA, HR, PR, and SO represents economic, environmental, labour practices, human rights, product responsibility and local community involvement, respectively. (Shown in Table 1)

2.3 Measurements for variables

Measurement of diversity

Entropy (H, see Equation 1) is introduced to measure the diversity of CSR practices in one host country, as it plays a central role in information theory as measures of information, choice and uncertainty (Shannon, 1948). A broad distribution describes the diversity, representing more uncertainty.

$$H = \sum_{i=1}^{N} p_i \times ln\frac{1}{p_i} \qquad (i = 1, 2, \dots, 6)$$ **Equation 1**

where H represents entropy, which describes the diversity of CSR practices, p_i is proportion for each category in one host country (see Equation 2), which indicates the degree of recognition for each category by the host countries.

$$p_i = \frac{N_i}{N_0} \qquad (i = 1, 2, \dots, 6)$$ **Equation 2**

where N0 represents the amount of ICCs who implement CSR practices in each host country; Ni represents the amount of ICCs who implement CSR practices in the specific category (i) in each host country.

Entropy has been applied to the assessment of business diversification (e.g. Ye et al., 2017). Diversity here is a little different from those business diversification indexes measured by entropy as p_i here is independent and the sum of p_i is not equal to 1. Therefore, the range of results here is not from 0 to 1, but the higher entropy represents the higher level of diversity.

Human development index (HDI) measurement

HDI is applied in this research to measure the developing levels of host countries. The HDI was created by the United Nations to emphasise that people and their capabilities should be the ultimate criteria for assessing the developing level of a country, not economic growth alone. Three dimensions are used to assess the HDI, including (a) the health dimension assessed by life expectancy at birth, (b) the education dimension measured by mean of years of schooling and expected years of schooling, and (c) the economic dimension measured by gross national income per capital. Each country has their scores ranged from 0 to 1 based on the three dimensions. While the HDI describes a comprehensive approach regarding human development levels for various countries, which cares not only about economic growth but the development of human by considering the national policy choices. The HDI is thus regarded as the proxy to describe the institutional environment for CSR practices. The higher HDI scores indicate higher developing levels.

2.4 Regression model

Regression analysis is used to explore the relationship between the diversity of CSR practices and the developing levels of host countries measured by HDI. HDI of host countries is regarded as the independent variable, while the diversity of CSR practices as the dependent variable. Besides, the amount of ICCs who implement CSR practices in that host country (N0) would also affect the diversity of CSR practices, since more ICCs may bring more possibilities of implementing diversified CSR activities in that country. The amount of ICCs in specific host countries (N0) is as the control variable for this test. The testing model is shown as follows (Equation 3):

$$H_j = \beta_0 + HDI_j \times \beta_1 + N0_j \times \beta_2 + \varepsilon_j$$ **Equation 3**

where the subscripts j indicate individual host country, H_j is the dependent variable - diversity of CSR practices, HDI_j is the independent variable – the developing levels of host countries, $N0_j$ is the control variable, the amount of ICCs in specific host countries, β_0 is the intercept, β_1, β_2 are the coefficients of corresponding items, and ε_j is the error term.

3. DATA ANALYSIS AND RESULTS

The regression model is tested by using R software (R Development Core Team 2008), which is an open source statistical analytical software program. The results of the testing are shown in Table 3.

Table 3: Testing results for the diversity of CSR practices and HDI of host countries

Variable	Coefficients	Std Error	t-statistic	p-value

Intercept	0.6755	0.1349	5.0076	6.47e-06***
HDI_j	0.9300	0.1877	4.9541	7.80e-06***
$N0_j$	0.0101	0.0042	2.4244	0.0188*
Goodness of Fit:				1.15e-07***
R-squared:				0.4528
Adjusted R-squared:				0.4322
Observations:				56

Note: *, **, and *** indicates significance at the 0.05, 0.01 and 0.001 levels, respectively.

The developing level of host countries measured by HDI is tested to be significantly correlated to the diversity of CSR practices. The estimated value of the coefficient of HDI is 0.93, which is significant at the 0.1% level, showing a strong positive correlation between HDI and diversity of CSR practices. This is to say, ICCs would implement more diversified CSR practices in developed countries than in under-developed countries. The p-value of the regression model equals to 1.15e-07, which is much smaller than 0.001, showing a good result in testing the hypothesis. The hypothesis that *the diversity of CSR practices in the host country is positively related to the developing levels of that country*, is thus supported. Therefore, the Equation 3 can be written more specifically in Equation 4.

$$\boldsymbol{H = 0.6755 + 0.93 \times HDI + 0.01 \times N0} \qquad \textbf{Equation 4}$$

By examining the CSR reports, it is found that in the under-developed countries, especially disaster-prone countries, such as Haiti and Nepal, ICCs focus on local community involvement (SO) practices only, especially on disaster-relief activities. For example, after the devastating earthquake occurred in Haiti in 2010, most of the ICCs doing business in Haiti mentioned their disaster-relief activities in the following few years. Apart from SO practices, in some under-developed countries, labour practices (LA) attract attentions of ICCs as well, specifically, training and education and occupational health and safety. In Angola, for example, 88% (7 out of 8) ICCs mentioned their practices related to training and occupational safety (LA), and 63 (5 out of 8) ICCs mentioned their local community practices (SO).

At least three categories of CSR indicators were valued and mentioned in developing countries and developed countries. Local community practices (SO) and labour practices (LA) in particular, were demonstrated by almost all the developing or developed countries. Health and safety issues aroused more attentions than the aspect of training. While in the highly developed countries, all the categories of CSR indicators except human rights (HR) were mentioned and demonstrated by ICCs.

There are two outliners in the analysis– India and South Africa, as they are with relatively low HDI but with a high diversity of CSR practices. In India, healthcare and issues related to children are most frequently mentioned in local community practices (SO); other ICCs cared about carbon emission or energy, supplier network and hiring local employees in India. Different ICCs implement different CSR practices in South Africa, which makes CSR practices in South Africa diversified. Some ICCs implement the strategic initiatives to stimulate socio-economic development in South Africa; some valued the issues related to human rights such as no discrimination in employment and racial equality in South Africa; and of course local community involvement initiatives were conducted in South Africa, such as donations, and education support.

4. DISCUSSIONS AND CONCLUSIONS

This research explores the diversity of CSR practices in 56 various international construction markets. It is found that CSR practices by ICCs would be more diversified when the developing level of the host market is high. Societal expectations/needs of the stakeholders in the host markets could be reflected from the developing levels of host markets and also differ according to the characteristics of specific host markets. Generally speaking, host countries with low developing levels have more needs to settle the basic livelihood, care about the healthcare issues, and train the workers. Instead, in the developed market, there are more expectations for companies to contribute to the society. Mahmood and Humphrey (2013) state that it will place more emphasis on economic benefits to society rather than on environmental and human rights issues, when a country moves towards a market economy and industrialisation. As the average levels of health and education are high in the developed markets, their expectations for companies are not only limited to solving the basic livelihood problems of poor people, but also various on labour practices, environmental practices, and economic contributions such as creating jobs. It is needed for ICCs to communicate with communities for the conductions of construction projects in the developed markets. Besides, the guidelines, regulations or laws regarding environmental, economic, or labour aspects of CSR practices may be mature and strict for ICCs to follow and abide by in the developed markets, so that the CSR practices conducted there may be more diversified.

This research provides the view that the diversity of CSR practices are positively related to the developing levels of the host markets. Our findings suggest that the contexts where companies embed play an important role in the conduction of CSR practices. The expectations of stakeholders and compliance pressure in the developed countries may be higher than those in the less developed countries. The ICCs need to take the expectations of various stakeholders in the host markets into account to make their CSR strategies and conduct their CSR practices properly.

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Urban NGOs as Niche Actors in Informal Settlement Upgrading and Construction

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Abstract

This paper concerns how several NGOs position themselves as intermediate actors in the growing field of informal settlement upgrading (ISU) in South Africa's Western Cape. The paper argues that small-scale organizations, unencumbered by political mandates, although by no means apolitical, utilize community participation in order to produce more appropriate upgrades and cultivate public ownership and livelihoods compared to state led ISU programs. The methodology of this paper comes from the comparative case studies, semi-structured interviews with fifteen actors involved in Western Cape ISU, and site observations amassed during a research stay at the urban sector NGO, Development Action Group (DAG). The paper characterizes several NGOs with offices and projects based in Western Cape informal settlements as competitive and positively disruptive non-profit actors in the categorically for profit construction industry. Although shepherding ISU projects through various innovative practices, such as introduction of land tenure, alternative technology, savings schemes, etc., their real innovation is sourcing informal communities in their own physical redevelopment.

Keywords: informal settlement upgrading (ISU), non-governmental organizations (NGOs), participatory planning, transition management theory, innovative construction

Introduction

In the metropolitan region of Cape Town, a presumed 115,000 households live in informal zones, including approximately 30,000 without access to running water and 73,000 without basic sanitation. Since South Africa's democratic transition, NGOs in the Western Cape have been redefining their roles in the urban development and construction sector, becoming intermediate actors in the growing field of informal settlement upgrading (ISU). Inconsistency exists between the country's progressive national policies and local government's bureaucratic, exclusive top-down approach to redevelopment (Huchzermeyer 2009). This paper argues that when NGOs expedite ISU by employing participatory planning, meaning the power begins and ends with the involvement and capacity of the resident, the result is a more sustainable and inclusive process.

This paper discusses the expanding field of ISU, participatory planning, and transition management (TM) theory to analyse NGOs as niche actors within the state-led funded but often privately executed construction of low-income housing. More likely to employ enabling measures, such as capacity building and in situ upgrading, the paper sees NGOs as utilising participatory planning as ISU innovation, before critiquing the current governance structure of ISU and urban development present in the Western Cape.

The methodology of this paper derives from interviews from fifteen actors involved in Western Cape ISU work. With the exception of one representative from the parastatal Housing Development Agency (HDA), all interviewees are either academics or NGO affiliates, largely from architecture, planning, economics or project management backgrounds. These practitioners answered questions ranging from what their incentives were to conduct ISU projects, how they access funding and work within state policy, whether they design for informal communities or with them, and if they see their projects as ad hoc solutions or part of a wider redevelopment scheme for the city of Cape Town and by doing so attempt to foster a more sustainable urban transition. Operational knowledge garnered while serving as an editorial assistant at the urban development NGO Development Action Group (DAG) also contributes to the research base of this paper.

Informal Settlements in the Western Cape

In the Western Cape of South Africa, the vast majority of informal settlements lie on undesirable land and standard construction practices incline towards low-density housing. In response to the low level of private sector interest in ISU across the country, national and provincial governments dominate the sector (Swilling 2006), but NGO facilitated cases of ISU have been expanding in number and scale. Since its 1994 democratic transition, South Africa has invested in a variety of capital-intensive housing delivery programmes, and yet its urban housing crisis has intensified over the last twenty years. Reasons for this range from the unequal spatial and economic makeup bequeathed from the colonial and apartheid regime periods to the growing rate of in-country migration to the metropolitan areas (Cross 2006), mainly the political and commercial centres of Johannesburg, Cape Town, Pretoria, and Durban.

Cape Town, the centre of Western Cape politics and economy, began as a colonial city and its urban form reflects that history. It was designed based on a supposed duality between the ordered Europeanized African metropolis and the unplanned indigenous community (Berrisford 2011). Colonial policy divided South Africa's racial categories into a set hierarchy with those of European ancestry at the top, Black Africans at the bottom, and a created racial category known as Coloured in between. Coloureds comprised South Asian slaves, mixed races, and primarily the Cape indigenous Khoisans, who had been culturally assimilated by the Dutch and shared the Afrikaans language with the white population. They received a social position above darker skinned Black Africans, which wrought tension between the two. The Natives Land Act of 1913 stripped Blacks of the right to hold any kind of land title, preventing families from investing in their households and building intergenerational wealth. During the post WWII years when South Africa's economy was breeding a middleclass, the vast majority of the population was barred from earning this stabilizing wealth. At present, the national economy has slowed and the land still available for investment is marginal, the urban poor are in a weak position to lead their own upgrading (Macgregor. Personal interview, 29 July 2012).

In 1994 when apartheid finally collapsed, the now legal free movement of people powered a massive urban migration across the country. Low cost, hastily constructed housing shot up along urban peripheries, especially around former Coloured and Black townships, where authoritarian planning had left neighbouring land undeveloped (Huchzermeyer 2011). The majority of present day Cape Town's supposed 117,000 informal settlements reside in a state of semi-legitimacy (HDA 2013) with the exception of shacks beneath power lines or within flood zones. Much of the informal development occurred on government owned land, which the Western Cape Provincial Government (WCG) appeared to accept especially among the Black African townships on the grounds that they served as transitional living arrangements useful until government built housing became available (DAG 2010). It is important to note that this was not the case in the traditionally Coloured townships closer to the urban core. The City of Cape Town (CoCT) had much greater control of these areas than the WCG and preferred to see overcrowding in formal housing or backyard units attached to formal housing rather than completely informal neighbourhoods. The fear was that shantytowns would grow to levels beyond the possibility of redevelopment (Hennessy & Smith 1994).

A number of responses have been made at the national, provincial and municipal level to address these inherited disparities and complications of urbanization, but without sustainability or community participation fully in mind (Swilling 2012). The closest thing to a sustainability blueprint would be the nationally composed "Breaking New Ground (BNG): A Comprehensive Plan for the Creation of Sustainable Human Settlements." The report denotes a new acceptance of the permanency of informal settlements and an institutional attempt to include as many South Africans in the government's taxable revenue and rental stream (Massey 2013). The national government composed BNG to incorporate subsidised rental and owned housing through municipally built structures ranging in density and type. They claim that BNG has led to the formalisation of about 200 informal settlements to date (NDHS 2004). "It planned to promote a shift from a conflict and neglect paradigm to one of incorporation and cooperation [through] a market-driven and neoliberal housing approach" (Massey 2014), but it has not spurred any broad plan to move South African cities towards a socio-technical sustainable transition (Lawhon 2012).

ISU Construction and Governance Structure in Cape Town

In South Africa, it is not the National Planning Commission or Department of Economic Development responsible for ISU programmes, but the National Department of Human Settlements (NDHS). This occasionally causes local economic development and integrated planning to be excluded from the ISU process (Cirolia. Personal interview, 16 June 2014). The National Treasury allocates budgets for all nine provinces, whose separate departments are liable to national mandates. The disparities between different department mandates have been criticized for impeding interdepartmental cooperation as well as sometimes conflicting with one another's directives (DAG 2010). Since the start of the 1994 democratic transition, national, provincial and municipal divisions have been in a constant state of restructuring. This complicates attempts amongst civil society groups to conduct ISU because determining whose approval or funding is necessary for a certain kind of intervention is often unclear even among government officials (DAG 2010). The WCG contains thirty municipalities comprising five rural districts and one metropolitan district, the CoCT. Within the CoCT are six local councils, retaining a collective 3,740,026 people according to 2011 census. The province rather than the municipality tends to be the more active in constructing housing and infrastructure, especially in cases of ISU redevelopment (DAG 2010).

Of the two national parties, the Western Cape Provincial Government (WCG) in which the CoCT sits has maintained a Democratic Alliance (DA) majority since 2009. More centrist in political ideology, the DA is the main opposition party to the nationally dominant African National Congress (ANC). Most informal settlement constituents of the Western Cape vote ANC, a major factor in servicing and financing ISU in the Cape. Addressing informal settlements tends to be a top-down process. The national office funds all provincial ISU programmes through the Provincial Human Settlements Development Grant. The Western Cape received 2.056 billion Rand (~USD 196 million) for the 2014-2015 fiscal year, a figure gaged from poverty indicators gathered in the last census, which took place in 2011. A shortage of approximately 375,000 homes in the city of Cape Town and 521,305 province wide feeds informal housing development. The WCG projects that it would take thirty-eight years and R74.2 billion (~USD 70 billion) to address the problem of shack and backyard living as it stands now. Not only is this vastly beyond their budget, the valuation does not account for the amount of land such a project would consume if done by standard government led construction practices. The same WCG report identities thirty-two sites suitable for upgrading, meaning the land has a minimal risk of flooding, can be serviced cost effectively, already owned by the state and within or near Cape Town's periphery. These sites' combined land mass is far too small to accommodate the necessary 375,000 hectares of land required of the government's one house, one plot scheme.

South Africa's famous Research and Development Programme policy framework (RDP) came out of a wave of state packages meant to overturn apartheid legacies. It has born a sea of freestanding units built to minimum standards and without regard for energy or design innovation. Unit sizes fluctuate widely depending on the project and even on single neighbourhood projects the floor space varies, but the indoor environment averages 36 m² on a 250 m² plot (Moolla et al. 2011). Despite a scarcity of urban land, the current regime of housing delivery safeguards low-density development. The annual delivery of houses is an insufficient 10,000 meant to address a citywide shortage of 400,000. The current system proliferates urban sprawl and exacerbates its services. Imposing external, technical solutions does not support sustainable redevelopment due to its slow nature and focusing solely on housing creation does not support community growth. Undeniably RDP housing needs building in South Africa to alleviate the overcrowding, resource drain and general precarious nature of informal urban settlements. However, collectively RDP's top-down planning and monotonous design of freestanding square frames do not differ much from the apartheid era's housing provisions (Lodge 2003). Construction of infrastructure has also been slow to adopt innovative practices (Swilling 2006). RDP housing and infrastructure development usually involves master planning large-scale sites atop vacant government-owned land. Marie Huchzermeyer calls this contractor driven rollover or greenfield development schemes (2004: 3). Only in the last few years has a respect for in situ and incremental strategies coupled with community planning given a new vocabulary to RDP.

Around 2008, the NDHS launched the National Upgrading Support Programme (NUSP), to serve as platform for municipal ISU programmes. In partnership with the World Bank and UN-Habitat created Cities Alliance, NUSP sponsored the evaluation of sixteen pilot projects of ISU. The analysis asserted that the conventional ISU methodologies could not meet the national mandate to eliminate informal settlement living by 2014 (NDHS 2012), a conclusion that has proven true. It called for a radical change in ISU policies and proposed incremental upgrading as the key to solving the housing crisis. Although focused on improving municipal upgrading it allows for greater outsourcing of development to NGOs and private contractors, who can either receive institutional support from NUSP's sub-agency, the Upgrading Informal Settlements Programme (UISP) or financing from the Urban Settlements Development Grant (USDG).

This marks the muddled landscape and regime actors of the Western Cape's ISU system. Its NGOs, niche actors according to transition management theory, are in a modification stage, still changing their institutional arrangements and honing their community participation product through pilot projects. NGOs in Cape Town, as with NGOs across South Africa, have only recently emerged from a critical period marked by a crisis of purpose. The majority of apartheid era NGOs were designed to stand in opposition to a known enemy in the form of the state, combating forced evictions and informal settlement demolition, as well as managing rent protests in townships receiving inadequate services. Organisations to come out of this period include the Development Action Group (DAG) and the Community Organisation Resource Centre (CORC), the major organisation in an alliance of Cape Town non-profits affiliated with the influential Slum Dwellers International. After the democratic transition, many of these opposition NGOs restructured into lobby firms, drafting policies and programmes concerned with addressing informal development, which the newly established government could adopt. DAG had been founded by a group of architects and activists during the late apartheid period to contest groundless evictions and informal settlement demolition, but rebranded itself as a housing service provider to suit the democratic state. Promoting sweat equity and active citizenship, half of its funding comes from private donors, the other from its research publications and revenue from housing delivery. In 2008, DAG completed its last housing provision based project and shifted towards an advocate role in order to experiment with novel solutions in ISU and prove them appropriate and viable enough to influence established government policy.

The Urban Sector Network, a national association of institutions advocating people centred approaches in housing policy and development, thrived during the early transition period but deteriorated in the 2000's. It ultimately dissolved due to network infighting, conflicting approaches and the disbanding of numerous NGOs (van Donk. Personal interview, 28 July 2014). The striking decline of the NGO sector is attributed to the solidification of policy but constant change in formal governance structures. The framework for redevelopment had formed, but the government department appropriate to contact when conducting a specific ISU was ambiguous. Also damaging was the propensity to operate in opposition to the state. Certain institutions were too accustomed to a clear face of imbalanced development, i.e. apartheid, and could not adapt (Cole. Personal interview, 10 June 2014).

Only recently has a new organisation, Isandla Institute, attempted to revive the Urban Sector Network by holding conferences and publishing research on informal development. The Institute considers itself a tangible place where ISU deliberation and engagement can happen between firms. Recognizing that communities have a part to play in development, they hope to create a right to the city charter for South African cities, like those of Brazil and Mexico (van Donk. Personal interview, 28 July 2014). Isandla Director Marie van Donk perceives a recent resurgence of urban development NGOs in Cape Town built from the survivors of the apartheid and democratic transition periods and younger firms founded by new professionals and creatives. Such actors tend to be more interested and determined to employ more community and technologically driven schemes than state actors (Cuff. Personal interview, 28 July 2014).

There are five categories to which present Cape urban development NGOs tend to fit. Quasi-government NGOs ranging in their independence yet still subject to some federal mandate, which assist national, provincial and municipal ISU programmes. The Housing Development Agency (HDA) offers the most prominent example, designed to unlock land and structures, normally government-owned, suitable for housing and human settlements. Next there are legislative or rights-based lobbies, who promote ISU as a state obligation on the basis of federal mandates, such as Abahlali baseMjondolo of the Western Cape Western Cape Anti-Eviction Campaign. There are the clean-tech clusters interested in a re-architecture of current ISU systems, and then the academic institutions, like University of Cape Town's African Centre for Cities and Stellenbosch's Sustainability Institute (Cirolia. Personal interview, 16 June 2014). Finally, engagement firms encompass the practice-based groups, like DAG, CORC, and Violence Prevention through Urban Upgrading (VPUU).

VPUU, by far the youngest of the leading engagement institutions, has earned international attention since its initial pilot upgrade in 2006. They trace criminal activity through community testimony and selected strategic nodes for restoration, reblocking foot highways and installing better outdoor lighting. They work in four Khayelitsha settlements near the N2 Gateway's targeted settlements discussed subsequently. They set up a scheme, where the CoCT acted as the executive agency for their upgrades and shared financing responsibilities with the German Development Bank. Planning came from the German firms AHT Group and Sun Development, as well as ten local design consultants. In many ways, VPUU have achieved the transition management goal of amalgamating into a regime actor, now an entity within the Cape Town Mayor's Office. However, VPUU's projects still relies on German Development Bank funding and other NGOs see them as cagey with their skillsets and guilty of mainstreaming their projects since becoming beholden to government assignments. They may have infiltrated the regime, but have not prompted much structural change in government led ISU. This acceptance of a "normative of the formal" shows the possibility of a niche actor backsliding into the deep-rooted national and urban regime's practices (Macgregor. Personal interview, 29 July 2012).

John Abbott, the leading academic in ISU theory within the South African context, proposes that urban development NGOs are well positioned to integrate livelihoods techniques into their upgrades and facilitate the community, government, and private enterprise in specialist partnerships (Abbott 2000). However, when it comes to partnering with one another, an aversion to collaborate has often hindered the field. There is no logic behind this lack of partnership or feelings of competition between NGOs. According to the fact-findings of this paper, very few main firms depend on the same funding streams and the amount of neighbourhoods requiring ISU is only growing. If the goal is to sell one's all-encompassing approach to ISU for full government implementation, then this might explain antagonism between firms, but no interviewee supposed that this was a possibility. Personal interviews revealed that small disagreements or dislike of certain people within another NGO had deterred collaboration over a several year period. This even occurred in two cases where those unpopular individuals were no longer associated with the NGO. In the transition management framework, this could potentially accelerate a sustainable urban transition. Competition among niche actors intensifies the niche actor's will to improve its product or practice's level of innovation, allowing a better range of ISU pilot projects based on participatory planning (McMeekin & Southerton 2012).

Conclusion

Informal settlements are not a side effect of urbanization but intrinsic to its process. Their capacity to be upgraded into safe and legitimate housing options will weigh heavily on the state of sustainable development over the next century. Policies centred on eradicating informal settlements through demolition and relocation are neither socially, economically or environmentally sustainable. Urban governance needs to foster a political acceptance of upgrading through participatory planning and design. The stage at which informal settlers are brought in and the extent of their participation governs the success and sustainability of informal settlement upgrading. Fixing the community to their environment's redevelopment, participatory planning allows more appropriate interventions and public ownership of the upgrade. This paper deems resident driven, NGO facilitated ISU as an innovative approach, especially when these key stakeholders engage other network actors, such as municipal officials, academics, CBOs, private sector investors and contractors, etc. Rather than rely on a regime of government managed and implemented projects the goal should be a transition towards a diversity of participatory schemes that can serve as pilot projects and eventually create a standard framework for sustainable ISU.

This paper acknowledges the limitations to its methodology and analysis. Observational knowledge is inherently subjective. Interviewees were overwhelming from non-profit or academic backgrounds, which influenced the knowledge base of the paper. The author was likewise an employee of an urban sector NGO, which also influenced the paper's experiential understanding.

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Electrical conductivity of cement paste containing conductive rubbers

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Abstract

With more demands on smart materials and intelligent construction, investigations into electrical conductivity of cementitious composite, such as cement-based sensor for strain sensing, are attracting increasing attentions. In this paper, various types of conductive rubber fiber, produced from rubbers having (1) carbon black, and (2) aluminium/silver as a filler, were incorporated into a cement paste, and their effects on the electrical conductivity of a cementitious composite were investigated. The preliminarily research results have shown that for the rubber fiber content larger than 2.75wt.%, the electrical resistivity of the composite clearly decreased with curing ages; otherwise the resistivity of the composite kept as high as that of the plain cement paste, regardless of the rubber fiber type. The percolation threshold was in the range of 1.1 wt.% to 2.2 wt.% for carbon black filled rubber fiber (CR) and 0.77 wt.% to1.65wt.% for aluminium/silver filled rubber fiber (AR). After 7 days of curing, resistivity of the composite with CR was almost constant regardless of rubber content used, while resistivity of the composite with AR noticeably decreased with increasing rubber content. After 28-day of curing, resistivity of the composites containing CR or AR decreases with increasing conductive rubber content. Having capability to improve conductivity of cementitious composites, these conductive rubbers have demonstrated a high potential for self-monitoring of strain changes and damage in concrete structures.

Keywords: conductive rubber, cement paste, electrical resistivity, curing ages, polarization.

1. INTRODUCTION

As one of widely used materials in the construction of buildings, pavements, harbors and bridges, concrete is always subjects to multivariate detriments such as winds, waves, earthquake forces, long-term corrosive ambient and even unexpected sabotage. During the long-term service under the effect of these factors, some invalidations in concrete structures like sudden cracking, splitting and falling, may cause tremendous losses on humanity lives and properties. Therefore, real-time observation and evaluation of concrete structures by sensing technology is gradually attracting more and more attentions both in engineering research and practice.

Several sensing techniques like strain gauge, optical fibre, piezoelectric ceramic and shape memory alloy have been proposed to monitor the concrete structural health, in conjunction with the scan techniques of X-ray or C-scan in labs which could detect the cracks and damages of concrete samples in microscale. However, embedding the additional non-intrinsic sensors into the concrete is always accompanied by some negativities on the mechanical and durability of concrete structures (De Backer, De Corte & Van Bogaert 2003; Neild, Williams & McFadden 2005) (Butler et al. 2016; Leung et al. 2000) (Sun et al. 2008) (Mu et al. 2018) (Suzuki, Shiotani & Ohtsu 2017) (Chen & Chung 1993) (Aghlara & Md Tahir 2018). Meanwhile, these sensors are often expensive and difficult to install and preserve over a long period of time. Thus intrinsic cement-based sensors with good compatibility, durability and economic efficiency in concrete structures have been developed, which can monitor the induced deformations, cracks and damages through the altered electrical resistance by external factors (Cutler et al. 2010; Liu et al. 2018).

Generally according to the chemical composition of cement-based sensors, there are two types of frequently-used conductive fillers with one by carbonic materials and another by metallic materials. Also, conductors can be separated into the conductive fibers and particular powders based on their size and shapes. It is believed that for the identical content of conductors, the conductivity of fibers reinforced cementitious composite is superior to conductive powders (Oberlin, Endo & Koyama 1976). This is mainly due to the larger length-diameter ratio of conductors has more opportunity to form continual conductive passages in the composite.

Inspired by the above-mentioned studies and the investigations on the reinforced cementitious composite by recycled rubbers, this paper proposed to use novel conductive rubbers, consisting of silicone rubber and conductive particles (carbon black and aluminum/silver), for cement-based material sensors. It is to focus on the effect of conductive rubbers on the electrical conductivity of conductive rubber reinforced composite.

2. EXPERIMENTAL MATERIALS AND PROCEDURES

2.1. Raw materials

Carbon black filled rubbers (CR) and aluminum/silver filled rubbers (AE) were collected from the Jones Tech Co., Ltd., with physical and mechanical properties listed in Table 1. Owing to the finished products from the company are linear rather than in the form of fibers or powders, those rubbers were artificially cut into small bars and then sliced to 12 fibers per bar (Figure 1). General purpose cement from the Independent Cement & Lime Pty Ltd. was used throughout. The silica fume from the Concrete Waterproofing Manufacturing Pty Ltd was applied for partial substitution of cement. High range water reducer produced by SIKA Australia Co., Ltd. assisted to better dispersion of rubber particles in composite, as well as the felicitous workability. The laboratory tap water is used during the experiments.

Figure 1. Preparation of conductive rubber scraps, cut lines and the sliced rubber fibres

Table 1 Physical and mechanical property of PR, conductive CR and AR

Rubber types	Conductive filler	Density (g/cm^3)	Volume resistivity (Ω·cm)	Tensile strength (MPa)	Elongation (%)	Shore Hardness	Working temperature (°C)
CR	Carbon black	2.1±0.25	0.100	1.5	230	70±5	-55~160
AR	aluminium/silver	2.2±0.25	0.008	2.5	150	75±5	-55~160

2.2. Preparation of rubber/cementitious composite

Stainless steel molds at the size of 50 mm ×50 mm ×50 mm were firstly cleaned, assembled and oiled. Silica fume substitution ratio of 0.2 and the water reducer at the ratio of 0.8% were selected for all mixture groups, and the different contents of conductive rubber particles and water cement ratio are depicted in Table 2. The mixture of cement, silica fume, water and water reducer were mixed in a Hobart mixer. The mixing procedure was following the international standard C305-14 by Highway and Transportation Officials Standard, with first mixing at low rate of 140 ±5 r/min for 30 s and then at higher rate to 280 ±10 r/min for 1 min. After that, the composite was poured into the oil treated molds at the first 20 mm height and was vibrated, the rubber fibers which were air-dried for a week beforehand was half in the center of composite, filling the mold to the height of 30 mm and the same fibers embedding for that layer. After filling up the mold, two copper meshes with thickness of 0.5 mm, width of 45 mm and length of 65 mm were symmetrically embedded into the cubic composite as electrodes, with the average space at 30 mm. One day curing at standard curing chamber, the specimens were demolded and numbered, before further cured in the chamber with controlled temperature at 20 ±5°C and humidity of 95%. The end product, its specific size and rubber distribution are shown in Figure 2 after 28 days curing.

Table 2 Mixture ratio of plain cement paste and the composite

Number of bars	Rubber content	Fillers in Rubber	Cement	Silica fume	water	Water reducer (%)
0	0%	—	0.8	0.2	0.42	0.8
5 Bar	0.55wt. %	Carbon black	0.8	0.2	0.42	0.8
5 Bars	0.55wt. %	Aluminium/silver	0.8	0.2	0.42	0.8
10 Bars	1.1wt. %	Carbon black	0.8	0.2	0.42	0.8
10 Bars	1.1wt. %	Aluminium/silver	0.8	0.2	0.42	0.8
25 Bars	2.75wt. %	Carbon black	0.8	0.2	0.42	0.8
25 Bars	2.75wt. %	Aluminium/silver	0.8	0.2	0.42	0.8
35 Bars	3.85wt. %	Carbon black	0.8	0.2	0.42	0.8
35 Bars	3.85wt. %	Aluminium/silver	0.8	0.2	0.42	0.8

Noted: the wt. means the rubber content to the weight of cement and silica fume.

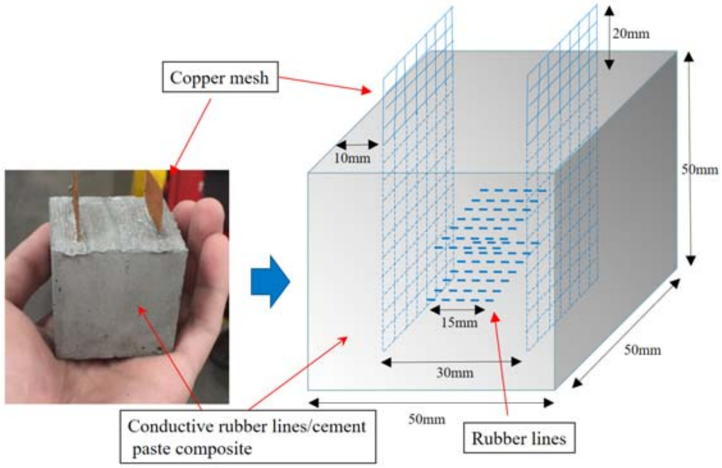
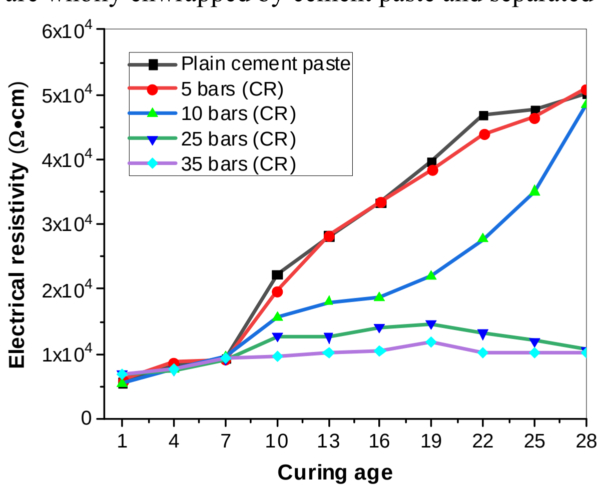


Figure 2. Schematic illustration of conductive rubber fibres reinforced cement paste

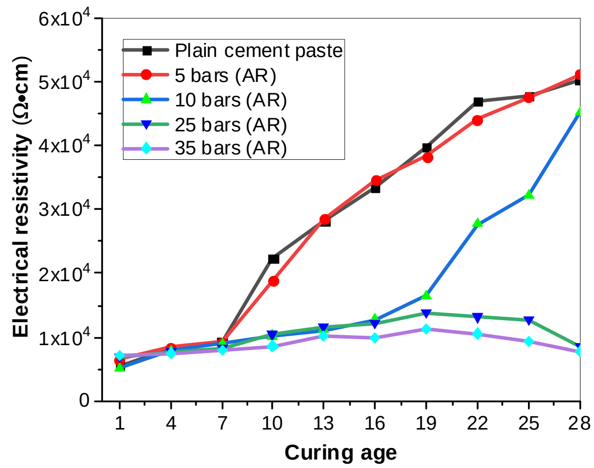
3. RESULTS AND DISCUSSION

3.1. Effect of curing ages on resistivity

Figure 3 shows the electrical resistivity changes of plain cement paste and the paste reinforced by conductive rubbers with curing ages. For the composite with 5 bars of conductive rubbers, both for CR and AR, their electrical resistivity is just as high as plain cement paste. In this case, the content of conductive phase is relatively low and measured only 0.55% to the weight of cement, causing that the sliced conductive fibers are wholly enwrapped by cement paste and separated from each other.



(a) CR reinforced composite



(b) AR reinforced composite

Figure 3. Electrical resistivity changes with curing ages for rubber reinforced composite

With the proportion increased to 10 bars (1.1%), the resistivity at the early curing stage is just like the counterpart of plain paste and increased with curing time. However, after 10 days curing, the growth tendency is much gentler than that of 5 bars reinforced composite or plain cement paste, and the resistivity of 10 bars rubber reinforced composite clearly lower than that of 5 bars and plain paste. This maybe out of the existence of water content in the specimens, which is relatively high at the early curing time, induces severe polarization in the composite and increases the resistivity. It could also explain that the electrical resistivity for the 25 bars and 35 bars conductive rubber reinforced composite is lightly decreased at the later curing ages, for the weakened polarization and the recovered conductivity.

For different types of conductive rubbers reinforced composite, the AR assisted composite performed better electrical conductivity in comparison to that consists of CR, especially when the rubber content exceeded 10 bars. This is also reasonable for the conductivity of AR is much better than CR (Table 2). When the resistivity got rid of the effectiveness by water content in the later hydration period, the effects from the sliced conductive fibers were gradually coming into force and dramatically increased conductivity, the more rubber proportion, the more significant of that effect and the lower resistivity.

3.2. Effect of rubber content on resistivity

Figure 4 shows the electrical resistivity of reinforced composite with different rubber contents at 7 days curing ages. Interestingly, with the rubber content increased from 5 bars (0.55%) to 35 bars (3.9%), the resistivity of composite illustrated no clear reduction especially for CR reinforced composite. This is mainly owing to the severe polarization in the composite, whose negativity on electrical conductivity compensated the positive effect by conductive rubbers and maintained the high resistivity. For composite with AR, whose conductivity was higher than its counterpart, could slightly reveal the positive effect of rubber content even if that was weakened. In general, both for these rubbers reinforced composite, the percolation never existed at the 7 days curing age.

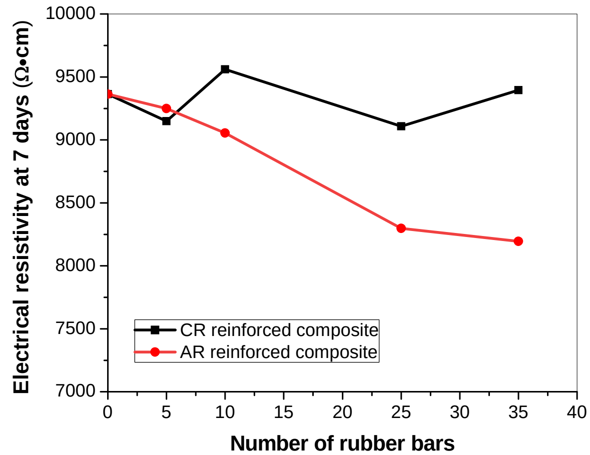


Figure 4. Electrical resistivity of composite with different rubber content at 7 days

Furthermore, the electrical resistivity of rubber reinforced composite with different rubber content at 28 days curing ages were displayed in Figure 5, from which an electrical reduction could easily detected and evaluated. However, limited by current experimental tests, the exact percolation threshold is still unknown, thus the resistivity distribution possibilities based on the current results were also plotted in Figure 5. For CR reinforced composite, this value might be in the range of 10 to 20 bars according to the fitting curve, which was narrowed down to approximately 7 to 15 bars for AR reinforced composite. The exact value could be observed by decreasing the content span in later experiments. After 28 days cement hydration, the free water in the composite is consumed and conversed into immobilized water, leading the weaker polarization in the composite, and thus the conductivity improvements by rubbers could be expressed. In summary, it demonstrated that the conductive rubber does have the capacity to improve the electrical conductivity of cementitious composite as conductive fillers.

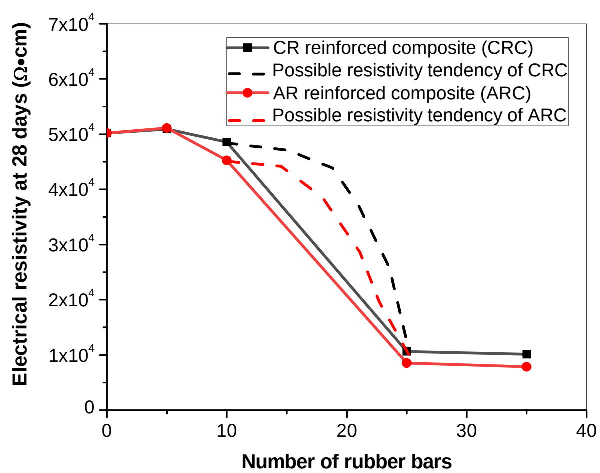


Figure 5. Electrical resistivity of composite with different rubber content at 28 days

4. CONCLUSION

This paper attempts to explore the electrical conductivity of cement paste with reinforcement of conductive rubbers. The main conclusions are displayed as follows:

(1) The conductive rubbers filled by carbon black or aluminum/silver have good performance on the electrical conductivity improvements of cementitious composite.

(2) The percolation threshold is approximately 1.1wt.% to 2.2wt.% for the composite with carbon black filled rubbers and 0.77wt.% to1.65wt.% for that with aluminum/silver filled rubbers.

(3) The polarization will great affect the measured resistivity because of the existed water content in the composite, especially at the early stage of cement hydration. Fortunately, the effect is gradually decreased with the curing age.

5. ACKNOWLEDGMENTS

All the authors acknowledge the research support from Australian Research Council (ARC), Australia.

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Exploring the Relationship between Stakeholder Characteristics and Project Performance

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Abstract

Understanding stakeholder characteristics, including stakeholder power and interests, plays an essential role in managing stakeholders, especially in the context of complex projects. A project manager is expected to analyse and determine whose interests should be taken into account in a decision-making process and why. It appears that much of the literature has focused on identifying a level of stakeholder power and interests with very limited or no regard to the relationship between these stakeholder characteristics and project performance. The objective of this paper is, therefore, to utilise statistical analysis to explore the extent of the influence that stakeholder characteristics have on project performance. The paper uses the Crawford-Ishikura seven-factor table for evaluating roles (CIFTER) to measure the level of project complexity. A comparison is presented to demonstrate how stakeholder characteristics affect project performance in the context of the level of project complexity. The results will contribute to the body of knowledge on managing project stakeholders.

Keywords: Stakeholder Power, Stakeholder Interests, Project Performance, Complex Project.

1. INTRODUCTION

Stakeholder management (SM) plays an essential role in project success, especially in the context of complex projects (CPs). A network of stakeholders who have different power and interests might result in a complex decision-making process, which ultimately affects project performance (PP). Therefore, understanding: (1) stakeholder characteristics, including stakeholder power (SP) and stakeholder interests (SI); and (2) the relationship between these characteristics and PP; is of vital importance (Nguyen et al., 2018).

It is noted that much of the literature has focused on evaluating a level of SP and SI with very little or no regard for relationships between these stakeholder characteristics and PP. Also, an investigation into SM in the context of CPs is crucial.

This paper examines the impact of SP and SI on PP, with special emphasis on this impact in the context of CPs and non-CPs. In the context of CPs, the initial findings reveal that high level of SP has a negative impact on the PP, and there was no statistically significant impact of SI on the PP. Moreover, there was no significant impact of both SP and SI on PP in non-CPs.

2. LITERATURE REVIEW

2.1. Project Complexity

As projects have become increasingly complex, there has been rising concern about project complexity and its effects on managing projects (Baccarini, 1996). In this context, 'complexity' can be seen as 'the property of a project which makes it difficult to understand, foresee and keep under control its overall behaviour, even when given reasonably complete information about the project system' (Vidal et al., 2011). It means that a CP is based on, the project characteristics and the ability of managers to overcome the diverse factors that might increase project complexity. Therefore, understanding the nature of CPs is very important. To better understand the nature of CPs, there is a need to quantify complexity. The Crawford-Ishikura seven-factor table for evaluating roles (CIFTER) (GAPPS, 2007) is one of the main project classification methods used by institutions in the project management field (Bosch-Rekveldt, 2011). CIFTER takes into consideration project management aspects that broadly focus on the interaction between the project and its business environment (Bosch-Rekveldt, 2011).

2.2. Stakeholder Characteristics

This sub-section presents two fundamental stakeholder characteristics, namely SP and SI. It is of interest to note that the stakeholder matrix usually uses two characteristics, for instance, power/interest, influence/interest and power/urgency. In particular, combining power and interest is widely applied (Nguyen et al., 2018). To-date, it seems that much of the literature has paid attention to identifying a level of stakeholder power and interests with very limited or no regard to the relationship between these stakeholder characteristics and PP.

2.2.1. Stakeholder Power (SP)

SP can be seen as 'the ability of those who possess the power to bring about the outcomes they desire' (Salancik and Pfeffer, 1974). There are three types of power: (1) coercive power, based on physical resources such as force or threats; (2) utilitarian power, based on material or financial resources (for example, possession of goods, services and money); and (3) normative/social power, based on symbolic resources (for example, prestige, esteem, love and acceptance) (Etzioni, 1964). Power is acquired by supplying or withholding material, financial, symbolic or physical resources. Power can be increased by obtaining political support from local and national authorities. A stakeholder may also have a formal, economic and political power. SP in a project can be defined as the ability to affect the implementation and/or outcomes of the project.

2.2.2. Stakeholder Interests (SI)

SI can be seen as the interests of each stakeholder group in impressing its expectations on project decisions (Olander and Landin, 2005), including when, why and how stakeholders are involved or perceived to be involved (Caniato et al., 2014). Understanding SI is an essential success factor in the context of CPs (Park et al., 2017) as it is essential for identifying and analysing the positions and interests of stakeholders involved in projects. A stakeholder can have different types of interests, such as physical and information interests. Physical interest might include some basic stakeholder requirements and some tangible benefit, for instance, financial benefits. Whereas, information interest can be seen as a knowledge-based interest; it drives stakeholders to obtain data and information in regards to the project in order to improve their knowledge as well as protect their interests in the project implementation phase (Leung et al., 2013).

2.3. Project Performance (PP)

Time, cost, quality, project objectives and stakeholder satisfaction might be used as criteria for project evaluation. Criteria for PP are well established and include time, cost and quality (Shenhar et al., 2001). The project management body of knowledge suggests time, cost, quality, scope, and stakeholder satisfaction for project success criteria. Project success is evaluated based on completion of the project objectives within the constraints of time, cost, quality, and other achievement criteria. They might include client satisfaction, achieving the strategic objectives of the client organisation and business success, benefits for stakeholders and project personnel, and other business value achievements (Ika, 2009).

3. RESEARCH METHODOLOGY

A quantitative method was adopted to analyse data collected using online survey. Data were collected from 136 participants who have worked in the capacity of a project manager or project team member. Figure 1 shows a research model which explores the extent of the influence that SP and SI have on PP. The next sub-sections present a brief summary about the different part of the research methodology.

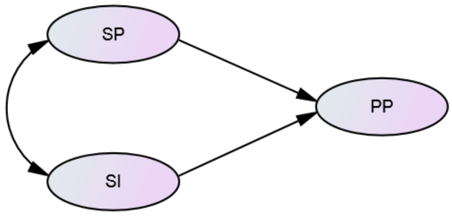

Figure 1. Research model

3.1. Project Complexity

As mentioned previously, CIFTER has been used to determine the level of project complexity. Table 1 presents seven CIFTER factors. Project complexity level is determined by how each of these factors gets assessed in comparison with its level in an 'average' project. In doing so, linguistic terms (e.g. 'Very low', 'Moderately low', 'Similar level/ Similar number', 'Moderately high, Very high') that are associated with five-point Likert scale (1 to 5) were used. The projects with the total scores above 21 are considered as CPs and the ones that equal to or below 21 are considered as non-CPs. In our survey, a participant was asked to consider a recently completed project carried out by his/her organisation; and was asked to compare his/her selected project with the average projects, based on the CIFTER's seven factors. The total score of these factors determines the level of project complexity.

3.2. Stakeholder Power

The authors used nine items (see Table 2) to operationalise the SP. These items are adapted from Agle et al. (1999), Parent and Deephouse (2007), and Leung et al. (2013).

Table 1. Seven CIFTER Factors

No.	Measurement items
1	Number of different organisations involved in the project
2	Number of distinct disciplines, methods, or approaches involved in project execution
3	Level of stakeholder agreement about the project outcomes
4	Level of importance of legal, social, or environmental implications on project execution
5	Overall financial impact (positive or negative) on the project's stakeholders
6	Level of importance of the project to my organisation
7	Level of stability of the overall project context

Table 2. Stakeholder Power Measurement Items

No.	Measurement Items
1	Stakeholder had the right to expect the project management team would protect his/her interests
2	Stakeholder's approval was important for project execution
3	Stakeholder attempted to influence the project
4	Stakeholder provided critical resources to the project
5	Stakeholder threatened to withdraw critical resources
6	Stakeholder regularly supported the project management team
7	Project management team regularly found themselves confronted by the stakeholder
8	Stakeholder made things easy for the project management team to deliver the project
9	Stakeholder made things difficult for the project management team to deliver the project

3.3. Stakeholder Interests

There are seven items for measuring SI (see Table 3). Four items are adapted from (Leung et al., 2013) and three items were developed considering stakeholder demands (Rowlinson and Cheung, 2008, Lappi and Aaltonen, 2017) and the role of a stakeholder in a decision-making process (Havard et al., 2015).

Table 3. Stakeholder Interests Measurement Items

No.	Measurement Items
1	Stakeholder was interested in having unlimited access to project information
2	Stakeholder was interested in receiving regular up-to-date project information
3	Stakeholder always expected their demands to be considered as a priority during the project
4	Stakeholder demanded to actively participate in the decision-making process
5	Stakeholder's benefits were potentially influenced by the project
6	Stakeholder was concerned with the distribution of power among all stakeholders
7	Stakeholder continued to protect their interests, in the decision-making process

3.4. Project Performance

The PP measurement items include time, cost, scope, quality, and stakeholder satisfaction. These criteria for measuring PP are widely used. Table 4 presents six measurement items for PP. PP criteria can be classified into two sub-criteria, namely project quantitative performance (PP_{Qn}) and project qualitative performance (PP_{Ql}). Quantitative performance indicators include project's time and cost. Qualitative performance indicators includes project quality, scope and stakeholder satisfaction.

3.5. Statistical analysis tool

Structural equation modelling (SEM) was used to explore the relationship between the latent variables. SEM is a well-known statically analysis technique for analysing, estimating and testing models that estimate relationships among observed and latent variables.

Table 4. Project Performance Indicators

No.	Measurement Items	Classification
1	Extent to which the project was delivered on schedule	PP_{Qn}
2	Extent to which the project was delivered on budget	PP_{Qn}
3	Extent to which the project scope expectations were met	PP_{Ql}
4	Extent to which the project's quality objectives were met	PP_{Ql}
5	Extent to which my organisation achieved its desired project outcomes	PP_{Ql}
6	Number of project stakeholders that achieved their desired project outcomes	PP_{Ql}

4. RESULTS AND DISCUSSION

Based on the classification using the seven CIFTER factors, there were 78 CPs and 57 non-CPs. As mentioned earlier, SEM is used to find out any initial relationship between latent variables, 1) SP and 2) SI; and PP.

Figure 2 and 3 present the result for testing the relationships between (1) SP and (2) SI; and PP for both cases, CPs and non-CPs. Please note that, in order to simplify the presentation, latent variable indicators and error terms are not shown.

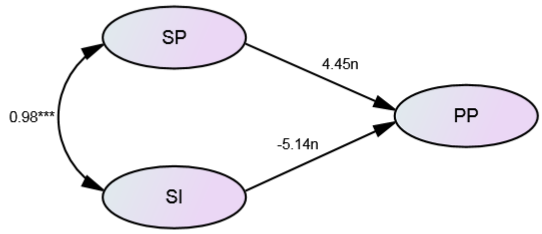

Figure 2. Non-CPs

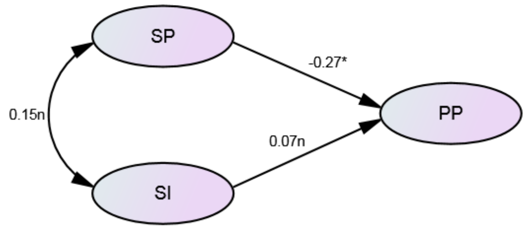

Figure 3. CPs

(n: $non\ significant$; $*\ p < 0.10$;$**\ p < 0.05$;$***\ p < 0.001$. Standard coefficients are shown)

In the case of non-CPs, the regression weight for SP and SI in the prediction of PP is not statistically significantly different at the .05 level (p value are .77 and .74, respectively). It means that no significant impact was found between SP and PP as well as SI and PP.

In the context of CPs, however, the regression weight for SP in the prediction of PP is different at p value .057. It means that increasing in stakeholder power has negative impact on PP. In addition, the regression weight for SI in the prediction of PP is not significantly different at the .05 level ($p = .63$). It appears that increasing SI has a non-significant impact on PP.

There are interestingly findings in the relationships between (1) SP; (2) SI and (1) PP_{Qn}; (2) PP_{Ql}. Table 6 and 7 present these relationships. SI has a significantly negative impact on PP_{Qn} in both CPs and non-CPs.

There is a similarity in the relationships between SP and (1) PP_{Ql}; (2) PP_{Qn} in CPs and non-CPs. SP has a significantly negative impact on PP_{Ql} in both CPs and non-CPs. However, there is no significant evidence impact was observed between SP and PP_{Qn} in both scenarios.

Table 6. Non-CPs

	PP_{Ql}	PP_{Qn}
SP	R	n
SI	R	R

Table 7. CPs

	PP_{Ql}	PP_{Qn}
SP	R	n
SI	n	R

(R: Statistically significant relationship ($p < .05$); n: non-significant)

There is a difference in the relationships between SI and PP_{Ql} in CPs and non-CPs. SI has a significant negative impact on PP_{Ql} in non-CPs. However, there is a non-significant relationship between SI and PP_{Ql} in the context of CPs.

Moreover, in non-CPs there was a significant correlation between SP and SI (0.98) with the covariance between SP and SI is significantly different from zero at the 0.001 level (two-tailed). However, in the context of CPs, the covariance between SP and SI was not significantly different from zero at the .05 level ($p = .26$) (two-tailed).

5. CONCLUSION

The paper presents a study on the relationship between 1) SP; 2) SI and PP in both CPs and non-CPs. The authors used the seven CIFTER factors to assess the level of project complexity. In the non-CPs, there is a significant correlation between SP and SI. However, no significant correlation between SP and SI in the context of CPs was found. Interestingly, in CPs, SP has a negative impact on PP. In contrast, in the non-CPs, there was no significant relationship between (1) SP and (2) SI; and PP. Exploring these relationships in more detail, the authors found that SP has significant affect PP_{Ql} and non-significant affect PP_{Qn} in CPs and non-CPs. Similarity, SI has significant affect PP_{Qn} in both project types.

Moreover, SI had significant affect in PP_{QI} in non-CPs whereas non-significant affect in the context of CPs.

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Cost Estimation Software for Private Residences in the State of Kuwait

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Abstract

The construction of residential projects takes a major proportion of the construction industry in the State of Kuwait. In general, construction of private residences faces cost overruns. The main problem is the lack of owner's ability to estimate the construction budget in the planning phase due to in-sufficient knowledge and experience. The consequences of this is the time delay and cost increases in the construction phase. This paper provides a general understanding of performing a construction estimate for private residences. A real private residences numbers were collected from experienced contractors. Such numbers were analyzed to introduce the estimate into three ranks: "Super Deluxe", "Average", and "Below Average".
The ranks are classified mainly on the finishing division (materials and level of quality) since it is considered the main factor that influencing the total housing budget. On the other hand, it was found that concrete structure expenditures are fixed relative to the total build area for all ranks.
The paper presents a software that provides a primary estimate for residential projects based on a real case studies numbers and costs. The software would calculate the construction division's costs separately and summing all to get the total estimated budget. The software was designed to the minimum required inputs. The user has to determine the total construction building area and have the option to decide the required rank for finishing his villa.

Keywords: *Home Construction, Cost Estimating, Finishing Cost, Private Residences Cost*

INTRODUCTION

In the affluent oil-rich State of Kuwait, the construction of residential projects constitutes a major part of the building activities. Fueled partly by the affluence and availability of attractive government housing subsidy and loan programs. It is also a common knowledge that private residence projects are considered small in the scope of work and size. In general the implantation of these projects is usually accompanied with cost increase and time delay as well as the owner dissatisfaction.

The combination of rapidly growing demand for construction of private residences, owners construction inexperience and knowledge, and the large pool of unqualified contractors has resulted in numerous court cases. As the review of literatures, costing of private residences has not receiving the attention it warrants from research community in general.

The specific objective of this paper is to establish a user-friendly software for estimating the private residence budget and cost breakdown for construction divisions. Another aim is to seek the factors to be considered in the planning phase to introduce the owners with a cost estimating background.

LITERATURE REVIEW

1. Cost Estimation

Estimating is the process of defining and calculating the expected quantities and costs of the materials, labor, and equipment for a construction project. It should always include some indication of accuracy (e.g. + x percent)". (PMBOK 2017)

Any type of estimation should address risks and uncertainties. Estimates are generally used for budget calculations, value analysis, decision making, project costing and planning control. Experience is essential in the process of cost estimating and calculating the future cost of a project for all the resources within a time frame.

In any construction project, there are many estimates and re-estimates for the cost performed throughout all the project phases. It is mainly based on the phase of the project development.

The American Association of Cost Engineers defines accuracy as "the degree of conformity of a measured or calculated value to some recognized standard or specified value." Accuracy depends on the amount of quality information available as well as the judgment and experience of the estimator. Consequently, as the amount of information and specific details increase, so does the degree of accuracy.

In the residential building construction, in spite of the many types of cost estimates used at different stages of a project, cost estimates can best be classified into two main categories Preliminary and Definitive.

In the planning and design stages of a house, preliminary cost estimate reflects the overall budget needed for the house. Estimating methods may vary by type and class of estimate.

A preliminary estimate or conceptual estimate is based on the conceptual design of the house at the state when the basic information for the design and the construction known. Design information includes the level of design complexity, the total area of the house, and the overall design. While construction information mainly depends on two main categories, first the cost needed to complete the house structure itself, second is the finishing materials level chosen by the owner.

The detailed estimate or definitive estimate includes all the resources and materials which are needed to complete the project as well as overhead and contractor's profit. For this type of estimate, an estimator needs a full set of drawing and project instruction manuals. This type of cost estimate displays all required materials, labor, time to complete the project, complete cost details and overhead and also contractor profit. The definitive estimate is made when the scope of work is clearly defined and the house finishing materials are selected and all the construction activities are listed with their exact costs.

2. Risk Associated with Projects

Every construction project might deal with some risks, which includes cost overrun, time delays, unsafe construction, and low quality. Therefore, it is important to understand the definition of risk, and what its sources are. In general, a risk can be defined as any uncertainties that, if it occurs, would affect one or more objectives. Usually, six types of risks can be defined for the construction area: legal risks, scheduling risks, technical risks, financial risks, management risks and environmental risks.

Residential construction is one of the most risky and challenging construction fields since the financial risks are the main and most frequent issue facing the owners, this is considered as a constraint during all construction phases which also has a negative influence on the contactor's performance.

As noted from (Subramani, T. Sruthi, P S. Kavitha, M. 2014) regarding the topic of cost overrun, successful project completion is associated with completing the project within the set time and budget. In construction projects, there is always a chance of facing problems related to cost increase, delays, low productivity and quality. It is noted that there were more cases of cost overruns than time overruns. This makes the problem of cost overruns to be of great significance.

Moreover, as concluded from (Koushki, Parvis: Kartam, Nabil;2004), there are many factors which cause cost increase or overruns. The most significant cause is the contractor related problems, the second cause is owners lack of knowledge and experience, followed by materials delays, weather problems, labor problems, and variation orders and other combined factors.

On the other hand, choice of materials to be used in any residential house also affects the projects time and cost overruns. Against what is expected, houses built with imported material faces less amount of time delays and cost increase, compared with residential projects that use local materials. This is because of the reliance on the availability of the local materials, which mostly results in disappointments, unlike imported materials which may be planned and ordered prior to the execution phase.

3. Factors Affecting Quantity Takeoff and Pricing

In the field of private residence construction, mainly the Internal finishes and its level of quality have a huge influence on the total construction costs. The main driver for most of the project cost overruns is poor estimation during the planning phase. Accurate budget estimates need wide and practical knowledge in the field and market. There are three factors that should be considered in pricing the interior finishes in the estimating process. First of all, quantity, the general rule that there are cost discounts for larger volume applies to interior finishes. When there are large spaces or similar spaces, the manpower productivity for installation increases and the amount of material waste decreases. Furthermore, manufacturers often provide discounted pricing for the high volume of materials. For smaller spaces, the finish work is generally more difficult. There are more cut-outs and this is much more manpower intensive. Also, equipment is considered as fixed pricing items on projects regardless of the size of the project. The second factor is the location of the construction site. Contractor rates will vary from area to area because of the transportation travel time that is needed in far areas.

The third factor is the seasonal effect on work. For example, in Kuwait, labor rates are affected by Holy Ramadhan month. Also, in July and August when the heat is considered the highest in Kuwait and there is a limited working hour for the manpower. In summary, the above-mentioned factors affect the pricing of interior finishes for the construction of houses. An estimator should always be aware of these aspects and be able to adjust their pricing.

METHODS

Data collection for this study is divided into case studies survey and market survey, supported by interviews that done with relevant parties as residences owners. A numerous number of private residence projects were randomly selected from among projects located in different districts in Kuwait and have different plot areas.

Analyzing data into 3 categories of ranking determined according to finishing materials and quality. Such categories were decided by interviewing owners and contractors who agreed that the finishing could be classified as Super Deluxe, Average and Below Average in Kuwait. Such classification level is reflecting prices and qualities for finishing aspects. (Figure 1)

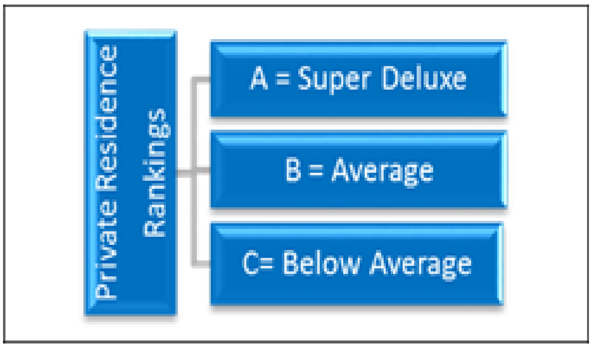

Figure1. Private Residence Rank

A construction breakdown is established with different divisions and tasks referred to the Construction Code Guide for the Kuwaiti Society of Engineers. The breakdown is simply designed to be understandable for all experienced and non-experienced users. (Table 1).

Table 1. Construction Breakdown

<table>
<tr><th colspan="2">Division</th><th>Activity</th></tr>
<tr><td colspan="3">Reinforced Concrete</td></tr>
<tr><td colspan="3">Masonry</td></tr>
<tr><td colspan="3">Manufacture</td></tr>
<tr><td colspan="3">Miscellaneous (Guard + Water + Electricity)</td></tr>
<tr><td rowspan="20">Finishing Activities</td><td rowspan="3">Doors & Windows</td><td>Aluminum</td></tr>
<tr><td>Interior Wooden Doors</td></tr>
<tr><td>Shutter</td></tr>
<tr><td rowspan="12">Finishing</td><td>Roof Isolation</td></tr>
<tr><td>Basement Isolation</td></tr>
<tr><td>Toilets & Kitchen Isolation</td></tr>
<tr><td>Décor</td></tr>
<tr><td>ceramic</td></tr>
<tr><td>Marble</td></tr>
<tr><td>Toilet Ware</td></tr>
<tr><td>Kitchen Ware</td></tr>
<tr><td>House Exterior</td></tr>
<tr><td>Plastering</td></tr>
<tr><td>Painting</td></tr>
<tr><td>Landscaping</td></tr>
<tr><td>Metals</td><td>Handrails and Railings</td></tr>
<tr><td colspan="2">Electrical Works</td></tr>
<tr><td colspan="2">Plumbing</td></tr>
<tr><td colspan="2">Elevator</td></tr>
<tr><td colspan="2">AC</td></tr>
</table>

CASE STUDY

Several Houses samples with different designs, areas and building areas are used by applying all finishing ranks. Case studies costs is adjusted according to market prices to get the lump sum. Price per square meter is calculated. Then the percentage weight for each task cost is computed. This was repeated for all samples with the three finishing ranks. Finally, the average for the percentages and costs per square meter is determined for all ranks to get a unified estimate per square meter and generalize the task percentages. Table 2 shows a sample of the case study.

Table 2. Residence Sample for Three Finishing Ranks

House #3			*Building Area=684			*House Area=400					
Division		Activity	Quantity	Unit	Unit Price	Total A	Percentages A	Total B	Percentages B	Total C	Percentages C
Reinforced Concrete						15775.00	11.53	15775.00	13.43	15775.00	14.67
Masonary						5317.50	3.89	5318.00	4.53	5318.00	4.94
Manfacture						24040.40	17.58	24040.00	20.46	24040.00	22.35
Miscellany (guard + water + electricity)			-	L.S	1	3000.00	2.19	3000.00	2.55	3000.00	2.79
Finishing Activities	Doors & Windows	Aluminium	dfor60m2big- 135kdfor9small - 1800kdfor1			5329.80	3.90	4935.00	4.20	4540.20	4.22
		Interior Wooden Doors	(100kd*21-1800big)			3910.00	2.86	2890.00	2.46	3400.00	3.16
		Shutter	12	Win	150	1944.00	1.42	1800.00	1.53	0.00	0.00
	Finishings	Roof Isolation	400	m2	6	2400.00	1.75	2400.00	2.04	2400.00	2.23
		Basement Isolation	-	LS	-		0.00		0.00		0.00
		Toilets & Kitchen Isolation	175	m2	4	700.00	0.51	700.00	0.60	700.00	0.65
		Décor	967	m2	5	9670.00	7.07	4835.00	4.12	4835.00	4.50
		Ceramic	830	m2	14	11620.00	8.50	6640.00	5.65	5085.00	4.73
		Marble	300	m2	28	8400.00	6.14	4200.00	3.57	0.00	0.00
		Toilet ware	10	Pcs	300	3000.00	2.19	2500.00	2.13	2000.00	1.86
		Kitchenware	26	L.m	180	4680.00	3.42	4305.60	3.66	3961.15	3.68
		House Exterior	668	m2	10	6680.00	4.88	6145.60	5.23	5653.95	5.26
		Plastering	1315-710	m2	3.5,6.5	8560.00	6.26	7875.20	6.70	7245.18	6.74
		Painting	2000	m2	1.75	3500.00	2.56	3220.00	2.74	2962.40	2.75
		Land scaping	92	m2	8	736.00	0.54	460.00	0.39	322.00	0.30
	Metals	Handrails and Railings	-	LS	1	1800.00	1.32	1656.00	1.41	1523.52	1.42
	Electrical works		-	LS	1	4200.00	3.07	3800.00	3.23	3800.00	3.53
	Plumbing		-	LS	1	5500.00	4.02	5500.00	4.68	5500.00	5.11
	Elevator		-	LS	-	0.00	0.00	-	0.00	-	0.00
	AC		-	LS	1	6000.00	4.39	5500.00	4.68	5500.00	5.11
					Total A=	136762.70	Total B=	117495.40	Total C=	107561.41	
					KD/m2=	**199.95**	KD/m2=	**171.78**	KD/m2=	**157.25**	

RESULTS

A. Breakdown Unified Percentages.

The Unified Percentages for the breakdown for each finishing rank is determined and shown in Figure 2.

B. Software.

A friendly excel software for estimating the private residences activities and total cost by just entering the total building area and required finishing category. Figure 3 is a screen shot for the final software format and the using instructions.

C. Software Errors.

The Software is tested as shown in Table 3 to check the error for each finishing rank by the formula 1.

$$Error = \frac{Estimated\ Residence\ Cost - Actual\ Residence\ Cost}{Actual\ Residence\ Cost} \times 100 \quad (1)$$

CONCLUSION

The main aim of this study is to provide a practical guidance to private residence owners who are in the planning phase. Private residence owners who spent more time on the re-planning phase issued less change orders, selected more experienced contracting company, and experienced less time delay and cost increases during the implementation phase of their projects.

The estimation process according to the finishing category is minimizing the financial risk during project implantation. Private residence samples shows that the cost of the main concrete structure (skeleton) is almost fixed to the building area. The software is a tool for overall estimation and breakdown costs with a ±10 % margin of errors.

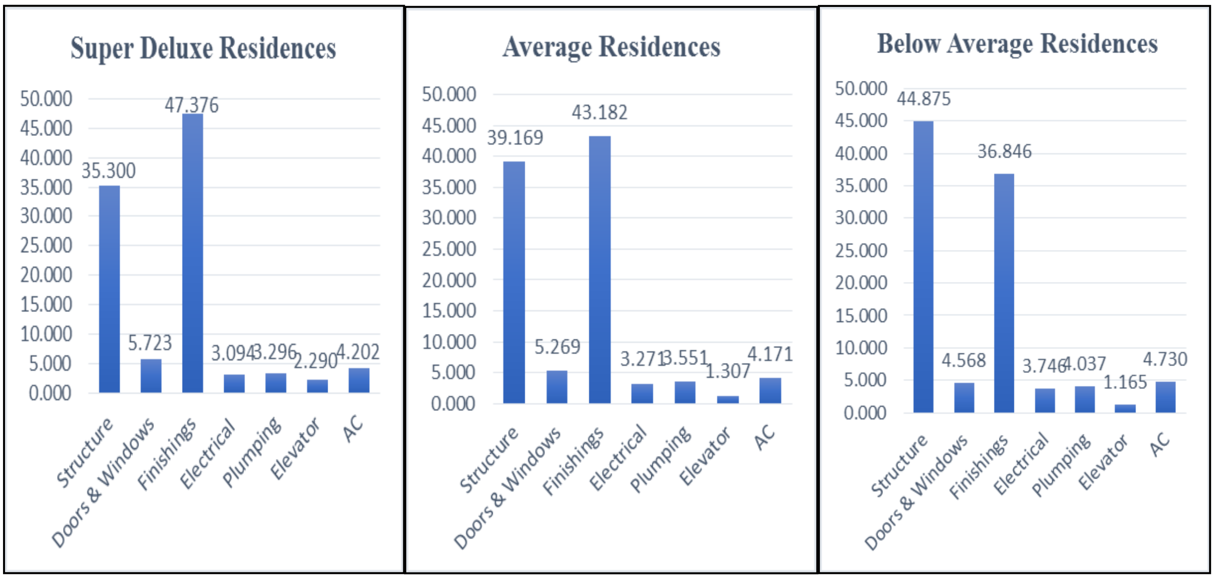

Figure 2. The Unified Percentages for Three Finishing Ranks

House Building Area	**1200** m2
Type of Finishing	**Super Deluxe**

Cost Breakdown:

Reinforced Concrete			30,485.92	KD
Masonry			7,569.89	KD
Manufacture			37,241.75	KD
Miscellaneous (Guard + Water + Electricity)			3,000.00	KD
Finishing Activities	**Doors & Windows**	Aluminum	5,631.95	KD
		Interior Wooden Doors	4,362.06	KD
		Shutter	2,719.72	KD
	Finishings	Roof Isolation	3,923.06	KD
		Basement Isolation	3,998.99	KD
		oilets & Kitchen Isolatio	1,153.42	KD
		Décor	11,776.56	KD
		Ceramic	22,369.19	KD
		Marble	18,166.79	KD
		Toilet ware	4,217.09	KD
		Kitchenware	5,932.17	KD
		House Exterior	11,083.57	KD
		Plastering	13,205.98	KD
		Painting	6,073.68	KD
		Land scaping	1,092.30	KD
	Metals	Handrails and Railings	2,248.75	KD
	Electrical works		6,873.04	KD
	Plumbing		7,321.73	KD
	Elevator		4,100.00	KD
	AC		9,334.72	KD

Estimated Total House Cost=	**223,882.33**	**KD**
Price / m2=	**186.57**	**KD**

Private Residence Cost Estimator

The purpose of the software is to estimate private residence total budget with the breackdown cost in the project planning phase.

Instructions:

1. In the first cell, enter the total area to be constructed. (i.e: Basement area + First floor area .. etc.)

2. In the second cell select the finishing quality:
- *Super Deluxe:* All materials and finishing used are of high quality and premium prices.
-*Average:* All materials and finishing used vary between regular and high price/quality.
-*Below Average:* Materials used of lower grade quality and prices. (i.e House renting).

3. Get your estimate.

Figure 3. Software Screen Shot

Super Deluxe					
Residence #	Actual Residence Cost (KD)	Software Estimated Cost (KD)	Actual KD/m²	Estimated KD/m²	Error %
1	229483.85	231108.41	185.07	186.38	0.708
2	407219.7	431632.07	173.28	183.67	5.995
3	136762.7	130665.93	199.95	191.03	-4.46
4	189331.8	192448.89	184.53	187.57	1.646
5	210638	205817.14	191.49	187.11	-2.29
6	146843.04	145298.74	191.95	189.93	-1.05
7	153541	157041.11	184.99	189.21	2.28
8	258370	260012.72	184.55	185.72	0.636
9	290620	283497.47	189.95	185.29	-2.45
10	357289.32	367319.98	179.18	184.21	2.807
11	337765	355758.25	175.01	184.33	5.327
12	178372	184680.86	181.46	187.87	3.537

Average					
Residence #	Actual Residence Cost (KD)	Software Estimated Cost (KD)	Actual KD/m²	Estimated KD/m²	Error %
1	207137.94	207016.3	167.05	166.95	-0.06
2	365286.96	386510.73	155.44	164.47	5.81
3	117495.4	117107.38	171.78	171.21	-0.33
4	170681	172411.07	166.36	168.04	1.01
5	182630	184377.36	166.03	167.62	0.96
6	130758	130205.62	170.93	170.2	-0.42
7	139913.04	140716.56	168.57	169.54	0.57
8	235148	232889.37	167.96	166.35	-0.96
9	259967.88	253911.24	169.91	165.96	-2.33
10	330252	328943.15	165.62	164.97	-0.4
11	317351.8	318593.92	164.43	165.07	0.39
12	162636.8	165457.68	165.45	168.32	1.73

Below Average					
Residence #	Actual Residence Cost (KD)	Software Estimated Cost (KD)	Actual KD/m²	Estimated KD/m²	Error %
1	181871.29	181058.97	146.67	146.02	-0.45
2	314178.02	337764.99	133.69	143.73	7.51
3	107561.41	102564.79	157.25	149.95	-4.65
4	149501.04	150847.18	145.71	147.02	0.9
5	151640	161294.25	137.85	146.43	6.37
6	116914.2	114000.09	152.83	149.02	-2.49
7	125762.04	123176.57	151.52	148.41	-2.06
8	196702.76	203647.23	140.5	145.36	3.53
9	220615.41	222000.18	144.19	145.1	0.63
10	284778.08	287506.12	142.82	144.19	0.96
11	284651.7	278470.82	147.49	144.29	-2.17
12	143194.82	144776.59	145.28	147.28	1.1

Table 3. Software Errors

ACKNOWLEDGMENTS

My acknowledgment goes to Kuwait Foundation for the Advancement of Sciences (KFAS).

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Mechanical properties of fly ash/GGBFS based geopolymer concrete incorporating recycled aggregates

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Abstract

Geopolymer concrete containing recycled aggregates is featured with extending the life cycle of construction materials and conserving the natural resource, along with embracing the sustainable binder-geopolymer. The benefits stemming from geopolymer concrete with recycled aggregate definitely contributes to the sustainability of construction materials. In this study, the recycled aggregate, sourced from construction and demolition waste, was used as a replacement for natural aggregate in geopolymer concrete with replacement ratios of 50% and 100%. In addition, ground granulated blast furnace slag (GGBFS) was used to substitute fly ash at levels of 10%, 20%, and 30% of total binder, in order to enhance the properties of geopolymer concrete. The mechanical properties of the geopolymer concrete were investigated, including compressive strength, elastic modulus, flexural and splitting tensile strengths. The results revealed that using recycled aggregate had a limited effect on the workability of geopolymer concrete, while the inclusion of GGBFS resulted in a significant decrease in workability. The mechanical investigations showed that the mechanical properties decreased with the increase in recycled aggregate replacement. Conversely, the incorporation of GGBFS enhanced the mechanical properties and this improvement was more obvious in the geopolymer concrete with recycled aggregate.

Keywords: Recycled aggregate, Geopolymer concrete, Workability, Mechanical properties, Sustainablity

1. INTRODUCTION

Construction and demolition waste (C&DW) has aroused challenging concerns of society. Reusing C&DW into new engineering construction, for example as a constituent in new concrete, can alleviate this issue, together with reducing the consumption of natural aggregates, and giving additional value to solid waste. Recently, several efforts have been devoted to using recycled aggregate into geopolymer concrete. Geopolymer concrete is formed by synthesizing aluminosilicate materials with alkaline solutions to form the slurry for binding coarse and fine aggregate particles in the production of concrete (Duxson et al. 2006). Apart from involving lower carbon footprint and less energy consumption compared with OPC concrete (Juenger et al. 2011), geopolymer concrete exhibits other excellent performances, such as comparable mechanical strength, low shrinkage, significant resistance to creep, and good durability under acid environment (Ding, Dai & Shi 2016; Reddy, Dinakar & Rao 2016; Zhang et al. 2017).
It has been reported that the mechanical properties of geopolymer concrete with recycled aggregate were stronger than the recycled concrete based on ordinary Portland cement (OPC), due to the different formation processes of geopolymer concrete that result in much denser and stronger reaction

products (Shi et al. 2012). Moreover, the refined microstructure of geopolymer paste results in the better durability properties of geopolymer concrete containing recycled aggregate than that of recycled OPC concrete (Shaikh 2016). Liu et al. (2016) stated that there was no identified interfacial transition zone around the interface of the old cement paste of recycled concrete aggregate and the new geopolymer paste. These results acknowledge the promising prospects of utilization of recycled aggregates in geopolymer concrete.

On the other hand, many experimental studies indicated that ground granulated blast furnace slag (GGBFS) could be blended with geopolymer source materials in an effort to improve the performance of geopolymer. For instance, Nath & Sarker (2014) reported that every 10% increment of the included GGBFS content benefited concrete with an improvement of about 10 MPa in compressive strength. A significant increase in strength due to the inclusion of GGBFS was also observed by other researchers (Bernal et al. 2011; Deb, Nath & Sarker 2014; Khan et al. 2016). In regards to the durability properties, GGBFS blended fly ash geopolymer exhibited good resistance to mass transport (Ismail et al. 2013), elevated temperature and fire (Bernal et al. 2011), and sulfate attack (Ismail et al. 2012).

In this work, the mechanical properties of fly ash/GGBFS geopolymer concrete with recycled aggregate were investigated. The recycled aggregated was originated from C&DW and replaced natural aggregate at the levels of 50% and 100%. In addition, GGBFS as 10%, 20% and 30% of the total binder was incorporated into mixture in order to enhance the properties of geopolymer concrete. This study would support the producers of C&DW to gain considerable financial benefit through applying the C&DW aggregates into geopolymer concrete productions and favor the stakeholders of geopolymer material industries with more sustainability in their products.

2. MATERIALS AND METHODS

2.1. Material

Commercially available fly ash and GGBFS were used as the source materials in this study, with their chemical compositions presented in Table 1. The percentage of fly ash and GGBFS retained particles on the 45-μm sieve was 1.2% and 2.0%, respectively. Sodium hydroxide and sodium silicate (NS) were used as alkaline activators with NS to NH ratio of 2.0. Sodium hydroxide solution of 12 M concentration was prepared by mixing 97–98% pure pallets with tap water. The commercially available D-grade sodium silicate solution with a modulus ratio (Ms) (SiO_2/Na_2O) of 2.0 (SiO_2=29.4%, Na_2O=14.7%, water 55.9%) was obtained from PQ Australia Ltd.

Table 1 Chemical composition of fly ash and GGBFS

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	MnO	K_2O	Na_2O	P_2O_5	TiO_2	SO_3	LOI
Fly ash	65.9	24	2.87	1.59	0.42	0.06	1.44	0.49	0.19	0.92	–	1.53
GGBFS	36	13.8	0.3	42.6	5.8	0.4	0.27	0.21	0.1	0.8	0.56	-1

The natural coarse aggregate was crushed basalt aggregate from a local quarry. The recycled coarse aggregate was supplied by a local C&DW recycling plant in Sydney. Locally available river sand was adopted as fine aggregate. The physical properties of aggregates are given in Table 2. Figure 1 shows the particle size distributions of aggregates, which meet the requirement as per ASTM C33-16.

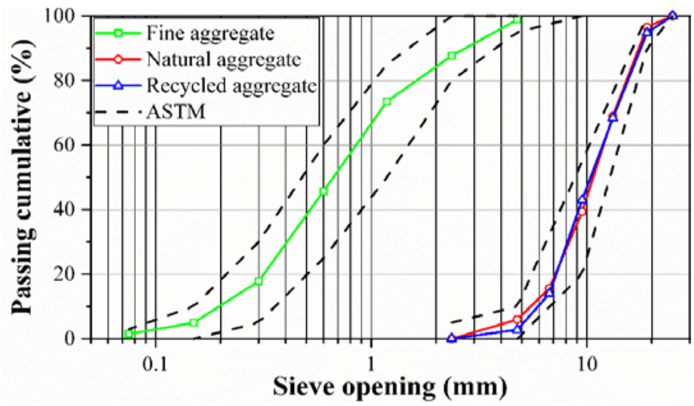

Figure 1. Particle size distribution curves for aggregates used

Table 2. The physical properties of aggregates

Aggregate	Maximum size (mm)	Specific gravity (SSD)	Water absorption (%)	Crushing value (%)
Natural aggregate	20	2.88	1.57	16.65
Recycled aggregate	20	2.34	6.78	24.54
Fine aggregate	5	2.61	4.02	
Constituents of RCA (wt.%)				
Concrete products	Clay masonry units	Natural stone	Glass	
74.49	21.64	2.26	1.61	

2.2. Preparation of specimens

The mix proportions of geopolymer concrete studied are given in Table 3. In this study, twelve mixtures of geopolymer concrete were designed to study the effects of the recycled aggregate and GGBFS on the mechanical properties of geopolymer concrete.

Table 3. Mix proportions of geopolymer concrete

Label	Geopolymer concrete mixture quantity						
	FA	GGBFS	SS	SH	Sand	NA	RA
S00	420	0	165	66	550	1220	0
S10	378	42	165	66	550	1220	0
S20	336	84	165	66	550	1220	0
S30	294	126	165	66	550	1220	0
S00R50	420	0	165	66	550	610	610
S10R50	378	42	165	66	550	610	610
S20R50	336	84	165	66	550	610	610
S30R50	294	126	165	66	550	610	610
S00R100	420	0	165	66	550	0	1220
S10R100	378	42	165	66	550	0	1220
S20R100	336	84	165	66	550	0	1220
S30R100	294	126	165	66	550	0	1220

Concrete ingredients were mixed in a laboratory tilting drum mixer. Coarse and fine aggregates, prepared in saturated surface dry condition, and the binders (fly ash and GGBFS) were dry mixed thoroughly in the mixer for 2 min. Then, the premixed alkaline activator solution was added slowly and evenly into the mixer over a period of 1 min. Then mixing was continued for further 3–5 min to ensure a uniform mixing. The fresh concrete was cast into moulds and put on a vibration table to ensure compaction. Subsequently, the specimens were wrapped with plastic films. Then the specimens were stored at room temperature of approximately 28 °C for 1 h, followed by heat-cured at 75 °C for 1 day. Next, the specimens were demoulded and wrapped with plastic films, and then stored at an ambient temperature ranging from 15 to 20 °C until the ages of testing.

2.3. Test methods

The slump value was measured immediately after mixing as per ASTM C143-15. Compressive strength test was determined at 3, 7 and 28 days using cylindrical specimens with 100 mm diameter and 200 mm height according to ASTM C39-18. The elastic modulus was determined based on the stress within 0 to 40% of the ultimate load and the corresponding strain of cylindrical specimens according to ASTM C469-14. Tensile splitting strength tests were conducted using cylindrical specimens with 100 mm diameter and 200 mm height in accordance with ASTM C496-17. The flexural strength was determined using prismatic specimens of size 100 × 100 × 400 mm with third-point loading as per ASTM C78-18.

3. RESULTS AND DISCUSSIONS

3.1. Workability

The fresh geopolymer concrete was highly cohesive and viscous. The slump values of the geopolymer concrete mixtures are shown in Table 4. The slump value of concrete decreased with the increase of GGBFS content in the binder and this effect appeared to be more pronounced at the higher content of GGBFS. On the other hand, the slump value exhibited a slightly increasing trend with the increase of recycled aggregate content for the mixture with the same content of GGBFS.

3.2. Compressive strength

Table 4 shows the compressive strength for the test mixtures at 3, 7 and 28 days. Due to the heat treatment can accelerate the dissolution and geopolymerization, the high strength was gained in the early age. The compressive strengths at 3 days and 7 days achieved more than 77% and 90% of its corresponding 28-day strength respectively. Table 4 also shows that the compressive strength of geopolymer concrete increased with the increase of GGBFS content in the binder, with regardless of the aggregate type and curing age. However, the replacement of natural aggregate by recycled aggregate had an adverse effect on the compressive strength. Moreover, the effect of recycled aggregate on the compressive strength was more pronounced in the mixtures based on fly ash only. For instance, the strength reduction factor at recycled aggregate replacement ratio of 100% was more than 43% for the fly ash based geopolymer concrete, while the factors were less than 36%, 26%, and 27% for the mixtures having 10%, 20% and 30% GGBFS respectively.

Table 4. Test results and standard deviations for the properties of geopolymer concrete

	Slump (mm)	Compressive strength (MPa)			Elastic modulus (28-day) (GPa)	Flexural strength (28-day) (MPa)	Splitting tensile strength (28-day) (MPa)
		3-day	7-day	28-day			
S00	190	20.2 ± 1.37	23.7 ± 0.54	26.1 ± 1.23	13.34 ± 0.62	3.50 ± 0.34	2.76 ± 0.02
S10	180	36.6 ± 2.89	41.7 ± 3.16	43.5 ± 1.90	20.75 ± 0.59	4.56 ± 0.14	3.97 ± 0.08
S20	155	41.0 ± 2.21	45.3 ± 1.57	47.0 ± 2.43	21.79 ± 0.53	4.87 ± 0.34	4.71 ± 0.19
S30	130	45.4 ± 1.36	51.0 ± 2.82	52.3 ± 0.78	22.32 ± 0.87	5.01 ± 0.21	4.77 ± 0.04
S00R50	210	12.7 ± 0.66	13.0 ± 1.20	14.0 ± 1.12	11.65 ± 0.79	2.66 ± 0.07	1.92 ± 0.06
S10R50	195	27.2 ± 1.14	30.9 ± 1.01	31.9 ± 1.00	16.78 ± 1.02	4.00 ± 0.22	3.42 ± 0.15
S20R50	170	28.7 ± 0.92	33.4 ± 1.67	35.6 ± 0.87	16.95 ± 0.57	4.24 ± 0.16	3.69 ± 0.11
S30R50	130	36.0 ± 0.74	40.9 ± 3.28	43.0 ± 0.84	17.96 ± 0.53	4.36 ± 0.25	4.16 ± 0.13
S00R100	225	12.2 ± 0.75	13.0 ± 0.04	13.7 ± 1.16	9.59 ± 0.93	2.19 ± 0.18	1.66 ± 0.02
S10R100	200	22.1 ± 1.12	26.5 ± 2.52	27.5 ± 1.46	12.78 ± 0.79	3.37 ± 0.17	2.63 ± 0.13
S20R100	180	30.5 ± 1.00	34.5 ± 1.68	34.8 ± 1.54	14.33 ± 0.46	3.91 ± 0.14	2.95 ± 0.12
S30R100	140	34.1 ± 2.63	37.9 ± 0.85	38.1 ± 1.66	17.03 ± 0.70	4.22 ± 0.32	3.54 ± 0.06

3.3. Elastic modulus

Table 4 shows the elastic modulus of test mixtures at 28 days. The elastic modulus decreased with an increase in recycled aggregate replacement ratio. The reductions of elastic modulus were about 20% and 40% due to the 50% and 100% replacement of natural aggregate with recycled aggregate respectively, and the reductions were 15% and 22% for the mixtures with 30% content of GGBFS. Also, the elastic modulus of the mixtures blended with GGBFS was higher than that of the mixtures based on fly ash only. Although the increase in the content of GGBFS over 10% had a marginal effect in the elastic modulus of geopolymer concrete with natural aggregate, it had continual improvement on the elastic modulus in the case of mixtures with 50% and 100% content recycled aggregate.

3.4. Flexural strength

As shown in Table 4, the flexural strength of the mixtures with recycled aggregate was lower than that of the mixtures with natural aggregate and decreased with the increase in recycled aggregate content. In addition, the mixtures incorporating GGBFS underwent less reduction in flexural strength incurred by the replacement of natural aggregate with recycled aggregate, compared with the mixtures based on fly ash only. It also can be seen that the flexural strength showed an ascending trend when the content of GGBFS was increased.

3.5. Splitting tensile strength

As shown in Table 4, a similar trend to compressive strength or flexural strength is observed in the case of splitting tensile strength. The strength slid in all the geopolymer concrete with recycled aggregate, declining with the rise in the content of recycled aggregate. The 50% and 100% replacement of nature aggregate by recycled aggregate resulted in the strength loss in the range of 0.54 to 1.01 MPa, and 1.09 to 1.76 MPa, respectively. Additionally, the addition of GGBFS into mixtures improved the strength significantly. Specifically, the strength was improved more than 0.97, 1.28 and 1.87 MPa respectively for the geopolymer concrete incorporated with 10%, 20%, and 30% GGBFS compared with geopolymer concrete only based on fly ash.

4. CONCLUSION

This paper investigated the effects of blending GGBFS with fly ash and replacing natural aggregate by recycled aggregate on the mechanical properties of geopolymer concrete. Based on the experimental results, the following conclusions were drawn:

1. The substitution of fly ash for GGBFS reduced the workability of geopolymer mixture, while the replacement of natural aggregates by recycled aggregates resulted in a little increase in the workability.
2. The replacement of natural aggregate by the recycled aggregate adversely affected all the mechanical properties of geopolymer concrete. In addition, the mechanical properties declined with the increase in recycled aggregate replacement ratio. However, geopolymer concrete with recycled aggregate still possessed sufficiently high compressive strength up to 43.1 MPa and 38.5 MPa for the recycled aggregate replacement ratios of 50% and 100% respectively.
3. The improvement in mechanical properties of geopolymer concrete was achieved with the substitution of fly ash for GGBFS. Moreover, the inclusion of GGBFS diminished the detrimental effect on mechanical properties caused by the replacement of natural aggregate by recycled aggregate.

5. ACKNOWLEDGMENTS

All the authors acknowledge the research support from Australian Research Council (ARC), Australia

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Interaction of solar radiation and natural convection in low-e glass double-skin facade

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***Abstract**: Solar energy is a desired source for building as it can consume over 40% of the energy worldwide. Building envelop plays a critical part in energy consumption as it is the interface between outdoor solar radiation and indoor environment. Its role becomes even important for those mid-rise and high-rise buildings with big glazing facade. Under the circumstance, low-emissivity (low-e) glass facade has been frequently adopted to reflect the solar radiation during the summer. However, during the winter (or cold) time, the desired solar radiation is also reflected by the low-e glass, resulting in a higher energy consumption. Therefore, in this study, a low-e glass double-skin facade was proposed to solve the problem. The proposed low-e glass double-skin facade can be easily combined with the existing double-skin facade, which contains an outer glazing wall (clear glass) and an inner low-e glazing. The cavity constructed by the two skins can provide heated air to the indoor under solar radiation, which can further reduce the indoor heating requirement. The viability of the proposed design was confirmed numerically in this study. Non-gray radiation model with three bands of the spectrum was adopted to simulate the performance with 0.05-0.4 m cavity gaps under solar radiation. It was known that the 0.2-0.3 m cavity gap provides relatively higher average air velocity and temperature at the outlet. The proposed design provides a practically viable and efficient solution to overcome the weakness of low-e glass for winter usage.*

Keywords: Low-e glass, solar chimney, double-skin facade, energy saving, numerical simulation.

1. INTRODUCTION

Solar energy has attracted explosively growing interest in hunting, storing and using energy from the sun for various industries, especially since the shortage crisis of traditional energy resources. The building sector is one of the focuses in adopting solar energy, which is because the building could consume about 42% annual energy usage of the whole world, mainly for heating, cooling and air conditioning (Lotfabadi, 2015). Due to the external solar radiation and their large interaction areas, building envelope (e.g. windows, doors, roofs, etc.) plays a critical role in the overall energy consumption of buildings. It has been estimated that windows account for approximately 25% of the energy use in the typical residential building (Petersen *et al.*, 2015), where the percentage is much larger for those mid-rise and high-rise buildings with large glazing façade.

Low-emissivity (usually called low-e) glass is one of the most frequently adopted envelope materials to reduce the heat transfer between the indoor and outdoor without compromising the visible view. According to a comprehensive study (PR Newswire, 2018), the global low-e glass market is projected to display a robust growth represented by a compound annual growth rate of 10.35% during 2018 – 2023. The special characteristic is realized by the spectrally selective low-e coating. Solar radiation contains three bands of spectrum, including ultraviolet (UV, short wavelength), visible and infrared (IR, long wavelength). UV and IR are the high-energy part in the solar radiation, which can be largely reflected by the low-e coating, while most of the visible light can penetrate through to enable the visible view. The structure of the low-e glass can be seen in Figure 1. In summer, the low-e glass can reduce the penetration of the high-energy part of the solar radiation into the building, and it also can decrease the indoor heating loss during the winter.

Many studies have been taken to address the energy saving after adopting low-e glass. For example, a combined case study and modelling analysis have been taken by Culp and Cort (2014), which indicates that the average source energy saving based on low-e window ranges from 24 to 36% with a simple payback period of 4.7 to 12.9 years across U.S. climate zones. Although the low-e glass has shown excellent performance in energy saving, which is largely due to the reflection of the solar radiation in summer. However, during the winter, the desired external solar radiation, especially the high-energy parts of the spectrum, is also blocked by the low-e glass. If the solar radiation can be used during the winter, the overall energy saving of the building can be greatly improved.

Although several studies (Bansal *et al.*, 2005, Chantawong *et al.*, 2006) have been found in the literature attempting to use window solar chimney for cooling, no study has been found for low-e glass double-skin façade for heating purpose. Therefore, in this study, a low-e glass double-skin facade was proposed to reduce the energy consumption of a building by using the solar energy to heat the indoor air. The innovation of the proposed low-e glass double-skin facade is a visible view, which is impossible for the traditional solar chimney due to the opaque absorption wall. Also, as the external wall (facade) is fully sealed, the problem for water leakage during the raining is then solved.

2. METHODOLOGY

2.1. Low-e glass double-skin facade

Figure 1 shows the proposed low-e glass double-skin facade combined with exiting double-skin façade. The outer skin located on the right is the clear glass, while the right side (inner skin) shows a low-e double glazing. The low-e double glazing contains two layers of clear glass, and the internal face of one glass is pained with the low-e coating. At the indoor side, the bottom and top openings are the inlet and outlet of the low-e glass cavity, where both openings are controlled by dampers. This can be also adopted combined with roof (Shi L *et al.*, 2016).

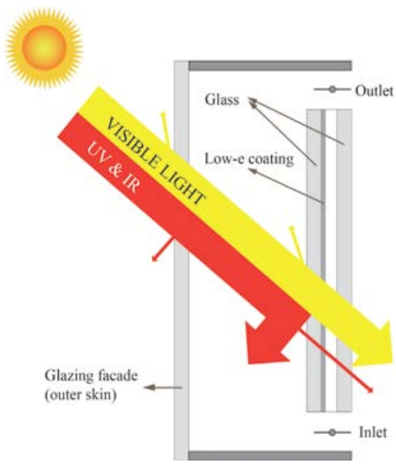

Figure 1. Proposed low-e glass double-skin facade. Dimension of the cavity is 1.0 m (H) × 1.0 m (W) with various thicknesses. Dimension of both inlet and outlet are 0.1 m (H) × 1.0 m (W).

The proposed design can serve both the summer and winter. During the summer, both inlet and outlet are closed, and the inner skin (low-e glass) can reflect most of the UV and IR radiation from the sun. Both the large cavity constructed double skins and the small cavity inside the low-e glass can further serve as insulation layers to reduce the thermal conduction. During the winter, the inlet and outlet are opened, and the internal air in the big cavity are then heated under the interaction of both radiation and natural convection. Therefore, the airflow from the inlet to the outlet can be heated up under the solar radiation, which then results in the reduced heating requirement for building to save the energy (Shi L, 2018). In this study, the focus was on the situation under heating period during the winner.

2.2. Numerical theory

The low-e glass double-skin facade is the interaction between the solar radiation and natural convection. To describe the natural convection between the air and those glazing wall, Navier-Stokes equations together with the turbulence model were adopted. The details about governing equation of conservation can be found in Ref. (Shi and Zhang, 2016).

Regarding the turbulence model, realizable *k-ε* model was adopted as it can provide superior performance for flow boundary layers under strong adverse pressure gradients (Bacharoudis *et al.*, 2007). The term "realizable" means that the model satisfies certain mathematical constraints on the Reynolds stress, consistent with the physics of turbulent flows. The steady status transport equations for k and ε in the realizable k-ε model can be given by:

$$\frac{\partial}{\partial \vec{x}}\left(\rho k \vec{u}\right)=\frac{\partial}{\partial \vec{x}}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial \vec{x}}\right]+G_k+G_b-\rho\varepsilon-Y_M+S_k \tag{1}$$

$$\frac{\partial}{\partial \vec{x}}\left(\rho \varepsilon \vec{u}\right)=\frac{\partial}{\partial \vec{x}}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial \vec{x}}\right]+\rho C_1 S_\varepsilon-\rho C_2\frac{\varepsilon_2}{k+\sqrt{v\varepsilon}}+C_{1\varepsilon}\frac{\varepsilon}{k}C_{3\varepsilon}G_b+S_\varepsilon \tag{2}$$

where ρ is the density; k is the kinetic energy per unit mass; $\vec{u}$ is the velocity vector; μ is the dynamic viscosity; G is the generation of turbulence kinetic energy; Y is the contribution of the fluctuating dilation in compressible turbulence to the overall dissipation rate; S is the source term; C is the coefficient obtained by experiment; C_1=max[0.43, $\eta/(\eta+5)$], $\eta=Sk/\varepsilon$, and $S=(2S_{ij}S_{ij})^{0.5}$.

The radiation is also a very important part. Discrete ordinates (DO) radiation model as an important model for non-gray radiation simulation (Gholamalizadeh and Kim, 2014) was adopted in this study. DO model solves the radiative transfer equation for a finite number of discrete solid angles, where each associated with a vector direction fixed in the global Cartesian system. For the non-gray model, the radiation transfer equation can be written as:

$$\frac{\partial}{\partial \vec{r}}\left[I_\lambda\left(\vec{r},\vec{s}\right)\vec{s}\right]+\left(\alpha_\lambda+\sigma_S\right)I_\lambda\left(\vec{r},\vec{s}\right)=\alpha_\lambda n^2 I_{b\lambda}+\frac{\sigma_S}{4\pi}\int_0^{4\pi}I_\lambda\left(\vec{r},\vec{s}\,'\right)\Phi\left(\vec{s}\cdot\vec{s}\,'\right)d\Omega' \tag{3}$$

where λ is the wavelength; $\vec{r}$ represents the radius in the polar coordinate system; $\vec{s}$ is the vector direction; α_λ is the spectral absorption coefficient; I_λ is the intensity of the specified wavelength; $I_{b\lambda}$ is the blackbody intensity given by the Planck function; n is the refractive index; Ω' is the solid angle.

The governing equations together with the turbulence and radiation models were solved and implemented through FLUENT. The details about the numerical model can be seen in Ref. (ANSYS, 2013).

2.3. Numerical methodology

The DO model has two implementations, with energy coupled or uncoupled. The adoption of the implementation is much dependent on the situation. For the above problem with relatively low optical thickness, uncoupled energy implementation was utilized to benefit the convergence. The air was considered as the ideal gas, with a density of 1.225 kg/m^3 under ambient conditions. Table 2 shows a summary of properties of glass and air for modelling input.

For the non-gray model, three bands were adopted to represent the solar radiation. Total heat flux of the three bands keeps at 500 W/m^2 in this study. Glass was considered as the semi-transparent material during the modelling, with an emissivity of 0.8 to all three bands of spectrum. The low-e coating was considered as opaque and spectrum selective materials, with a high emissivity of 0.8 to the visible light and a relatively low emissivity to both UV and IR radiation. The details can be seen in Table 2.

Table 1 A summary of properties data for modelling inputs

Property	Glass	Air
Density (kg/m^3)	2700	1.225
Specific heat capacity (J/kg·K)	840	1006.43
Thermal conductivity (W/m·K)	1.05	0.0242
Absorption coefficient (1/m)	0.001	0
Refractive index	1.5162	1

Table 2 A summary of the emissivity under various bands

Band	Wavelength (µm)	Emissivity	
		Glass	Low-e coating
UV	0.15-0.4	0.8	0.2
Visible	0.4-0.76	0.8	0.8
IR	0.76-4.0	0.8	0.2

To evaluate the performance under various scenarios, the steady simulation was performed, as shown in Eqs. (1)-(2). According to our previous study (Shi and Zhang, 2016), a grid size of 50 mm can achieve grid independence for the similar scale fluid problem. As the steady simulation requires a less computational resource, the overall grid sizes within a range of 5-10 mm were adopted. Pressure-velocity coupling was solved by SIMPLEC scheme, where the ordinate discretization was based on second-order upwind scheme. During the trail simulation, it was found that after 1,500 iterations all the residuals are less than 10^{-4}. So, in this study, all the scenarios was calculated based on 1,500 iterations under steady condition.

According to the literature review, no related experiment was found in the literature regarding using low-e glass for heating purpose. Therefore, the validation of the numerical results will be given in the future when the experiment is available.

3. RESULTS AND DISCUSSION

Cavity gap represents the distance between the outer and inner skins in the double-skin façade. In this study, various of cavity gaps within a range of 0.05-0.4 m were investigated numerically. Figure 2 shows the temperature profiles under these cavity gaps. A range of 20-35 °C was adopted for the color bar to better present the temperature profile, even though the temperatures of some locations are higher than this. The details can be seen below. It can be seen that the high-temperature area is very close to the outer skin (the regular glass). This is much due to the natural convection between the glass and the internal air inside the cavity. The radiation from the sun and the reflected radiation from the low-e coating are much on the outer glass. It was observed that more area is with high temperature when the cavity gap keeps decreasing. It is due to the conservation of the energy that less air was heated under a small cavity.

Figure 3 shows the velocity profiles under various cavity gaps. Following the above temperature profile, it was observed that the area near the outer glass shows relatively higher temperature, where is the area with obvious thermal buoyancy (Cheng *et al.*, 2018). It then can be known that the area is with a relatively larger air velocity, moving upward to the ceiling of the cavity. It can be also observed that there shows an increasing vortex on the right side of the cavity under a bigger cavity gap. This is much due to the temperature gradient. Except for the vortex, no reverse airflow was observed for the studied cases.

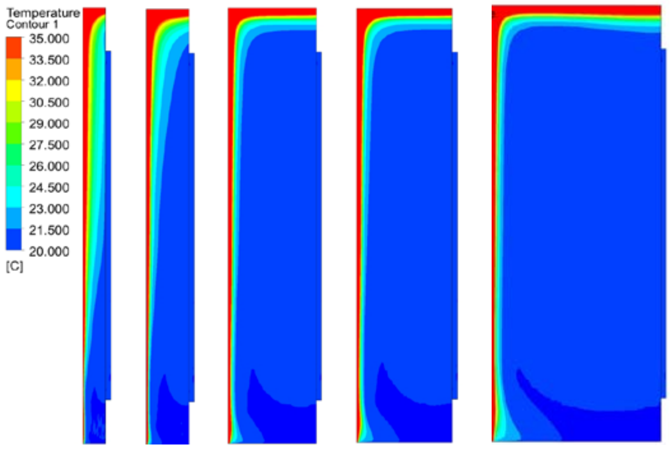

Figure 2. Comparison of temperature profiles under various cavity gaps. From left to the right the cavity gaps are 0.05, 0.1, 0.2, 0.3, and 0.4 m, respectively.

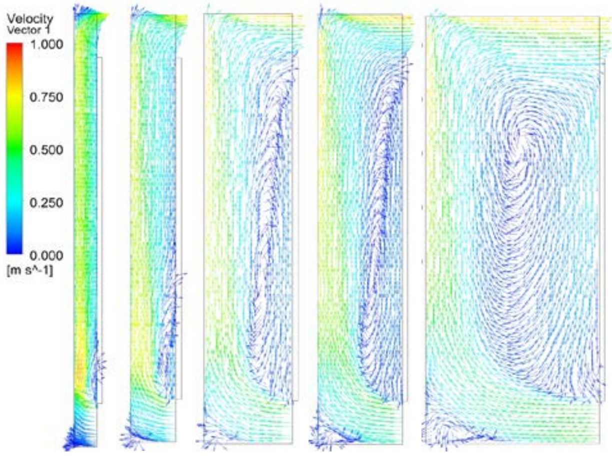

Figure 3. Comparison of velocity profiles under various cavity gaps. From left to the right the cavity gaps are 0.05, 0.1, 0.2, 0.3, and 0.4 m, respectively.

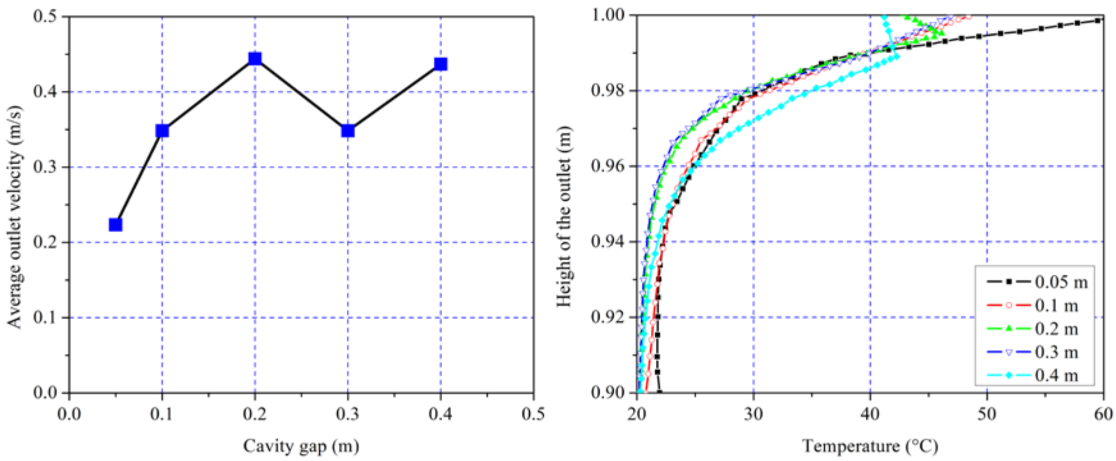

Figure 4. Influences of cavity gap on the temperature and average velocity. The left is the average outlet air velocity and right is the outlet temperature.

The influences of the cavity gap on the average air flow velocity and temperature at the outlet can be seen in Figure 4. The average airflow velocity was obtained by the overall air mass flow and outlet area. It can be seen that the average airflow velocity increase with a bigger cavity gap, but it decreases after 0.2 m and increase again after 0.3 m. For the range of 0.05-0.4 m cavity gap, the maximum average velocity happens under a cavity gap of 0.2 m. It is quite consistent with the results of the regular solar chimney in the literature (Shi *et al.*, 2018, Shi and Chew, 2012). From the temperature profile, it can be seen that the 0.2-0.3 m cavity gaps show relatively high temperature for the most part of the outlet. However, for the area very close to the ceiling, it can be seen that the temperatures are relatively higher with a small cavity gap. This is because less air is heated with a small cavity gap.

4. CONCLUSIONS

A low-emissivity (low-e) glass solar chimney was proposed in this study, which includes a regular glazing wall (outer skin) and inner low-e glass (inner skin). Low-e glass is a spectrum selectively materials which can reflect the majority of the high-energy part of solar radiation (ultraviolet, UV; and infrared, IR) and allowing visible light. The advantages of the proposed solar chimney include the visible view of the outdoor environment and protection from the external disturbance (e.g. raining). The performance prediction is mainly the combination of solar radiation and natural convection. To achieve this, non-gray radiation model, containing three bands, was adopted to simulate the external solar radiation. The viability of using the proposed low-e glass double-skin facade for double-skin façade was confirmed numerically. Unfortunately, there is no experiment available in the literature, where the related numerical results still need to be validated by experiments in the future.

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Towards Low Carbon Footprint: A Case Study of Sydney, Australia

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Abstract:

Climate change has become a global issue influencing human survival and development. Urban carbon emissions are the main factor contributing to climate change. Australia has a naturally high emissions economy (Wang, Zhao et al. 2016). However, under the Paris Agreement, it has committed to reduce emissions by 26 to 28 per cent below 2005 levels by 2030. Many Australian states and local government areas have prepared their policy and action plans toward GHG emission reduction. Blacktown City Council is the local government authority for the second most populated local government area in the Australian state of New South Wales. It developed and undertook the Blacktown Climate Change Action and Adaptation Plan (BCCAAP) for the period 2011 to 2016. The plan's actions towards GHG reduction are now complete. This paper retrospectively considered these actions. The boundary of the research, and energy consumption estimation has been limited to council's operations. It does not relate to energy or emissions from the community or local businesses, and it does not include actions undertaken after 2016. The results of this study show that of the 22 actions undertaken by the council during the study period, installation of energy saving units were the most cost-efficient, followed by retrofit dog kennel heaters to higher efficiency units, then replacing electric hot water systems with solar hot water systems and affixing variable speed drives to pool motors. A comparison of payback periods of the measures showed that installation of 350 KvA energy saving units provided the quickest payback.

Key words: Blacktown City Council, GHG emission, Cost efficiency, Energy audit, Payback period

1. INTRODUCTION

Climate change has become a global issue influencing human survival and development and urban carbon emissions are the main factor contributing to climate change (Ganaut 2011). Australia has a naturally highly emissions economy (Wang, Zhao et al. 2016). However, under the Paris Agreement, it has committed to reduce emissions by 26 to 28 per cent below 2005 levels by 2030 (Australian Government 2016). This will see emissions per capita halved and the emissions intensity of the economy fall by around 65 per cent. Across a range of indicators, this target is in step with other major developed countries like the United States, the European Union, Canada and New Zealand, and on a per capita basis, among the highest of major economies. In 2017, the Australian Government will review its climate policies and consider a potential long-term emissions reduction goal for beyond 2030 (Australian Government 2017).

This paper outlines greenhouse gas reduction measures undertaken by Blacktown City Council in its operations. Blacktown City is the second most populated local government area in New South Wales (Council 2017). This paper compares the measures regarding their level of emission control, their cost and payback period. The period studied was 2011 to 2016. All the data was supplied by the council, and its consultant Planet Footprint, which provides the council with services to monitor its energy and water usage and Scope 1 and 2 greenhouse gas emissions (GHG).

2. MATERIALS AND METHODS

2.1. Study Area

A modern bustling city of 48 residential suburbs, Blacktown City is home to more than 340,000 people (Council 2017) (Figure 1: Blacktown City in New South Wales and Australia). In 2011 Council adopted the Blacktown Climate Change Action and Adaptation Plan (BCCAAP), which outlined Blacktown City Council's commitment to addressing climate change for the benefit of current and future generations. It provided a snapshot of the achievements to date and highlighted the opportunities to reduce carbon emissions further. The BCCAAP also identified areas of vulnerability to climate change and recommended actions to assist in adapting to the impacts of climate change in Blacktown City. BCCAP is completed and this study retrospectively considers its outcomes relating to 2011-1016. (The council has since replaced BCCAAP with by a policy and strategy '*Responding to climate change*', but these are not the subject of this paper.)

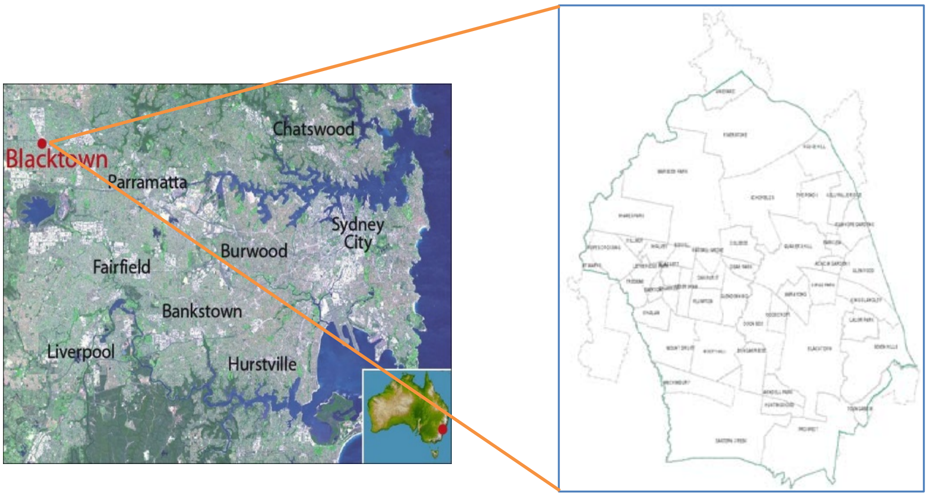

Figure 1: Blacktown City in New South Wales and Australia

In 2010, Blacktown City Council calculated its 2008-2009 operational ecological footprint as 1,802 hectares. Approximately 20% of Council's total ecological footprint for its operations is created by consuming electricity for council facilities and street lighting (Blacktown City Council 2015).

Figure 2 gives an overview of Council's Scope 1 and Scope 2 emissions in 2013-14. Scope 1 includes the direct emissions from fuel and gas burning, e.g. use of fuel in the council's fleet. Scope 2 covers emissions from electricity, in this case, the electricity used for council's facilities and street lighting. Blacktown City Council includes street lighting in its Scope 2 emissions, although many Australian councils count street lighting as Scope 3. This is because Scope 3 covers indirect, supply chain emissions, and while local councils in Australia are responsible for paying the electricity bills for street lights, the lights themselves are generally owned by electricity distribution networks.

The council's Scope 1 and 2 emissions for 2013-14 are represented in Figure 2: Blacktown City Council Greenhouse Gas Emissions by Source.

By the end of 2016, Blacktown City's population was 340,000. By 2036, it is forecast that Blacktown City will be home to close to 497,000 people, with 42.16% growth (id the population experts 2016). This equates to an average annual growth rate of approximately 2.1%. This growth in the community will create an increased demand for Council services and a corresponding increase in greenhouse gas emissions. Population growth presents both opportunities and challenges for Council and the community, with the potential for greenhouse gas emissions to increase in proportion to population growth.

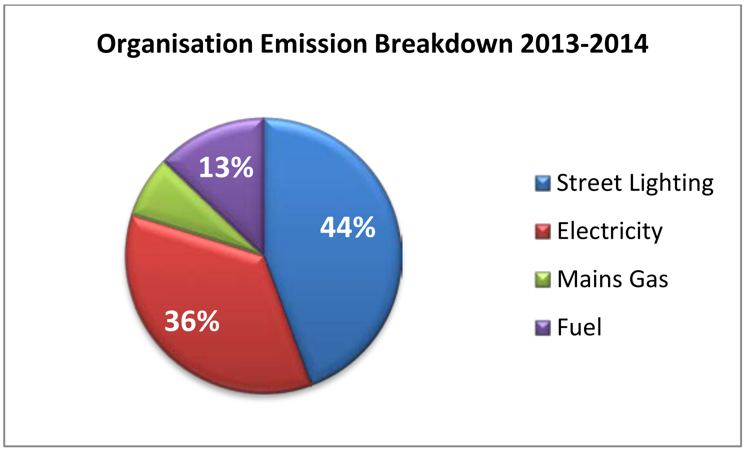

Figure 2: Blacktown City Council Greenhouse Gas Emissions by Source 2013-14

a. Energy audit process

The process for evaluation of the energy consumption before and after implementation of green initiative measures have been undertaken by the council, in an energy audit process. This is the process of reviewing energy use in each asset against similar buildings, identifying energy saving opportunities and cost-energy analysis.

The energy audit process used by the council can be described in the phased shown below (Laboratory 2011):

- Preliminary review of energy use: Facility benchmarked against similar buildings, Base energy load identified
- Site assessment: Site data collected, Immediate energy saving opportunities identified
- Energy and cost analysis: Saving energy estimated
- Completion of audit report: Action plan developed for next steps

b. GHG emission calculation

Australia's National Greenhouse Accounts (NGA) were used in this paper for estimating the GHG emissions before and after implementation of each measure. The National Greenhouse Accounts (NGA) Factors are prepared by the Department of the Environment and are designed for use by companies and individuals to estimate greenhouse gas emissions.

For calculating the GHG emissions from electricity use, before and after execution of each measure, the indirect emissions from electricity method has been used. The factors estimate emissions of CO2, CH4 and N2O expressed together as carbon dioxide equivalent (CO2-e). The greenhouse gas emissions in tonnes of CO2-e attributable to the quantity of electricity used was calculated with the Equation 1 (Australian Government 2015):

$$Y = Q \times \frac{EF}{1000}$$

where: Y is the emissions measured in CO2-e tonnes. Q is the quantity of electricity purchased (kilowatt hours). EF is emission factor, for New South Wales (kg CO2-e per kilowatt hour) (Ramesh, Prakash et al. 2010).

c. Boundary of the research and summary of the methodologies

The summary of the approach undertaken by this research in auditing the council's energy consumption and its GHG emissions calculation is shown in Figure 3: The summary of methodologies used in this study. As this figure shows, among all the phases of the Life Cycle Energy Analysis, which are Manufacturing, Operation and Demolishing, only the operation phase was used for this study. This is because this research focused on measures towards GHG emissions reductions on Council's existing assets, not new assets. So, practically the two other phases have been eliminated and all the analysis has been concentrated on the use phase.

The second phase of the study was the Energy Auditing Process. In this phase, all the opportunities for reducing energy use were distinguished according to an audit process. These measures or actions can be categorised as: improving HVAC systems, hot water supply, powering appliances, retrofitting lighting and installing solar power generation. These encompass most of the opportunities for mitigating energy consumption in any kind of building.

During phase three, the energy consumption of each asset was estimated before and after execution of each action.

In the final phase, the GHG emissions for each measure were calculated before and after implementation. Also in this step, the outlay cost, the payback period and cumulative GHG reduction were calculated.

3. RESULTS AND DISCUSSION

3.1. Council's emissions between 2012-2016

Table 1 shows the amount of Scope 1 and Scope 2 GHG emitted by the council during the years 2012-2016. Scope 3 emissions have not been estimated. Figure 4 also illustrates the trend of GHG emissions and the level of emissions reduction per year during the same period. As this figure shows, the council's emissions increased from 41030 tonne CO2-e in 2012 to 46179 tonne CO2-e in 2016. That means the average increase in the council's emission has been 11.15% during the period.

However, at the same time, the energy reduction measures were undertaken, so that emission reductions increased from 2814 tonne CO2-e in 2012 to 10547 tonnes CO2-e in 2016. That meant that the average 'growth' in emissions reduction was 374%, much higher than the emissions increase of 11.15%.

Deducting the total GHG emissions per year fromthe total GHG reductions e=resulting from the council's abatement measures, shows a net GHG emissions reduction during the study period., Despite the rising trend in the council's emissions, the abatement measures reduced emissions from 38216 tonnes CO2-e at 2012 to 35632 tonnes CO2-e at 2016. That means the average decrease of GHG emissions in the council's operations was 6.76% in total or 1.35% per year.

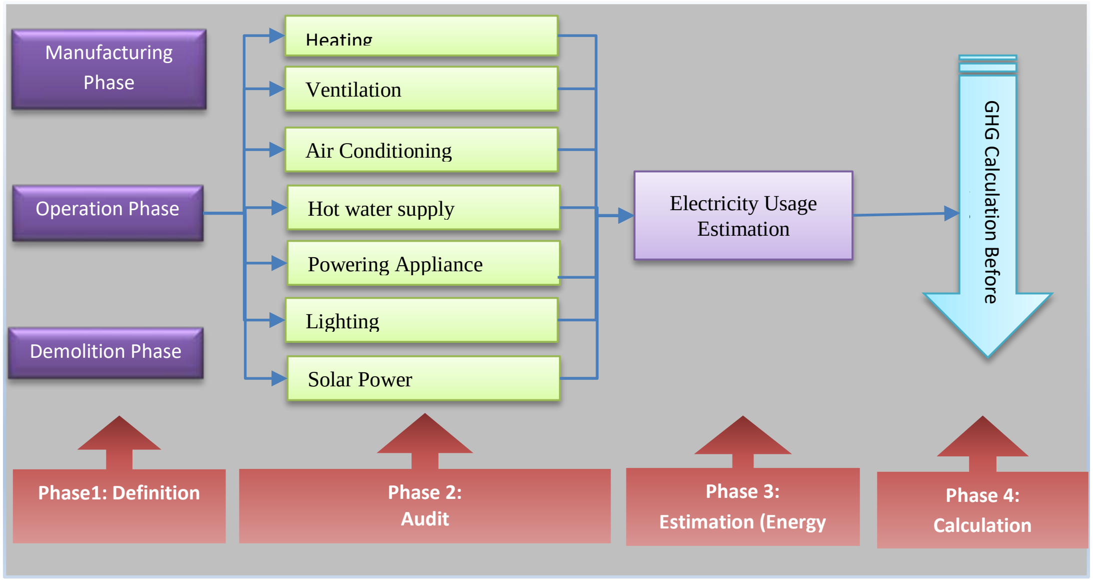

Figure 3: The summary of methodologies used in this study

Table 1: The estimation of Blacktown city council's GHG emission between 2012-2016

Year	Council gross emission (Tonne)	Council's emission reduction (Tonne)	Council emission after reduction by the measures
2012	*41030*	*2814*	*38216*
2013	*42261*	*4720*	*37541*
2014	*43529*	*6872*	*36657*
2015	*44835*	*7458*	*37377*
2016	*46179*	*10547*	*35632*

The abatement measures used by Council to reduce its GHG emissions between 2011 and 2016 are listed below:

- implement energy and water efficiency measures at Council's highest consuming sites
- Installation of 50kW solar power system at Council
- Installation of solar panels on other Council facilities
- Utilise renewable fuels (10% Ethanol in leaseback fleet, 20% Biodiesel in Heavy Vehicle Fleet)
- Divert Blacktown City's residential waste collection to the Alternative Waste Treatment Facility to be composted and the methane generated used to produce renewable energy to power the facility
- Purchase of GreenPower
- Regenesis carbon offset program – planting native carbon forests to offset carbon emissions
- Blacktown Solar City partnership program providing energy efficiency and solar power systems for local residents and businesses
- Development of a Sustainable Events Policy
- Development of a draft Environmentally Sustainable Buildings Guide
- Replace current air conditioning units with more energy efficient systems at 130 small sites owned by Council.
- 700kVA energy saving units at Council Civic Centre (voltage optimiser)
- 450kVA energy saving units at Emerton Leisure Centre (voltage optimiser)
- Install Building Management System at Council Civic Centre East and South Wings
- Development of a Sustainable Fleet Policy for Council
- Retrofit T8 lighting to LED at selected sites
- Retrofit dog kennel heaters to higher efficiency units at Council's Animal Holding Facility
- Replacement of air conditioning systems in the south and east wings of the Council civic centre.

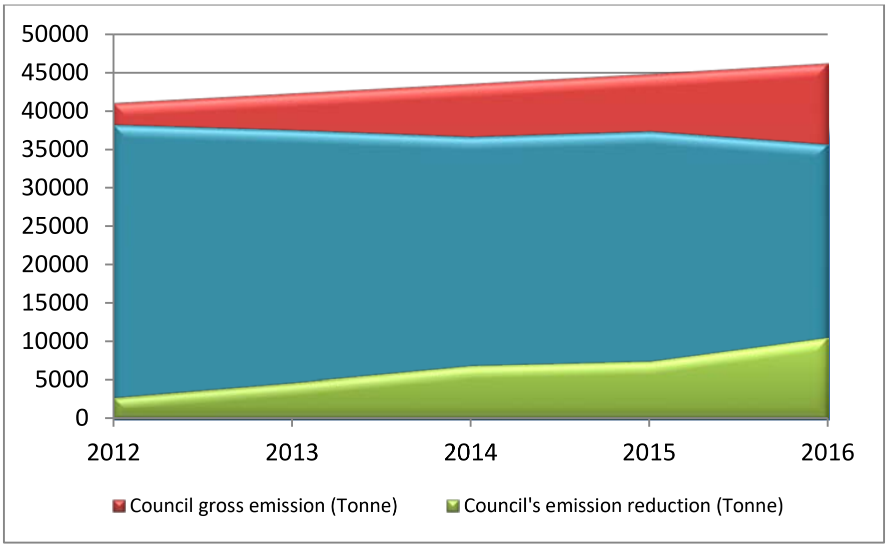

Figure 4: Blacktown City Council's emission and the amount of GHG reduction for 2011-2016

In NSW, where Blacktown City Council is located, electricity supply from the grid is carbon intensive because it is still largely derived from coal fired generation. This means that measures that reduce the demand for grid-fed electricity can be very effective in reducing greenhouse gas emissions and assist in saving money, sometimes offering attractive financial payback.

Figure 5 shows the comparison between payback times of the measures versus their cost per 0.01 tonne of GHG reduction. As this figure illustrates installation of 350 KvA energy saving units, with just 1 year payback time ranked top among the 22 measures. This action's cost per 0.01 tonne of GHG reduction was also the lowest. Affixing variable speed drivers to pool motors was the second most cost efficient of the actions.

On the other hand, replacement of the east wing air conditioning, with 37 years to payback time had the longest payback and its cost per tonne of GHG reduction was among the most expensive of the measures. Replacement of south wing air conditioning followed by upgrade of out-dated and inefficient kitchen equipment, had payback periods of 33 and 20 years respectively, and their cost per tonne of GHG reduction was among the highest. In some cases, the measures were taken because they were needed for practical purposes – such as to replace failing equipment - even when they helped only slightly to reduce energy demand and greenhouse gas emissions.

4. CONCLUSION

This paper compared specific greenhouse gas reduction initiatives undertaken by Blacktown City Council during the period 2011-2016. It compared each initiative's level of emissions control, cost and payback period. All data used was provided by the council.

Of the abatement actions undertaken by the council during the study period, installing energy saving units was the most cost-efficient. The next most cost-efficient actions were: retrofitting the dog kennel heaters to higher efficiency units, replacing the electric hot water systems with solar hot water systems and affixing variable speed drives to pool motors.

Future research directions could include investigating which types of measures would be most effective given specific budget thresholds. The aim would be to maximise emission reductions. If this problem can be solved, then other types of measures with different conditions and various options could be modelled to help councils to develop the most effective action plan for reducing their carbon footprints.

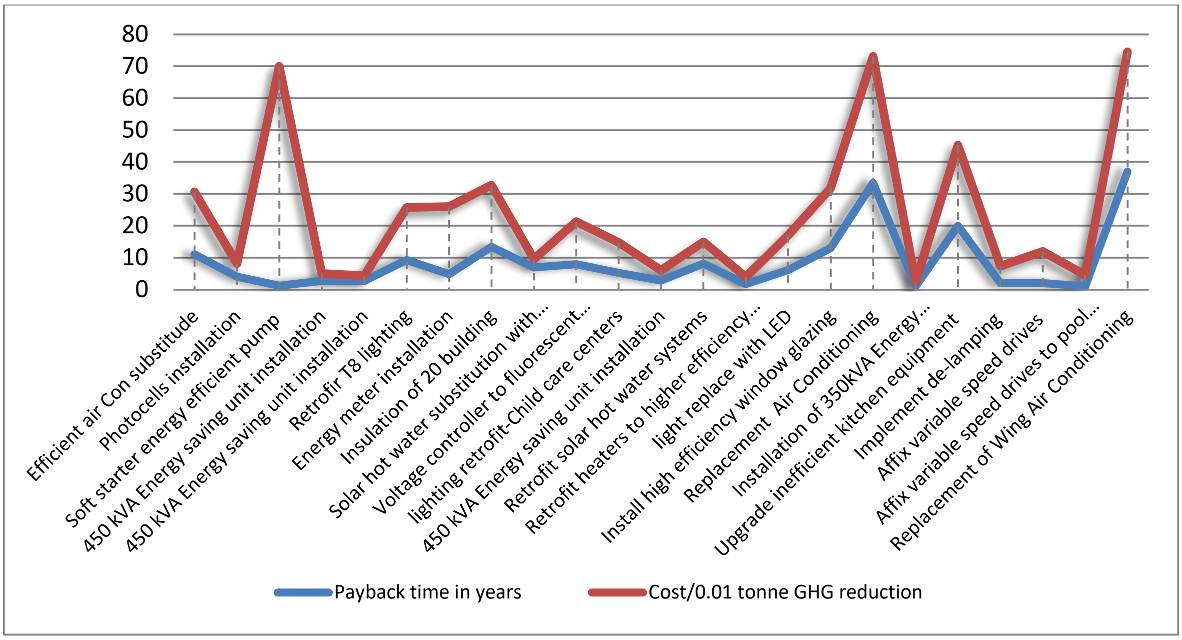

Figure 5: Comparison between payback times of the measures versus their cost per 0.01 tonne of GHG reduction

5. ACKNOWLEDGEMENT

The authors wish to acknowledge the financial support from the Australian Research Council (ARC) Discovery Project under grant number DP150101015. We also wish to thank the Planet Footprint team for their gracious support in providing the necessary data and information without which this work would not have been possible.

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Strategies for Reducing Psychosocial Risks of Construction Workers

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Abstract

Suicide rates of construction workers has been high due to high psychosocial risks involved. There is an urgent need to derive effective strategies for reducing psychosocial risks faced by the construction workers. This research aims to evaluate the strategies for reducing psychological risks in the construction industry. A mixed research approach was adopted. A survey was conducted with 150 construction workers from 3 commercial construction projects in Queensland. Interviews were conducted with six managerial staff. Demand hour system and working hour cap were perceived to be important by construction workers but disagreed by the management. Education and training for psychosocial health and safety was found to be important by both parties. This paper contributes to limited research on reducing psychosocial risks and improving psychological health and safety of construction workers.

Keywords: Psychosocial risks, strategies, construction industry.

1. INTRODUCTION

The construction industry employed the largest male workforce of all the industries in Australia in 2015-6 (Vandenbroek, 2016). The construction industry is physically demanding and has a strong macho culture. Many construction jobs are transient or project-based. Such a work environment cultivates a high level of psychosocial risk that adversely affects the mental health of the workforce.

Statistics show that construction workers' psychological health and safety is a global concern which requires serious attention. For example, the risk of suicide of the low-skilled construction workers in the UK was 3.7 times higher than the male national average (2011 – 2015) (Office of National Statistics, 2017), while the suicide rate for the U.S. construction industry was 53.3 per 100,000 population in 2012, more than 4 times the overall U.S. suicide rate 12.54 per 100,000 people in 2012 (McIntosh et al., 2016).

According to PricewaterhouseCoopers (2014), 25.1% of the Australian construction workforce experienced mental health conditions. This figure is one-quarter higher than the national average at 20%. In particular, substance use is more prominent in the construction industry than other sectors (PricewaterhouseCoopers, 2014). Psychological health and safety conditions such as stress, anxiety, and depression are often associated with poor health and safety and may lead to suicide (Boschman et al, 2013). With the suicide rates of construction workers 84% higher than non-construction workers (Milner, 2016), suicide and suicidal behaviour in the Australian construction industry is estimated to cost the economy AUD 1.57 billion dollars annually (Doran and Ling, 2015).

Despite these considerable workplace psychological health and safety issues, there is only limited research in the construction industry (Milner and Law, 2017). Unlike physical health and safety which has been heavily regulated, construction companies often overlook the importance of psychological health and safety of construction workers; and hence, only limited construction companies have strategies in place to mitigate risks to psychological health and safety. A better understanding of the risks affecting the psychological health and safety of construction workers is needed so that effective preventive measures can be formulated. This paper aims to evaluate the strategies for reducing psychosocial risks. The objectives are to evaluate the effectiveness of the strategies as perceived by the construction workers; and to identify the challenges of implementing these strategies from the perspective of the management. This paper contributes to filling the gap of limited research on reducing psychosocial risks.

2. PSYCHOSOCIAL RISK FACTORS

Workplace psychosocial risk factors are categorised by: job characteristics, such as economic and performance factors (Sobeih et al., 2009; Beswick et al., 2007); role in organisation, such as the under utilisation of skills or monotonous work (Goldenhar et al., 2003); social aspects, such as high staff turnover and poor communication due to the transient nature of construction (Lunt et al., 2008); job prospects, such as job insecurity and the fear of unemployment (Sobeih et al., 2009; Eatougha et al., 2012; Goldenhar et al., 2003); and organisational factors, such as role ambiguity, role clarity and role conflict (Gunning and Cooke, 1996).

3. STRATEGIES FOR REDUCING PSYCHOSOCIAL RISKS FACTORS

Strategies for reducing psychosocial risks specific to the construction industry is an area of literature which remains limited. Construction management staff have an institutional role in the prevention of psychosocial issues within the construction industry. However, at present only a limited number of solutions for such issues have been establish. This highlights the importance of increased attention to the psychosocial work environment, and how preventive solutions can be developed or tailored to the unique needs and challenges experienced in the sector.

3.1 Role in organization

Role in Organisation prevention is intended to mitigate three primary stressors: role ambiguity, role clarity, and role conflict. Proposed prevention methods include: (a) additional resources for training to up-skill staff on time management and improve communication so that stress does not become a distractor; and (b) an increased amount of time spent participating in one-on-one meetings with supervision staff to clarify any issues which arise surrounding one’s role within an organisation. Further one-on-one time and enhanced communication is associated with a greater understanding and satisfaction of ones role within an organization.

3.2 Job characteristics

Job characteristic prevention methods are introduced to alleviate the increase of stress associated with high job demand (Lunt et al., 2008). Proposed methods of prevention include: (a) systems which allow for increased hours during high demand periods in lieu of decreased working hours in periods of low demand; (b) the introduction of training programs which promote assertiveness for workers so they feel confident to raise an issue with management when they feel that their works demands are too substantial; and (c) systems which cap the number of hours worked during a week (the cap being predetermined during designated meetings).

3.3 Social factors

Social factor prevention methods are introduced to promote and increase awareness and to create a culture where workers are given the opportunity to raise psychosocial issues resulting from poor workplace practice (Beswick et al., 2007). Proposed methods of prevention include: (a) the introduction of transport services and communication technology to assist in solving problems from distance rather than being required on site; and (b) training which focuses upon communication skills that target on-going communication within teams or workers who are only in contact for a short period of time.

3.4 Organisational factors

Organisational factor prevention is introduced to establish communication mechanisms for becoming aware of psychosocial issues and encouraging workers to implement solutions that create cultural change. Methods for prevention include: (a) education programs introduced to encourage workers to be responsible for their own health and wellbeing; and (b) schemes that encourage greater communication within organisations, between both colleagues and management staff.

3.5 Job Prospects

Job prospect prevention is implemented to provide intrinsic motivation and a sense of security amongst the workforce. Proposed methods of prevention include: (a) educating the workforce, including subcontractors, manufactures, and suppliers on psychosocial issues, consequences and controls; and (b) further investment into professional development and training to better equip staff with future ambitions in light of potential promotions.

4. RESEARCH METHODS

A mixed methods research approach was adopted. A total of 150 representatives of the Queensland construction blue-collar workforce were surveyed, with 119 providing responses that were eligible for data analysis, representing a 79% response rate. The remaining 21% of participants responded incorrectly to the attention filter questions and therefore, the responses provided were deemed to be ineligible for data analysis. They were required to evaluate the effectiveness of the strategies for reducing psychosocial risks in the construction industry, with 1 representing strongly disagree and 5 representing strongly agree. The participants were sourced from three mid-tier Queensland commercial construction sites. The participants were representatives of various age groups (predominantly ages 20-29, 38.33%), genders (predominantly male, 86.67%), levels of employment (predominantly tradesman, 54.17%), levels of education (predominantly vocational – Trade/Certificate, 46.22%), types of employment (predominantly full time, 76.67%) and marital status (predominantly single, 36.17%). After the survey, six interviews were conducted with the managerial staff to ask their opinions on strategies of reducing psychosocial risks and the challenges for implementing them. Their profiles are shown in Table 1.

Table 1. Interviewees' Profile

Interviewee	Employment Role	Experience
1	Project Management	>25 Years
2	Executive Board of Directors - Health and Safety	>15 Years
3	Executive Board of Directors - Human Resources	>15 Years
4	Project Management	10 Years
5	Senior Contracts Administrator	15 Years
6	Project Management	10 Years

5. RESULTS AND DISCUSSIONS

Descriptive analyses were used to evaluate the survey participants' perception towards the effectiveness of the strategies for reducing psychosocial risks in construction. As shown in Table 2, the results indicated a strong support for the introduction of systems which allow for increased hours during high demand work periods in lieu of decreased working hours in periods of low work demand (M = 4.20) and systems that cap the number of hours that one works during a week (M = 3.85) – the cap being predetermined during designated meetings.

However, there was substantially lower support for the strategies which are associated with social psychosocial risks, namely: providing transport services and social/communication technology to assist in solving problems from a distance rather than being required at the site of issue (*M* = 2.47), and training that focuses on communication skills that target on-going site communication within teams or workers who are only in contact for a short period of time (*M* = 2.72).

Table 2. Effectiveness of Strategies for Reducing Psychosocial Risk Factors

Strategies	**Mean**
Demand-Hour Systems	4.21
Working Hours Cap	3.84
Psychosocial risks education schemes	3.78
Professional development	3.78
Up Skill Workers	3.49
Assertiveness Training	2.92
Self-management training	2.89
Management One-on-One’s	2.76
Communication training	2.71
Management Communication	2.54
Transport Services	2.47

In contrast, the results from the interviews with the management demonstrated a high frequency in the mention of the ineffectiveness of both an hours cap system and a demand-orientated working hours system. Four out of six interviewees expressed that these strategies will increase the potential for financial hardship of construction workers due to limiting one’s working hours and may potentially further intensify existing stressors. Interviewee 6, questioned the understanding of typical working week within construction, arguing that “a typical week in construction is excessive… What is a ‘typical’ week?” Interviewee 4, further highlighted the barriers of working hours cap that “low hourly rates in construction call for longer working weeks to get by. Restricting such hours will cause further stress by limiting one’s available income”.

Almost all interviewees, however, showed strong support for both communication training (five out of six interviewees) and self-awareness education schemes (four out of six interviewees). Furthermore, interviewees expressed that it would be insufficient to introduce a single method of prevention, with four out of six interviewees stipulating that a multiple introduction scheme that saw the introduction of multiple mitigation techniques is the only way of ensuring such success.

Interviewee 1 commented that “any one technique on its own would be insufficient to tackle PSR’s. A comprehensive people management system is required to deal with each of the factors identified.” Therefore, further research should be conducted to identify the optimal combination of multiple-facet implementation of strategies.

Current intervention methods seem to have minimal long-term effect on alleviating the impact of psychosocial risk factors on construction workers. Existing literature has found that psychosocial risk factors require long-term prevention to alter the current culture of the construction industry and thus leading to better mental health (Andersen et al., 2010; Broadbent and Papadopolous, 2014; Gullestrup et al., 2011).

The following strategies for reducing psychosocial risks were both agreed by the construction workers and the managerial staff: (a) social aspect (i.e., the introduction of training which focuses upon communication skills that target on-going site communication within teams or workers who are only in contact for a short period of time); (b) organisational aspect (i.e., education programs introduced to encourage workers to be responsible for their own health and wellbeing, and not assume it is management's responsibility); (c) job prospect aspect prevention (i.e., educating the workforce, including subcontractors, manufactures, and suppliers on psychosocial issues, consequences, and controls); and (d) personal aspect (i.e., communication training and PSR awareness education schemes).

The implementation of these methods will assist in removing the 'closed off macho-masculine' culture that is a barrier to improving mental health. The ingrained cultural beliefs and practices in the construction industry, such as being masculine, consuming high levels of alcohol, and strong emphasis on 'toughing it out' rather than communicating problems, need to be changed. Everyone works in the construction industry deserves a psychologically healthy and safe working environment.

6. CONCLUSIONS AND FUTURE RESEARCH

To conclude, this study firstly evaluated the strategies for reducing psychosocial risks in the construction industry from the perspective of construction workers, then it explored from the management's perspective the challenges of implementing these strategies and the opinion on how to reduce psychosocial risks in construction sites. Despite demand hour system and working hours cap were perceived to be the most effective strategies from the construction workers' perceptive, they were strongly disagreed by the management. However, education and training to raise the awareness of psychological risks was perceived as important by both parties. Since this study is limited by the data from three construction sites in Queensland, it is suggested that a wider study should be conducted in future to determine the most effective strategies for reducing psychosocial risks in the construction industry.

7. ACKNOWLEDGMENTS

This paper was derived from the second authors' research project as part of the Bachelor of Urban Development (Honours) (Construction Management) at Queensland University of Technology.

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Different Grades and Different Green Premiums: A Cross sectional Analysis of a Green Certification Scheme

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Abstract

Green certification is often hailed as an effective means of resolving information asymmetry by providing prospective buyers with credible proof of a level of quantitative sustainability performance of a property. These certification schemes are also considered as providing the credible identification labels needed to generate a market premium. This study analyzed whether different market premiums (financial implications) exist across different ratings of the HK-BEAM certification scheme. The paper used hedonic price model (HPM) to evaluate the influence of green certification rating levels on residential property prices in Hong Kong. The results indicate, on average, that HK-BEAM certification increases price values by between 5.3% and 6.7%. Most importantly, the results indicate that significant price premium differences exist across the different ratings available for HK-BEAM certified buildings. The findings provide a strong proof of the existence of a premium across ratings.

Keywords: Green certification, BEAM Plus scheme, rating system, residential property, green buildings, Hong Kong

1 Introduction

Globally, buildings (both residential and commercial) contribute significantly towards energy consumption, reaching 20% to 40% in developed countries alone, and exceeding contributions from other major sectors such as industrial and transportation (Pérez-Lombard et al. 2008). Because of this, environmental authorities across the globe have introduced green certification schemes as technical instruments to assess and evaluate environmental impact of buildings on one hand, and encourage development of green buildings on the other hand (Bernardi et al. 2017). Notable examples of green certification systems adopted around the world include; Building Research Establishment Environmental Assessment Method (BREEAM) in the United Kingdom, Leadership in Energy and Environmental Design (LEED) in the United States, the Haute Qualité Environnementale or HQE (High Quality Environmental standard) in France and Comprehensive Assessment System for Built Environment Efficiency (CASBEE) in Japan (Bernardi et al. 2017; BREEAM 2015; U.S. Green Building Council 2015). Since green buildings can bring large amount of benefits to building occupants and developers, it is possible that this would become a catalyst to influence property prices. It has been revealed in the literature that green buildings can enhance residential property prices (Chegut et al. 2014; Florance 2008; Fuerst and McAllister 2009; Kats 2003; Wadu and Sze Man 2013; Wing Chau et al. 2004). Previous studies mainly compared the difference in property prices between certified and non-certified buildings, rather than buildings with different green certification ratings.

Building contributions towards greenhouse gas emissions in Hong Kong is alarming, accounting for approximately 70% of the total emission but the Hong Kong government has initiated various policy measures to attain sustainable development and low-carbon living (see Wong et al. 2016). Studies within the context of Hong Kong have examined energy use assessment of HK-BEAM (Hong Kong – Building Environmental Assessment Method), BREEAM and LEED (Lee and Burnett 2008). Wadu and Sze Man (2013) investigated the impact of green features on residential buildings prices. Gou and Lau (2014) analyzed different green building certification systems at international (LEED, BREEAM, CASBEE), national (China Green Building Rating System) and local Hong Kong (BEAM-Plus) level. Hui et al. (2017) recent study only evaluated the effects of BEAM-Plus certification on property prices in Hong Kong. However, no study was conducted to compare the impact of different green certification schemes i.e. HK-BEAM Plus's Platinum, Gold, Silver and Bronze on residential property prices in Hong Kong. This study therefore examines the price premium brought by different levels of HK-BEAM-Plus scheme on residential property prices. The main hypothesis of the present study is to examine whether there is a positive relationship between property prices and the level of green certification of residential buildings in Hong Kong.

2 Literature Review

2.1 Green Buildings and Green Certifications

The U.S. Environmental Protection Agency (2014) defined green building as "the practice of increasing the efficiency with which buildings and their site use and harvest energy, water, and materials; and protecting and restoring human health and the environment, throughout the building life-cycle". Ries et al. (2006) study suggested that green construction can provide significant economic benefits through improved employee productivity, health and safety, saving from energy, maintenance and operational costs. In the context of Hong Kong, green building is a practice of reducing environmental impact of buildings on the environment which is achieved by planning throughout building lifecycle, optimizing resource efficiency and reducing waste and pollution (Hong Kong Green Building Council 2015). Green certification is a rating tool to indicate the level of environmental friendliness of real estate properties (Abdullah et al. 2017). Green certification systems further provide guidelines to measure, improve, certify, benchmark and label the lifecycle sustainability and performance of a project (Cheng and Venkataraman 2012).

2.2 BEAM Plus Green Certification in Hong Kong

Buildings are graded on four different levels of ratings with respect to HK-BEAM Plus (Platinum, Gold, Silver and Bronze). For instance, if a project will not achieve the threshold scores for bronze grade, it will be rated as "unclassified" (BEAM Society Limited 2012). Similarly, if the performance of a building meets the pre-defined criterion of BEAM Plus, credits will be awarded to the building accordingly (Ho et al. 2013). As at May 2018, the total number of registered BEAM Plus projects is 1061, while assessed BEAM Plus projects amount to 566 (Hong Kong Green Building Council 2018). It is noted that among all assessed buildings, 247 (43.6%) are residential buildings, accounting for the highest percentage among different building types (Hong Kong Green Building Council 2018).

2.3 Relationship Between Green Certification and Residential Property Prices

Property prices can be influenced by green certification ratings. It was found in the literature that investors will likely be attracted to green certified buildings if they will see more benefits over conventional properties (Kuiken 2009). The investments in green certified real estate developments have measurable benefits such as low resources utilization at the construction process, low operating cost with energy efficiency, low greenhouse gas emissions, improved indoor environmental quality, increased employee productivity and positive impacts on the image of the tenants. Tenants therefore should be willing to pay more on rent for green certified building as compared to conventional building (Eichholtz et al. 2010). In the context of Hong Kong, green certified buildings with HK-BEAM and HK-GBC assessment schemes have upgraded the quality of the buildings and therefore the property prices were increased between 3.46% and 6.61% while sales price premium increased by 8.3% (Wadu and Sze Man 2013).

3 Research Methodology

3.1 Hedonic Price Model (HPM)

Different researchers have used HPMs to examine the effects of various housing attributes on property prices. Such attributes include; property management (Hui et al. 2011), land use policies (Song and Knaap 2004), urban redevelopment (Ki and Wadu 2010), transportation (Atkinson-Palombo 2010; Bartholomew and Ewing 2011; Duncan 2011), urbanism (Tu and Eppli 2001), sports amenities (Tu 2005), architectural design (Plaut and Uzulena 2005), historic monuments (Ahlfeldt and Maennig 2008) and green features (Wadu and Sze Man 2013). HMP has the capacity to analyze implicit relationships between the commodity and its characteristics (Freeman 1981). It is pointed out by Hui et al. (2011) that the model is location-specific, hence it is not used to generalize the effects of a certain characteristic across different regions. The present study focuses on the effect of the green certification level on the property prices in Hong Kong, which targeted at a specific location. Therefore, the HPM would be a suitable tool for investigating the relationships.

In order to investigate the relationship between green certification ratings and residential property prices, the following semi-log form of HPM was used in this paper. The housing price was used in natural logs and regressed against a set of logs. The model contains 10 variables under three broad categories i.e. locational, structural and environmental attributes.

$$Ln(\text{P})_i = \beta_0 + \beta_1 Ln(AGE)_i + \beta_2 Ln(SA)_i + \beta_3 Ln(LVL)_i + \beta_4 (SV/MV)_i + \beta_5 (BV)_i + \beta_6 Ln(MTR)_i + \beta_7 (EAST)_i + \beta_8 (SOUTH)_i + \beta_9 (WEST)_i + \beta_{10} (BEAM)_i + \varepsilon_i$$

where, $Ln(P)$ represents the residential property price in natural logarithm; $\beta_1 \ldots \beta_9$ represents the coefficients to be estimated; β_0 denotes the constant term; and ε_i connotes the stochastic term. LnP measures Transaction price, LnAGE represents Structural building age, LnSA is for Saleable area, LnLVL indictes Floor level, LnMTR is Locational accessibility to MTR, LnSV is Sea view, LnMV is Mountain view, BV is Building view, LnEAST, SOUTH, WEST is Orientation, LnBEAMP, BEAMG, BEAMS, BEAMB are Environmental BEAM Plus certification i.e. Platinum (P), Gold (G), Silver (S), Bronze (B).

3.2 Selection of Data

The property prices are obtained from the Economic Property Research Centre Limited, with the agreement of sale and purchase records. The transaction period is from 2009 to 2015, from the year in which BEAM Plus Version 1.1 was launched. It is noted that the transaction prices obtained are nominal prices, which were converted to their corresponding real prices with the same base year. The prices were deflated to the base year of 1990 according to their class, with the use of the private domestic price indices published by the Ratings and Valuation Department. In this study, the neighborhood attributes such as nearby facilities and amenities are not considered, due to the fact that the selected buildings are all located in the same area and that they have similar accessibility to various amenities.

The selected buildings are all situated in the Kowloon Peninsula around the Mong Kok East Station (**Figure 1**). In the model, six private residential buildings with various BEAM Plus certifications, from silver to platinum, are selected in the analysis. Seven non-certified comparable are also selected for comparison purpose. By selecting residential buildings from the same market segment, the effect of neighborhood facilities such as shopping centers, transportation and public amenities, are deemed negligible. At the same time, all the selected residential buildings are relatively high-end ones targeting at higher income groups, making the comparison more accurate because the class and quality of the buildings may affect property prices.

[Insert Figure 1 here]

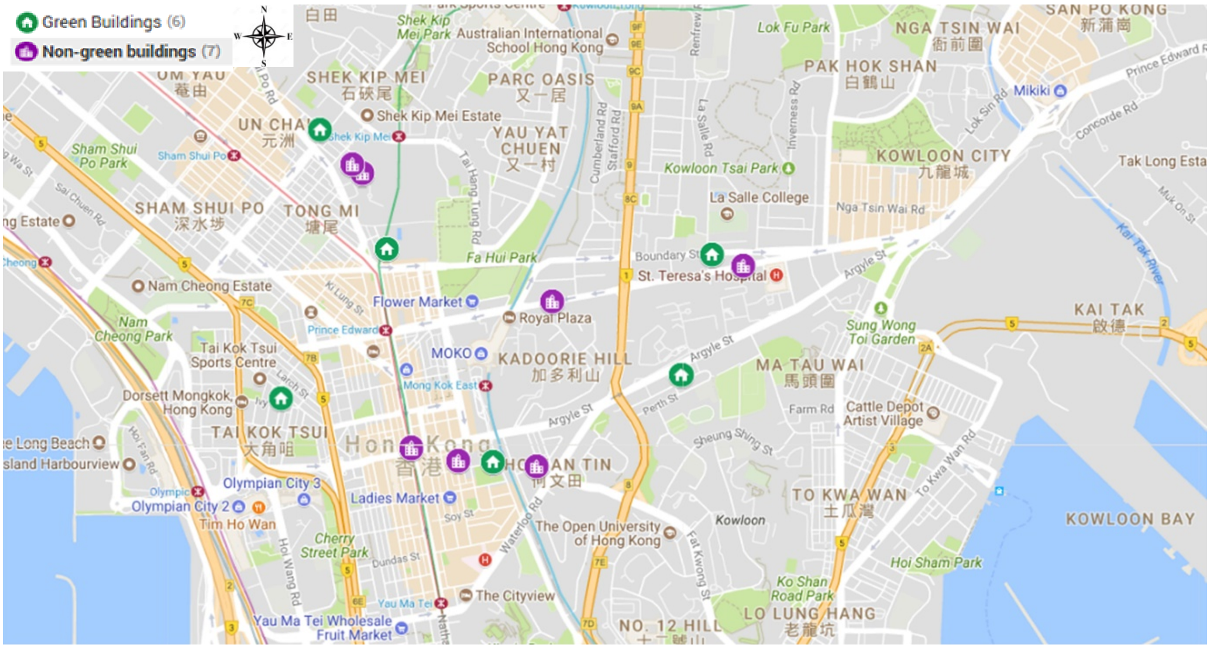

Figure 1. The study area and geographic distribution of the sample properties in Kowloon

4 Results and Analysis

4.1 Results of HPM

All the variables for BEAM Plus certified and non-certified buildings are statistically significant (see **Table 1 and 2**). Among the variables, the proximity to MTR stations and the southern orientation are found to be statistically insignificant. The adjusted R^2 value of the model is 0.933, implying that 93.3% of the variations in residential property prices can be explained by the selected independent variables. The F-value of the model is 1839.089, which is higher than the critical value, showing the explanatory power of the model. In consistence with the expectation, the variable of BEAM Plus certification is highly significant, with a positive coefficient and t-value of 7.783. The coefficient is 0.064, reflecting that residential properties with BEAM Plus certification have property value of 6.61% higher than non-certified buildings which means that buyers are willing to pay a 6.61% premium for the BEAM Plus certification for these properties.

[Insert Table 1 and 2 here]

Table 1. Descriptive statistics of BEAM Plus Model

	BEAM Plus vs Non-certified Buildings		BEAM Plus Platinum vs Non-certified Buildings		BEAM Plus Gold vs Non-certified Buildings		BEAM Plus Silver vs Non-certified Buildings	
Variable	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
LnP	2.08	0.687	2.14	0.714	1.94	0.724	2.09	0.750
LnAGE	0.42	0.408	0.59	0.366	0.48	0.451	0.48	0.447
LnSA	6.15	0.532	6.19	0.561	6.07	0.541	6.16	0.558
LnLVL	2.73	0.549	2.77	0.526	2.72	0.588	2.76	0.573
LnMTR	2.16	0.386	2.12	0.306	2.19	0.259	2.10	0.436
EAST	0.47	0.499	0.54	0.499	0.46	0.498	0.56	0.497
SOUTH	0.16	0.363	0.12	0.330	0.23	0.421	0.17	0.372
WEST	0.25	0.434	0.24	0.425	0.14	0.347	0.16	0.371
MV	0.10	0.300	0.13	0.331	0.12	0.328	0.16	0.366
BV	0.89	0.300	0.87	0.331	0.88	0.328	0.84	0.366
BEAM	0.44	0.497	0.25	0.431	0.27	0.444	0.17	0.378

Table 2. Coefficient BEAM Plus Model

	BEAM Plus vs Non-certified Buildings		BEAM Plus Platinum vs Non-certified Buildings		BEAM Plus Gold vs Non-certified Buildings		BEAM Plus Silver vs Non-certified Buildings	
Variable	Coefficient	Significance	Coefficient	Significance	Coefficient	Significance	Coefficient	Significance
Constant	-5.319	0.000	-4.874	0.000	-5.799	0.000	-5.228	0.000
LnAGE	-0.025	0.002	-0.031	0.001	-0.033	0.010	-0.042	0.000
LnSA	0.937	0.000	0.889	0.000	0.974	0.000	0.887	0.000
LnLVL	0.021	0.011	0.025	0.012	0.000	0.999	0.010	0.311
LnMTR	0.015	0.090	0.020	0.172	-0.009	0.525	0.029	0.009
EAST	0.078	0.000	-0.149	0.000	-0.064	0.000	-0.125	0.000
SOUTH	0.005	0.639	-0.036	0.008	-0.014	0.286	-0.023	0.115
WEST	-0.026	0.035	-0.076	0.000	0.006	0.652	-0.058	0.000
BV	-0.026	0.002	-0.011	0.308	-0.055	0.000	-0.022	0.038
BEAM	0.064	0.000	0.067	0.000	0.059	0.000	0.053	0.000
Adjusted R^2	0.933	-	0.931	-	0.952	-	0.950	-
F-value	1839.089	-	1277.909	-	1244.130	-	1389.486	-

4.2 Relationship between BEAM Plus Ratings and Property Prices

It was observed that when compared to non-certified buildings, buildings with BEAM Plus certification generally show positive relationship with property prices. The study found that buyers are willing to pay premium for different BEAM Plus ratings, as compared to properties without certification. For example, premium brought by different levels of ratings is positive, overall BEAM Plus (6.61%), Platinum (6.93%), Gold (6.08%), Silver (5.44%). However, there is no premium noted for Bronze rating. It was hypothesized that the higher the BEAM Plus rating, the higher premium it can bring to the residential property. The results show consistency with the hypothesis, in which the premium of buildings with BEAM Plus platinum certification is higher than those with gold certification, followed by properties with silver certification.

5 Discussion and Conclusions

The results of HPM model show that green features are considered in the decision to purchase property. BEAM Plus certification is a well-established green labelling system in Hong Kong, which reflects the level of greenness of properties. Buildings with BEAM Plus certification are likely to have more green elements and be more resource efficient. This has become an environmental attribute attracting people to buy properties with BEAM Plus certification. When choosing a property, potential buyers give structural and locational attributes higher priorities, since it is directly related to their convenience and enjoyment. For example, flats at a higher level would have a better view, while flats closer to public transport facilities can save occupants' travelling time. On the other hand, the public may not have comprehensive knowledge on the benefits of green buildings. They may understand that green buildings usually have more green features like green walls, but not other benefits like energy and cost savings, across different ratings of green certification. Thus, the level of green certification is not likely to be a primary concern to them, hence, the environmental attribute of BEAM Plus rating is given lower priority, when compared to structural and locational attributes.

Selected buildings for this study are relatively high end ones, targeting the middle class and the higher income group, therefore, it is assumed that the occupants would be more aware of quality of life and they may have more knowledge of the benefits of green buildings. As a result, the BEAM Plus certification gives them an incentive to pay more for a better quality of life, and certified buildings in turn have values higher than non-certified ones. In this study, the influence of green certification, in particular, the HK-BEAM Plus rating on property prices, is investigated. It was revealed that most of the variables are statistically significant. Results show that overall green certification (HK-BEAM Plus) generally has a positive impact on property prices, reflected as 6.61% in HPM. The positive effect of different certification levels on property prices are represented as follows; Platinum (6.93%), Gold (6.08%) and Silver (5.44%). This indicates that the government and the private sector still need to encourage public engagement so that people can have higher awareness on the positive impacts of green buildings and green certification. This may bring brand premium to green certified buildings and increase property prices of green certified buildings. The findings can inform property developers about the potentials inherent in green buildings.

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A critical literature review on bidding collusion in the construction industry

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Abstract

Bidding is the main form of competition in the construction market. Efficient operation of bidding is crucial to the achievement of reasonable allocation of resource and guarantee of efficiency in construction. However, collusion, one of the most common bidding behaviors in excessive competition, violates the standard market system with fairness, justice, and openness, undermines market competition order, endangers the healthy development of the industry, and undoubtedly needs effective and urgent governance. This paper presents a critical review of collusion in construction projects, outlines the definition of collusion in different research areas, the drivers of collusion in the bidding process as well as formation premises. This paper also describes the methods and measures of detection for collusion and the governance of the collusion. The results suggest that evaluating the performances of collusion prevention strategies, establishing the qualitative and quantitative model for the detection of collusion and forming a system from the perspective of cognitive behavior will be the directions for future research on collusion in the bidding process.

Keywords: construction industry, collusion, literature review

1. INTRODUCTION

Collusion covers all stages of human development and is very common (Shan et al. 2015a；Liu et al. 2017). A large number of scholars have been attracted to research collusion. Many scholars such as Chamberlin (1929), Bain (1956), Telser(1960), Stigle(1964), Orr and MacAvory(1965) had made positive contributions to the development of the collusion theory. Earlier research on collusion was mainly implemented in the field of public management, which was initially used to explain the phenomenon of price collusion between enterprises. The research mainly focuses on the relationship between the existence and the non-robustness of collusion and the level of industry concentration, the degree of product differentiation, and the cost symmetry of enterprises. In recent years, Laffont and Tirole (1986) explored collusion into industrial organizations by incomplete contract theory, then the general analysis framework of collusive organizational behavior is established. Thus the general research paradigm of organizational collusion theory come into being, that is to explore the causes of collusion, the key factors affecting the emergence of collusion and collusive preventive measures.

Regarding the research field, collusion theory expands monopoly organizations to the new field, including auction theory and the collusion problem in decision making (Zarkada and Skitmore 2000). Regarding the emergence and development of collusion, the collusion theory has gone through the development process from inter-organizational collusion to intra-organizational collusion, from static to dynamic, from two-layer organization to three-layer organization and even multi-layer organization.

The research on collusion in the bidding process has great significance to the real world. First, the bidding and tendering system are improving day by day, but the problem of collusion is becoming more and more intense, there is still a long way to put an end to collusion. Moreover, the criticality of the construction industry to the nationals requires the healthy development of the construction industry. Finally, collusion does do great harm to the development of society, economics and construction industries. So it is urgent to carry out systematic and comprehensive research on collusion phenomenon, theory, and preventive measures.

Based on this, to grasp the main dynamics of collusion in construction engineering, and look for the theory and method that can effectively reduce the loss brought by engineering collusion, this paper sorts out existing literature of collusion in construction engineering by following the classical pattern of collusion.

2. A SUMMARY OF BIDDING RESEARCH

In the construction industry, the competition between enterprises is mainly reflected in the bidding activities. And collusion is one of the most common bidding behaviors in excessive competition. Research on bidding mainly focuses on two aspects: bidding decision and bidding behavior. The former involves whether to bid, bidding model, information acquisition and processing, groups gaming, bidding strategy. The latter mainly includes collusion, and competition.

Figure 2. The trends and hot points of research on bidding in recent 10 years

Analyzing literature on bidding in the past 10 years by CiteSpace software, the result of trends and hot points is shown as figure 1 above. As is shown on the left side of figure 1, research on bidding is mainly distributed from 2007 to 2013, focusing on auction, model, competition, strategy, behavior, management and information. Most topics of the research last for a long time. And the number of research results varies little from year to year. While there are exception. Collusion, for example, is largely concentrated before 2013, and little research has been done since 2014.

The right side of figure 1 shows hot points of research on bidding in recent 10 years. The density of network is large, the connection between nodes is close, and there are few isolated nodes, which indicates that the research on bidding is mostly concentrated in similar field. According to the central value, hot points can be ranked as: decision, contract, uncertainty, competition, bidding, price, risk, behavior, bidding strategy, information, etc.

3. DEFINITION OF COLLUSION

In economics, collusion theory can be traced back to the cartel era, which is mainly used to explain the tacit collusion between enterprises when it comes to price competition. In medical management, collusion refers to patients with insurance and hospitals cheating insurance benefits (Tu 2014). In the field of engineering construction, collusion is very common and related to interests and has three forms including fraud, bribery, and kickbacks (Brown and Loosemore 2015). Studies have shown that in a particular environment, many project participants, including owners, designers, supervisors and governmental administrative authorities will carry out collusion jointly for improper benefits, which will bring losses to the project benefits (Yang and Wang 2006). Therefore, the phenomenon of engineering collusion can be viewed as a kind of bid-rigging act of engineering stakeholders that corrupting the interests of a project or public interest by fair means or foul (Le and Shan 2013). Guo (2008) specialized and visualized the phenomenon of engineering collusion, and described collusion as a phenomenon that in bidding process and construction process, the owner loses the fairness of bidding for rental, collaborates with bidders helping them earn construction qualification; Supervisor loses the independence of project supervision, caters to the construction organization issuing the false supervision report. As shown in figure 1, collusion in engineering construction can be divided into five types according to different participants (Huo and Zhang 2016).

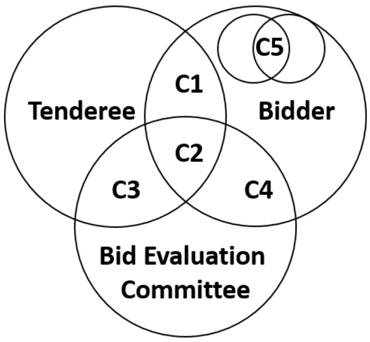

Figure 2. Five types of collusion in engineering construction

These collusive parties make a non-completely rational decision under uncertain condition through legitimate or improper means, which erodes the benefits of the project (Le and Shan 2013; Wu et al. 2013). If the market price of the project is higher than the project implementation price, the collusive parties will get other sources of income besides the contract price (An and Zhao 1999).

4. CAUSES OF COLLUSION

The causes of collusion are complicated, including the feasibility of its objective as well as the consistency of its purpose and the high degree of concealment (Brown and Loosemore 2015). Scholars believe that information asymmetry of engineering projects, limitation of contract terms, the complexity of project management and lack of professional ethics will lead to collusion (Bowen et al. 2012; Shan et al. 2015b; Guo 2008). Domestic scholars mostly use principal-agent theory to analyze the causes of engineering collusion. In the field of China's construction engineering, Guo (2008) believed that information asymmetry, inconsistency between the principal and the agent's objectives often lead to the adverse selection of the agents and moral hazard. At the same time, as it is impossible for the clients and the agents to cover all the points of the project contract, it may have an underlying problem for collusion to some extent. By using contract theory, principal-agent theory and auction theory, Zhang and Zhao(2008) analyzed the internal mechanism of the formation of collusion including information asymmetry, incentive imbalance, disorderly competition, right rent-seeking, etc. and the external environment of the formation of collusion including lack of integrity, defection of supervision system, imperfect property rights system, etc. Also, fierce market competition and narrow profit channels are also the causes of engineering collusion phenomenon (Shao and Wang 2011).

Foreign scholars mostly analyze the causes of engineering collusion from the aspects of professional ethics by semi-structured interview, statistical investigation, and case analysis. Bowen et al. (2011) found that a lack of professional ethics of employees of government construction administrative departments is the root and essence of collusion in the South African construction industry through questionnaires. The low professional quality of the employees in the construction administrative department is the most important factor to induce the phenomenon of engineering collusion (Graafland 2004) Furthermore; some scholars argue that imperfect national regulatory system and laws and the lack of positive industry atmosphere will contribute to collusion (Le 2014).

5. FORMING CONDITIONS AND DETECTION OF COLLUSION

Collusion belongs to the category of behavioral science, so lots of scholars carried out their research using game theory when analyzing the forming conditions of engineering collusion, including Yang and Wang(2006), Chen and Liu(2006), Ren and Zhu (2007), Yang (2010). Cheng et al. (2012) analyzed the decision behaviors and collusive conditions between owners, contractors and construction supervision with a combination of qualitative and quantitative methods, and found that the loss of independence of the supervision unit is the main prerequisite in final accounts audit for completion.

Scientific diagnosis for the identification of collusion is the precondition for the formulation of countermeasures. Because of the moving barriers, collusive organizations often exist in relatively stable enterprise groups and are no longer an accidental combination that is free to entry and exit (Huang and Yang 2008; Mehra and Floyd 1998). Shan et al. (2015b) obtained 24 diagnostic indicators through semi-structured interviews and established a collusion prediction and evaluation model based on fuzzy theory. Yin and Zhou (2009) proposed the identification standard of horizontal collusion in the bidding process based on previous literature and policy study. Besides, historical project data can also be applied to judge whether there is a possibility of collusion (Chotibhongs and Arditi 2012a). And on this basis, analyzing the differences in bid content, cost terms and cost structure between the collusive bidders and other bidders is also useful to determine the possibility of collusion (Chotibhongs and Arditi 2012b).

6. GOVERNMENT OF COLLUSION

Given the complex causes of collusion, governance measures should be timely, targeted and effective.

Tirole (1992) pointed out that clients can prevent collusion by stimulating regulators, reducing collusion benefits and increasing transaction costs. Fauregrimaud et al. (2000) deemed that the transaction cost of collusion is share-dependent, and the collusion governance should consider factors such as the economic environment and agents' risk appetite. Abdul-rahman et al. (2011) believed that the owner's attitude has great influence on the implementation of collusion, and different governance methods should be adopted for different levels of collusion. Shan et al. (2014) verified the effectiveness of leadership, system, training, and punishment in collusive governance respectively by using factor analysis and structural equation model of the partial least square method. Liu et al. (2017) believed that the possibility of collusion could be reduced through measures such as increasing the intensity of economic punishment and honorary punishment, reducing collusion benefits and regulatory costs, enhancing deterrence and improving regulatory efficiency, to curb collusion in bidding process effectively.

The studies of controlling measures of engineering collusion are usually based on principal-agent theory analysis or game theory model. In addition to this, Tabish and Jha(2012) verified the positive correlation between strategy and project performance by using structural equation model (SEM), pointing that leadership, strict rules, professional attainment training, and strong penalties are the four major engineering collusion containment strategies.

7. CONCLUSION

A large number of considerable in-depth studies have been carried out in engineering collusion focusing inducement, formatting condition, manifestation, detection, and prevention of collusion. Domestic scholars prefer theoretical analysis to solve the collusion problem, while foreign scholars prefer empirical research to analyze different dimensions of collusion. Even so, serious collusion problems remain in the construction industry.

In term of the process of collusion, most relevant literature only describe several collusion cases, which makes it difficult to recognize and determine collusion in reality. So, it is necessary to establish the qualitative and quantitative model for the detection of collusion. In term of the result of collusion, evaluating the existing collusion containment actions to find out the reasons for the poor governance will be one of the key directions for the next step of research.

Also, the research on engineering collusion can be carried out not only from the perspective of project implementation and management but also from the perspective of cognitive behavior. And in-depth studies should be carried out on the concerted action of the collusive bidders, corresponding prevention and control strategies regarding cognition of the bidders as a breakthrough point. It is useful to form a system that helps the tendered diagnose, and counter the collusion behavior of the bidders, select the good winning bidder and ensure the good project quality.

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Factor Analysis of the causes of conflict in Public-Private Partnership infrastructure projects in Ghana

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Abstract

Over the last couple of years, many governments in developing countries are increasingly adopting the public-private partnership (PPP) concept and Ghana is of no exception. The PPP concept has been used for some public infrastructure including water, ports and power plants. However, one of the critical risk factors that have been mentioned by many past studies is conflict between project parties. Conflict between stakeholders in PPPs have resulted in delay and distress of many PPP projects in Ghana. Therefore, this study aims to examine the major causes of conflict in PPP arrangement in Ghana. A list of causes of conflicts was derived through a comprehensive review of relevant literature. Questionnaire survey was conducted with PPP experts in Ghana. Further, the factor analysis technique was used to analyze the survey responses. Results show that the causes of conflicts in PPP arrangement in Ghana can be grouped into five unrelated categories, namely, Poor community relationship and engagement, Poor contractual agreement and political interference, Lack of knowledge on PPP project governance, Low level of interaction among key project parties and Poor leadership. It is believed that the outputs of this study will help investors and government agencies in assessing and reviewing the potential conflicting factors in their projects.

Keywords: Public-Private Partnership, Conflicts, Ghana, Factor analysis

1. INTRODUCTION

The public-private partnership concept has become popular in recent times particularly in developing countries (Osei-Kyei and Chan, 2016; Chan et al. 2010). Many governments in developing countries now see the PPP concept as a means to reduce the pressure on their public purse. Moreover, PPP is perceived by many governments in developing countries as an effective procurement tool to provide rapid local economic development (Osei-Kyei and Chan, 2016). PPP has no standard definition, and this is a result of the different motivate behind its adoption and implementation (Cheung et al. 2012). Nonetheless, all PPP project or contract has similar characteristics such as the sharing of risks, long term relationship and the financing of the public facility by the private sector (Osei-Kyei and Chan, 2015; Li et al. 2005).

Like any other government in developing countries, the Government of Ghana (GoG) has also shown strong commitment towards the implementation of PPP (Osei-Kyei and Chan, 2016). Essentially, Osei-Kyei et al. (2014) mentioned found out that some of the critical motivations for PPPs in Ghana include lack of public funds, private sector innovation, technology transfer and innovation, reduces public sector administrative cost', 'allows for shared risk', 'private sector possess better mobility' and 'private sector has ability to raise funds for project'. PPP is certainly not completely new in Ghana, in fact it has used since the early 1990's, however, its application has predominantly been in the management of public services. For physical public infrastructure, the PPP concept has received no attention (Osei-Kyei and Chan, 2016). The GoG made PPP a national policy in 2004 but it failed to be operationalized. The policy was reintroduced in 2011 with a national policy. Although some projects have been completed, many are still at the preparatory stages (Osei-Kyei and Chan, 2016). Essentially, some projects have completely failed. Undoubtedly, considering the immature PPP environment, PPP projects face a lot of risks in Ghana. Many risk factors have been associated with PPP projects in Ghana but one of the critical risk factors is conflict between project parties (Osei-Kyei and Chan, 2017). In every human institution, organization or environment conflict is bound to happen, the same applies to the construction industry. All construction projects are prone to conflict, however, projects procured through the PPP concept is more susceptible to conflict (Osei-Kyei et al. 2018). This is primarily because of the large stakeholder with diverse interests and beliefs. Therefore, the occurrence of conflict is very high and can lead to several negative effects on the progress of the project. In this regard, considering that conflict between parties is critical in Ghana's PPP, there is the need for more research to be conducted to explore the fundamental causes of conflict in PPPs in Ghana.

This paper aims to explore the major causes of conflict in PPPs in Ghana using the factor analysis technique. The factor analysis technique will enable researchers and practitioners to understand the major categories of the causes of conflicts in Ghana's PPP market. It is hope that the outputs of this research will inform all stakeholders of the major possible sources conflict in PPPs as this will enable them to develop a comprehensive conflict risk assessment for their PPP projects.

2. LITERATURE REVIEW

Indeed, many studies have been conducted on the causes of conflict in construction. However, majority of these studies focused on the traditional bid-build projects. Most of the past studies that focused on the traditional bid build projects found out that some of the significant cause of conflicts include poor financial projections on the client's side, poor public relationship, lack of funds, inadequate site investigation, slow client responses, lack of effective environmental impact assessment, low recognition and lack of authority (Kumaraswamy, 1997; Mahato and Ogunlana, 2011; Mitkus and Mitkus, 2014; Ejohwomu et al. 2016). Although, very few empirical studies on conflicts exist, Osei-Kyei et al. (2018) derived a set of root causes of conflicts which are associated with PPP projects (see Table 1).

Table 1. Set of causes of conflicts in PPP (Adapted from Osei-Kyei et al. 2018)

Root causes of Conflicts in PPP arrangements	Sources
Unfair risk allocation	Ibrahim et al. (2013); Chan et al. (2011)
Absence of proper communication channel	Chan et al. (2011);
Double meanings in output specifications	UNDP (2017)
Lack of understanding on the roles and responsibilities of parties	UNDP (2017); Tang et al. (2012)
Unexpected tariff changes	Babatunde et al. (2015)
Excessive contract variations	Cheung and Chan (2011)
Political interference	UNDP (2017); Osei-Kyei and Chan (2017)
Ambiguous goals and objectives	Ng et al. (2012)
Incomplete transfer of risks	Ibrahim et al. (2013); Kumaraswamy (1997)
Personality clashes	UNDP (2017); Kumaraswamy (1997)
Unrealistic time targets	Kumaraswamy (1997)
Delay in decision makings by parties	Acharya et al. (2006)
Delay in rectifying defects during service delivery	Osei-Kyei and Chan (2017)
Reluctance to seek clarification	Carmicheal (2002)

Inadequate compensation to displaced persons	Osei-Kyei and Chan (2017)
Unreliable service delivery	Osei-Kyei and Chan (2017)

They mentioned that some causes of conflicts related to PPP include, unfair risk allocation, unexpected tariff changes, personality clashes, political interference and ambiguous goals and objectives.

3. METHODOLOGY

A questionnaire was first developed using the set of causes of conflicts in Table 1. The questionnaire requested practitioners to rate from 1 – least important to 5 – extremely important the set of causes of conflict in PPP. The questionnaire survey targeted only experienced and knowledgeable PPP experts in Ghana. 150 questionnaires were sent out to potential respondents, after sending several reminders, 52 valid responses were received. Out the 52 responses, 11 are academics, 24 are from the public sector organizations and 17 are from private sector institutions. Around 48% of the total number of respondents have more than 10 years of PPP experience as either academic and/or industry practitioner (Osei-Kyei et al. 2018). This shows that the responses are valid and reliable for further statistical analysis.

In order to explore the underlying set of factors or categories for the 16 causes of conflicts in Table 1, factor technique was conducted. This tool is used to explore the underlying relationship of a set of factors. Essentially, factor analysis makes it possible for researchers to put into small number of categories, a large set of factors (Brown, 2015). However, usually to ascertain the adequacy of the data and suitability of a data set for factor analysis, some preliminary tests are often conducted. These tests include Kaiser-Meyer-Olkin (KMO) and Bartlett's test of Sphericity. The KMO value for the 16 set of causes of conflicts is 0.574 and this is above the recommended threshold of 0.50 (Norusis, 2008). Further, the value of the Bartlett's test of Sphericity for the data set is 216.59 which is large, and its associated significance test value is 0.00. This indicate that the population correlation matrix is not an identity matrix (Norusis, 2008). To derive the factor components for set of 16 factors, principal component analysis with varimax rotation was conducted. This extraction produced five -factor solution, with eigenvalues greater than 1.0. The five-factor solution explains 61.40% in the total variance. Table 2. Shows the five-factor solutions and their respective factor loadings.

Table 2. Initial matrix and rotated matrix of the causes of conflicts in PPPs in Ghana

Component	Initial Eigenvalues	Extraction Sums of Squared Loadings	Rotation Sums of Squared Loadings		
Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.804	23.773	23.773	3.804	23.773
2	1.852	11.575	35.348	1.852	11.575
3	1.551	9.695	45.043	1.551	9.695
4	1.422	8.889	53.933	1.422	8.889
5	1.196	7.474	61.406	1.196	7.474
6	0.98	6.128	67.534		
7	0.904	5.649	73.183		
8	0.816	5.1	78.283		
9	0.675	4.218	82.501		
10	0.585	3.658	86.159		
11	0.557	3.484	89.644		
12	0.516	3.228	92.871		
13	0.419	2.616	95.488		
14	0.298	1.863	97.35		

15	0.268	1.672	99.023		
16	0.156	0.977	100		
Extraction Method: Principal Component Analysis.					

4. RESULTS AND DISCUSSION

As shown in Table 4, five major categories of factors can be used to explain the underlying relationship of the set of 16 causes of conflicts in PPPs in Ghana. The five categories include: Factor 1 – Poor community relationship and engagement, Factor 2 - Poor contractual agreement and political interference, Factor 3- Lack of knowledge on PPP project governance, Factor 4- Low level of interaction among key project parties and Factor 5- Poor leadership.

Table 4. Factor components of the causes of conflicts in PPPs in Ghana

Factor components	**1**	**2**	**3**	**4**	**5**
Poor community relationship and engagement					
Inadequate compensation to displaced persons	0.776				
Personality clashes	0.756				
Incomplete transfer of risks	0.749				
Unexpected tariff changes	0.589				
Poor contractual agreement and political interference					
Unrealistic time targets		0.811			
Delay in rectifying defects during service delivery		0.65			
Ambiguous goals and mutual benefit objectives		0.562			
Unreliable service delivery		0.528			
Delay in decision makings by parties		0.511			
Lack of knowledge on PPP project governance					
Lack of understanding on the roles and responsibilities of parties			0.792		
Unfair risk allocation			0.691		
Low level of interaction among key project parties					
Double meanings in output specifications				0.745	
Absence of proper communication channel				0.60	
Reluctance to seek clarification				0.523	
Poor leadership					
Leadership inconsistency					0.682
Excessive contract variations					0.675

Factor 1- poor community relationship and engagement consists of four sub-factors, these include inadequate compensation to displaced persons, personality clashes, incomplete transfer of risks and unexpected tariff changes. Essentially, these causes have some relation with poor community relationship and engagement. Usually, poor community relationship and engagement leads to decision makings by project parties which are not in line with the interest of the public. Therefore, this result in several agitations and demonstrations which affect the progress of the PPP project. Factor 2 – poor contractual agreement and political interference also consists of four subcategories of factors including unrealistic time targets, delay in rectifying defects during service delivery, ambiguous goals and mutual benefit objectives, unreliable service delivery and delay in decision makings by parties. Essentially, when contract agreement and terms are not properly agreed between the public and private sectors, at the latter part of the project conflict may arise. Similarly, when there is too much interference by political leaders of a particularly political party in the tendering and negotiation stages, at the latter part of the project delivery, another opposition party that assumes office can terminate the current PPP contract or request for review which can lead to lengthy dispute. Factor 3- lack of knowledge on PPP project governance consists of two subfactors namely; lack of understanding on the roles and responsibilities of parties and unfair risk allocation. Because PPP is has not developed very well in Ghana, many practitioners lack the required knowledge on the governance of PPP project arrangement. As a result of this many local practitioners end up misallocating risks and agreeing on terms which they can not fulfil. This therefore results in conflict between the investor and the public authority at the latter stage of the PPP project arrangement on risk mitigation. Factor 4 - low level of interaction among key project parties consists of three subfactors, these include double meanings in output specifications, absence of proper communication channel and reluctance to seek clarification. Frequent interaction between parties helps to heal any wounds and frictions among them. On the other hand, if there is no cordial relationship between the public client and the project company, there will be double meanings in the interpretation of documents particularly the output specifications and other designs. The last factor, i.e. poor leadership consists of two sub conflicting factors. These include; leadership inconsistency and excessive contract variations. Poor leadership is mostly associated with the public clients. This where the key personnel responsible for making decisions on behalf of the general public is inconsistent with his/her decisions. Specifically, when the key personnel always change his/her decisions on the contract terms it can result in conflict between the public client and the investor.

5. CONCLUSIONS

Conflict is inevitable in the Ghanaian PPP market due to the diverse stakeholder interests and sensitivity of PPP project arrangements. Therefore, there is the need to explore more on the fundamental causes of conflict in PPP project arrangement. This paper adopted a questionnaire survey and the factor analysis technique to examine the underlying relationship existing between a set of 16 causes of conflicts in PPPs. The results show that the set of 16 causes of conflict can be grouped into five major categories, namely Factor 1 – Poor community relationship and engagement, Factor 2 - Poor contractual agreement and political interference, Factor 3- Lack of knowledge on PPP project governance, Factor 4- Low level of interaction among key project parties and Factor 5- Poor leadership.

The outputs of this paper inform local PPP practitioners in Ghana of the possible sources of conflicts in PPP project arrangement. Further, the results will be useful to practitioners when they are developing conflict risk assessment plan for their PPP projects. The findings of this paper also open discussions on the issues that could lead to conflict in PPPs. It is suggested that future research will consider adopting case study to enhance the current conflicting factors. Also, future research should develop a conflict risk assessment tool for PPP projects drawing on the findings of this paper.

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Developing Optimal Scaffolding Erection through VSM in Turnaround Maintenance

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Abstract

The liquefied natural gas (LNG) industry uses Turnaround Maintenance (TAM) to improve the reliability of equipment and ensure production capacity. Facility structures in LNG plants require tremendous amounts of scaffolding to facilitate relevant industrial operation and maintenance. As such, the productivity of scaffolding operations in TAM has attracted much attention in recent years. This study aims to use VSM, which is a common lean tool, to improve TAM scaffolder's productivity. A case study approach is adopted to evaluate lean implementation in scaffolding erection. It is found that VSM can be usefully applied to increase value adding time as waste activities in scaffolding erection are eliminated. It is expected that this research will contribute to the better understanding of lean implementation in scaffolding erection so that productivity improvement can be achieved.

Keywords: Turnaround Maintenance, Value Stream Mapping, Lean, Scaffolding

1. INTRODUCTION

Natural gas as cleaner-burning fuel is becoming increasingly important in many countries and regions to accelerate underpinning economic growth for decades into the future. Australian Bureau of Statistics' data released that LNG exports that will reach nearly 63million tonnes valued at $ 30.4 billion in 2018 are an ongoing source of strength for Australia's economy. In addition, Australia has almost $80 billion worth of LNG projects under construction (APPEA 2017). In order to maximise production capacity and ensure reliable and safe operation of all equipment, the LNG industry needs periodic maintenance on site, during which the LNG plants need to be shut down for inspections and repairs. According to Ben-Daya et al. (2009), TAM projects have short duration and high intensity. A 4-5 weeks of TAM may cost the entire year's maintenance budget. TAM is also a costly affair in terms of lost production and labour costs. According to a survey by (ManpowerGroup, 2011), the workers in Australian LNG industry are the highest paid in the world, earning about $US 140,000 per year compared to global average of $US 76,000. In reality, the duration of turnaround projects in LNG industry always exceeds the scheduled time due to delays of maintenance activities (Liu et al., 2008; Wenchi et al., 2015). For example, in order to achieve TAM completion with the stipulated period, 35% of common facilities maintenance was completed prior turnaround in a TAM project conducted by Abu Dhabi Gas Liquefaction Company Limited (Al Jaberi and Al Shamsi, 2016) .

The LNG industry has spent much effort on improving maintenance processes and gained extensive experience over the last twenty years, but it is found that there are still many problems predominately caused by delays. Complex structures of LNG plants require ever-changing of scaffolding construction for maintenance purposes. Although the maintenance workers could access the required facilities, the entire procedure can be negatively impacted through the need for scaffolding erection or dismantling (Moon et al., 2016). Shutdown management aims to enhance TAM processes, by reducing the average delay time and increasing the work efficiency of workers during the shutdown period (Van den

Heuvel, 2008). However, the industries need to meet construction needs for the required structures, such as industrial facilities and pipelines. These structures require tremendous amounts of scaffolding to facilitate industrial operation and maintenance. Scaffolding, as temporary structures, has a significant impact on construction operation and maintenance. The unique requirements of these temporary structures can often lead to delays caused by poor scaffolding planning and scheduling, including unnecessary rework and long travelling between activities, which will directly affect the productivity of the plant (Moon et al., 2016). In addition, although using scaffolding provides personnel and materials for construction activities, it can impede construction activities due to time-space conflicts and hazards (Kim et al., 2014). The scaffolding-related labour costs are considered an important aspect of reducing the total cost of the project (Moon et al., 2016).

Lean maintenance has been successfully used in the turnaround management to increase profitability and improve productivity (Anderson & Kovach, 2014; Mostafa et al., 2015). For example, Anderson and Kovach (2014) demonstrated that lean method could help the project team reveal the underlying links of activities in each phase of maintenance project in order to identify value adding activities and waste. Lean techniques and tools, such as Value Stream Mapping (VSM), brings in a new way of being to help identify customer values and eliminate non-value added activities (Zhang & Chen, 2016). By using VSM, Heravi and Firoozi (2017) investigated the production processes in prefabricated construction and found that VSM application is effective in time reduction and cost saving. In addition, as Riddell (2017) mentioned that through a lean construction project, focus on how, when and where scaffolding will be utilized is more closely examined. It appears that lean provides useful value in turnaround maintenance and scaffolding erection.

2. LITERATURE REVIEW

Lean concept has been successful used by construction companies to reduce the project costs and waste on construction site (Anderson & Kovach, 2014; Marhani et al., 2013). VSM is a lean techniques that has been adopted in lean construction, which helps identify all losses of current value stream and eliminate these waste to reach the future state. Lacerda et al. (2016) described that VSM implementation in the manufacturing field are crucial for reduction of waste and process improvement. Tyagi et al. (2015) used VSM based method to eliminate the wastes, inefficiencies and non-valued-added activities for productivity improvement. VSM has also used to improve the sustainable performance in construction projects (Rosenbaum et al., 2013), it can help resource optimization and cost reduction. However, there is a lack of studies to focus on investigation of human element factor in analysing the performance of future state process (Tyagi et al., 2015).

VSM is a lean tools for mapping construction process with respect to the non-value added steps, lead time, distance travelled. VSM optimizes not only part of the process, but improving the whole (Rother and Shook, 2003). Mapping helps customer visualize the sources of waste in value stream and describe in detail how the facilities should operate for working flow optimization. In order to identify non-value activities, the current state map (CSM) of the operation process is analysed. Based on identification of potential wastes, a future state map (FSM) is prepared for process improvement. According to Rother and Shook (2003), lean measurements such as Lead Time (LT), Processing Time (PT), Value Added Time (VAT) are easy to understand and implement when applying the VSM tool (see Table 1).

Table 1. VSM Key Indicators

VSM Key Concepts	Definitions	References
Lead Time (LT)	LT is the time that takes one piece to move all the way through a process from start to finish.	(Rother and Shook, 2003, Seth* and Gupta, 2005)

Processing Time (PT)	PT is the time that one product spends in a process step.	(Rother and Shook, 2003, Seth* and Gupta, 2005)
Value Added Time (VAT)	VAT is the time that actually transform the product in a way that the customer is willing to pay for.	(Rother and Shook, 2003)
Waiting Time (WT)	A delay in processing caused by waiting.	(Rother and Shook, 2003, Heravi and Rashid, 2017)

The traditional approach of TAM process improvement focuses on the equipment and value added processes. The TAM process improvement can help improve project uptime. However, it should be noted that the improvement is usually achieved in specific processes. The overall impact on the entire value stream is usually overlooked. Wiyaratn and Watanapa (2010) developed the systematic layout planning to increase productivity in the plant. Instead of focusing on specific production or maintenance processes, the entire value stream of the process is mapped in lean (Thomas and Joseph 2006). In addition, the lean method motivates employees as employee involvement is considered as one of the most important values in the lean concept. De Treville and Antonakis (2006) pointed out that lean production job design may improve employees' intrinsic motivation.

3. RESEARCH METHOD: CASE STUDY

In order to be better understanding of the effect of lean and ergonomics on productivity improvement in scaffolding erection. A case study approach is adopted to integrate ergonomics and lean construction in an LNG site. According to Yin (2002), the method of case study can deal with when a contemporary event is examined within its real-life context, and when the investigator has little or no capability of controlling the event.

3.1 Case Description

The case study in this paper presents a project in Dongara WA Australia. It was conducted by Cockburn Cement Ltd. Due to exposure, the pre-heater tower steelwork was deteriorating. Despite undergoing regular maintenance works, the plant steelwork has corroded due to being exposed to the environment and the refinery process and requires major refurbishment. This report required repairs on levels 5&6 of the pre-heater tower to return the structure to its as constructed structural integrity. In this case, scaffold erected on site shall be in good structural condition to achieve the project requirements. Also, this specialized work is necessary to complete a job on time and within budget.

3.2 Data Collection

In order to evaluate lean implementation in scaffolding operation, install scaffolding for temporary overhead protection walkways & exclusion zones in Dongara project was used to illustrate by observation on site. According to project schedule, it took three days to erect it. In this case study, value streaming mapping (VSM) as lean tool are used for assessing scaffolder productivity.

For the purpose of the lean implantation in scaffolding erection, value-added and non-value-added activities were categorised. In order to improve the proposed classification system, site interviews with scaffolding supervisor, and scaffolders helped in dealing with the identified activities which could be improved or removed from the lean perspective. The evaluation will be conducted on two indicators, including production efficiency (in term of processing time, waiting time, transportation time, and value adding time) and ergonomic assessment of scaffolds. All the data collection for CSM is based on the approach by Rother and Shook (2003). Data collection for scaffolding construction started at the scaffolding foundation erection, and ground-floor scaffolding, up to first-floor scaffolding erection, gathering snapshot data such as value-added time (VAT), processing time (PT), and number of scaffolders.

3.3 Data Analysis

3.3.1 VSM: current state map (CSM)

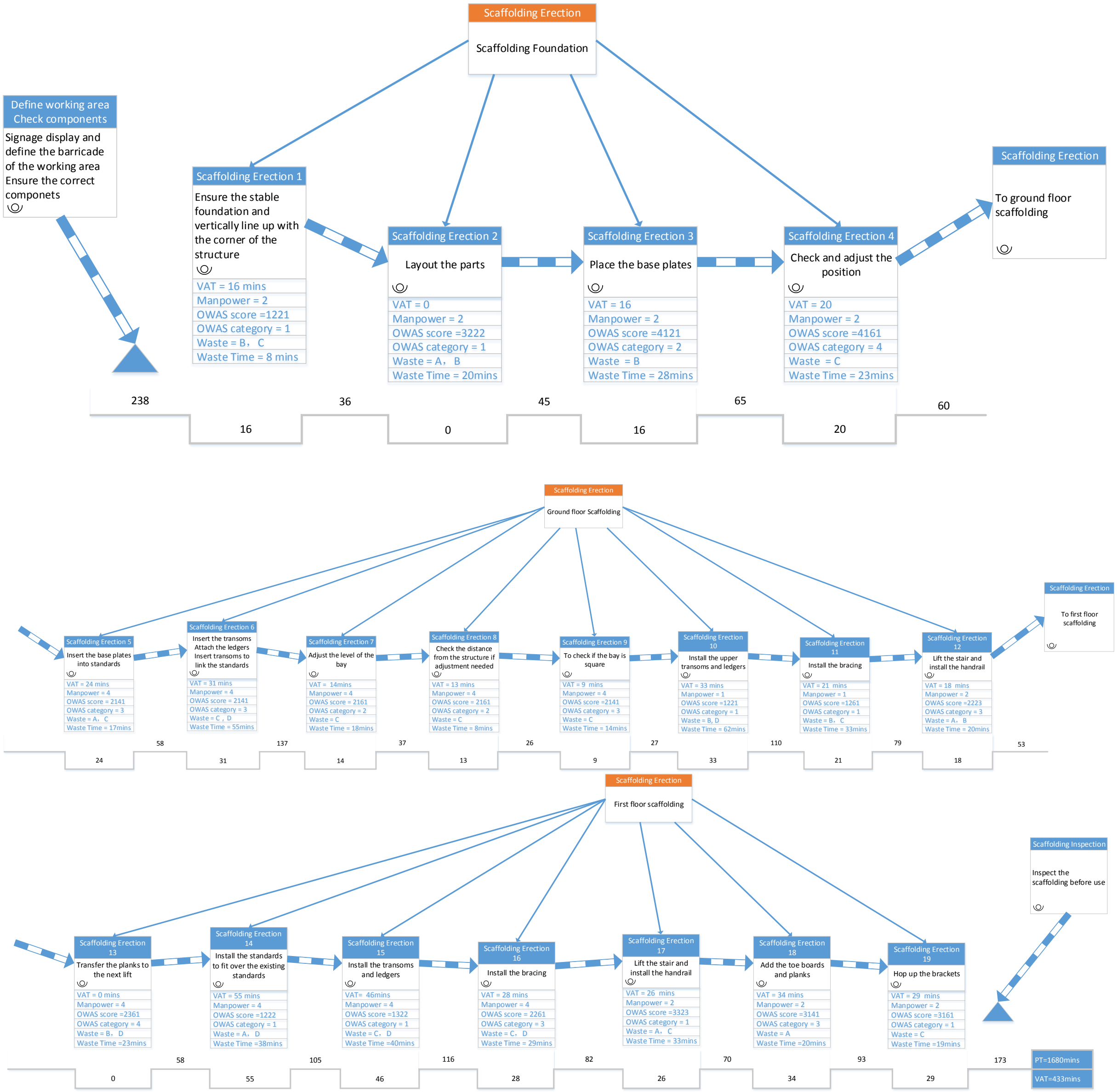

Fig.1 Current State Map

It should point out that the data analysis is only applied to the scaffolding erection and not to all the flow of scaffolding construction. After observing the scaffolding erection on each floor, table 2 provides a summary of the waste during the process of scaffolding erection. The details of waste in scaffolding erection are noted in table 3. The highest proportion of waste in scaffolding foundation and first-floor scaffolding erection is communication for working activities and something not related to work between supervisor and scaffolders. It accounts about 43mins and 87mins, respectively. For first-floor scaffolding erection, the highest proportion of waste during the process is about 82mins because of waiting for material delivery and incomplete previous activities. Fig 1 shows the CSM, the small boxes in the map represent the process of scaffolding erection, and all the scaffolding operations performed by scaffolder of the process are discriminated. The code used to identify the scaffolding operations in the value stream mapping included two characters: the first is operational activities, and the second one is workers' postures. The analysis of CSM reveals that waste time accounts for 30% of total processing time. It is surprising that significant portion of waste time is actually spent on communication ,which is about 38% ,and waiting is about 31%.The timeline at the bottom of CSM has two components, the first is scaffolding construction processing time (in minutes), which is calculated by adding the processing time for each process in the value steam. The second is value-added time in each scaffolding activities, which is about 25% in total processing time.

Table 2. Waste in scaffolding erection

Waste category	**Waste reasons**	**Minutes**
A Unnecessary Rework	Poor scaffolding operation planning	68
B Long Travelling	Scaffolding parts location; scaffolding parts transfer	72
C Communication	Poor scaffolding operation planning	209
D Waiting	Scaffolding parts transfer	159

Table 3. Details of waste in scaffolding erection

	Waste category	**Waste reasons**	**Waste time (minutes)**
Scaffolding foundation	A	Position of scaffolding parts cannot be accurately determined during the process.	20
	B	Some parts need to be transferred from scaffolding store area to foundation.	16
	C	Communicated work activities between supervisor and scaffolder	43
	D	N/A	0
Ground floor scaffolding	A	The adjustment of stair position and few standards.	17
	B	Some parts need to be transferred from scaffolding store area to erection area.	46
	C	Communicated work activities between supervisor and scaffolder, communication about something not related to work.	87
	D	Waiting for Scaffolding parts delivery when install the ledgers, transoms and bracing. Previous step was incomplete.	77
First floor scaffolding	A	Few installation was not complete at one time due to higher location.	31
	B	Few parts need to be transferred from scaffolding store area to erection area.	10
	C	Communicated work activities between supervisor and scaffolder, communication about something not related to work.	79
	D	Waiting for Scaffolding parts delivery when install the ledgers, transoms and bracing.	82

		Previous step was incomplete.	

The CSM provides a snapshot of the process of scaffolding erection and performance. It helps in identifying the wastes and direct improvement efforts. Figure 3 presents the FSM. The creation of FSM was the same as that followed during the process of creating the CSM. The ideal FSM of scaffolding erection in this case by showing the potential improvements may be achieved after the elimination of all waste. The percentage of value added time increased from 25% to 37%.

4. CONCLUSION

Scaffolding construction becomes an important concern to LNG industries, considering the relatively low productivity and high labor costs. Poor scaffolding design often leads to idling, rework, unnecessarily long travelling time between activities, which greatly reduces productivity. This paper shows that VSM can be usefully applied in scaffolding erection to identify waste and improve onsite installation productivity.

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Predicting Realistic Inspection Rate in Construction

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Abstract

A number of sampling plans are available for the calculation of the frequency of tests/inspection to be performed for a construction task. Not all the existing plans are suitable for the construction industry. In this study an alternative model adopting Minimum Cost Method is developed to determine the optimum number of inspections at which the cost of the inspections will be minimised. The method is based on minimising total costs including prevention costs, appraisal costs and failure/rectification costs. If the average defective proportion and its standard deviation for a process are known from past data and the cost ratio of failure and initial costs are available, then the minimum required number of inspections per lot can be calculated. An example is presented to illustrate the application of the method. The example has shown that the number of samples to be tested/inspected per lot not only depends on the average defective proportion but also on the cost of failure and the cost of prevention and appraisal.

Keywords: Inspection, Defective construction works, Minimum cost method, Optimisation.

1. INTRODUCTION

Construction sites are complex environments where multiple trades and suppliers are all working at the same time, often with different business objectives. Mistakes, errors and omissions can almost surely be expected. Yet, the rework they cause is a dirty, unspoken secret which has impacted construction costs and schedules for years. Though no one likes to talk about it, it is estimated that rework in construction projects costs a total of 12% of the contract value. That can be a big slice of the builder's revenue.

To start reducing rework, we need to identify where it happens. A study by Fayek et al. (2003) identified engineering and the associated reviews are the largest source of rework at around %60 that includes errors, omissions, and poor document control. In fact, the Building Research Establishment (BRE) in the UK reported that errors in building had 50% of their origin in the design phase. This study also shows that human resource capability, material and equipment supply, leadership and communications, and construction planning and scheduling cause 21%, 15%, 2% and 2% of total rework respectively (Building Point, 2016).

1.1. Cost of Quality in Construction Works

In a construction process, inspection/tests are an important activity. Without inspection a task cannot be completed successfully. Inspections/tests are normally carried out before and after the execution of a task. To prevent the occurrence of errors in a construction process inspections are considered as an essential activity.

The Construction Industry Development Agency in Australia (CIDA, 1995) estimated the direct cost of rework in construction was greater than 10% of project cost. Blyth (1995) comments in a compilation of existing case studies, that a typical construction company roughly spends 2% of its turnover on quality systems. Blyth's (1995) study also suggested that actual cost incurred on the quality system is difficult to determine. Davis et al. (1989) reported that the cost of providing quality assurance and quality control in engineering construction was estimated to be approximately up to 5%. Therefore, the total cost of quality, including rework (rework cost 10%) and quality assurance and control cost (5%) add up to 15% of the total project cost. According to Love and Li (2000), cost incurred on appraisal in construction (e.g. inspection and testing cost) is approximately 30% of the total quality cost or approximately up to 4.5% — calculated as 30% of 15% of total project cost. The total value of the annual turnover of the Australian construction industry in 2014 was valued at $204.5 billion (Australia's Construction Industry: Profile and Outlook, July 2015). Thus, if a 4.5% of the appraisal (inspection and testing) value is applied to this total annual turnover, then the approximate cost of inspection and testing could be estimated to be approximately $10 billion per annum.

1.2. The Need for Reconsideration of Inspection Policy

The implications of above-mentioned figures are that a significant proportion of the project cost savings can be achieved with the optimisation of inspection policy. The effort and time spent on inspection may reach a point of diminishing return if flawless standard is targeted for a constructed facility. Therefore, an optimisation approach that produces the minimum required inspections based on a given quality levels would be value-adding. "Inspect everything" is the common practice in the construction industry. With modernisation, and repetition of construction activity, a lower inspection rate (less than 100% inspection) may be more realistic and cost effective. It has been argued that well-planned inspections would significantly reduce poor-quality costs. Errors can be seen as chains of events, including causes, human error, defect, consequences and corrective measures. Most of such chains include repeated loops, which means that several human errors and defects occur before detection. There exist some sampling methods which are utilised to optimise the inspection cost in the manufacturing industry. Some of the methods available include single sampling plan, double sampling plan, multiple sampling plan, acceptance sampling, operating characteristic curve, and attribute proportional sampling (APS). For a stable process, acceptance-sampling plan is inappropriate because the number of defect incidents in a sample is not correlated with the number of defective items in the rest of the lot. A proof of this theory is given by Gitlow et al. (1987). For a cost effective inspection policy acceptance sampling does not include the calculation of optimum sample size. The Minimum Cost Method (MCM) is discussed in this study to overcome this limitation. The MCM is developed using different categories of quality costs, namely prevention cost, appraisal cost and failure/rectification cost. A systematic breakdown of these costs is provided in this study. An example is presented to clarify how the number of tests or inspections to be performed per construction task is dependent on the cost of inspection/test and the probability of occurrence of defects. The error rate is not constant throughout the construction process and generally with the progress of the construction process the performance level improves. Therefore, the inclusion of the learning curve is more appropriate for the calculation of the error rate. Normally, error rate reduces as the experience level matures. An equation has been developed to calculate a more realistic inspection rate using a learning curve model in conjunction with the MCM model. An example is presented to demonstrate that the inspection rate varies with the learning rate of the construction task.

2. CALCULATION OF OPTIMUM INSPECTION RATE

The inspection rate in this study is defined as the number of inspection per error. In this section another consideration provided in determining the number of tests/inspection is the cost of inspection and the cost of replacement of defective elements in future. It is obvious that, the more time and effort spent on inspection, the greater the confidence in the quality of the product. Most likely the extra effort and time spent on inspection may not be cost effective compared to the rise in required output quality level. However, if the inspection cost is high compared with the replacement costs, the number of inspections needs to be minimised. The number of inspections should be limited to the extent that gives the owner enough confidence that the product is of the desired/specified quality. The term 'enough confidence' can be expressed in statistical terms as the confidence interval. The Owner will have to be satisfied with a lesser number of inspections as the ratio of C_t/C_f increases, where Ct and C_f

are the cost of prevention/appraisal and the cost of failure, respectively. A model is developed below to determine the optimal inspection policy. This model establishes a relationship between cost parameters, the sample size (n), the lot size (N) and the defective proportion (p).

2.1. The MCM Model

There is a minimum total cost for a certain quality level. This is illustrated in the classic quality cost trade-off model (Ittner, 1992) demonstrated in Figure 1. Total cost represents the sum of prevention and appraisal (conformance) costs and failure/rectification (non-conformance) costs. This concept can be applied to determine the optimum sample size at which the total cost is minimised.

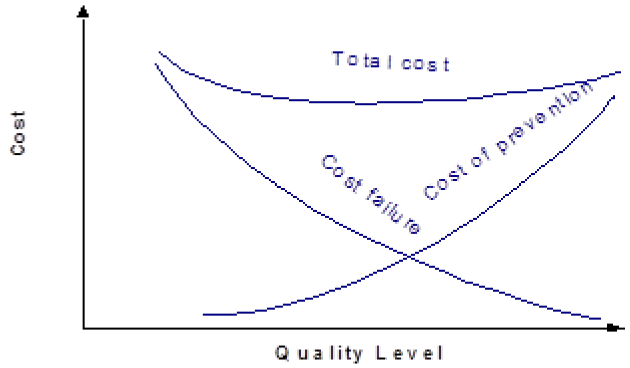

Figure 1. The classic quality cost trade off model

2.2. Development of the Model

In the MCM model the sum of prevention and appraisal (conformance) costs and failure/rectification (non-conformance) costs are minimised at a certain quality level. This quality level has a minimum sample size. Using the minimum cost model, we can determine the optimum fraction of a lot size for a specified ratio of cost of failure to cost of prevention and appraisal. The breakdown of the relevant costs is provided in Table 1.

Table 1. Different elements of inspection and rejection costs

Prevention Costs	Appraisal Costs	Failure/rectification costs
• Quality system development • Quality system management • Assessment of suppliers and subcontractors and maintenance of master lists • Quality consultant's fee • Fees of certifying agent • Audit planning • Quality circles and other system improvement initiative • Development and management of job description • Personnel selection	• Internal generic audits (eg of training or auditing), including attendance by staff on auditor and audit reporting • Attendance on external auditors for certification • Management review • Inspection • Testing • Calibration and maintenance of inspection and test equipment • Checking • Review of own work	• Demolition and reconstruction of contractor's work including wastage, scrap and replacement costs and all costs associated with attendance on this work and delays arising from the work. • All costs associated with attendance and delays related to sub contractors' re-work • Internal re-work of documents as a result of review including project quality, plans, calculations, sketches, shop drawings, variation claims, progress claims, programs and resourcing schedules • Re-work of issued documents such as those listed above • Re-printing and processing of documents • Re-inspection, re-checking or review of rework • Project non-conformance and corrective action not covered above • Dealing with client complaints • Dissatisfied client pacification • Project litigation including attendance on lawyers and barristers and professional indemnity insurance excess

• All training and professional development • Preparation of project quality plans including inspection and test plans • All costs associated with fulfilling the requirements of procedure which are extra-over those carried out before the quality system was in place.	• Independent review of work • Review meetings • Other verification activities • Internal audits of projects • Attendance on project audits by second parties • External audits of suppliers and subcontractors (where applicable) • Validation activities such as prototype testing and commissioning • Debriefing	payment • Reduction or non-payment of contract sum • Late payment and bad debts and interest on borrowing • The on-cost emergency resourcing of projects • Unnecessary duplication of filing system • Communication breakdown in head office and between head office and sites • Non-conformances and corrective action not project related • Client dissatisfaction which is not known • Prime consultant dissatisfaction • Supplier and subcontractor dissatisfaction • Loss of client as a result of the above • Loss of reputation as a result of the above • Project indemnity insurance premiums • New staff getting to know “the way the firm works"

Let,
C_t = the cost of prevention and appraisal (for detail refer to Table 1)
C_f = the cost of failure/rectification (for detail refer to Table 1)
N = lot size
n = sample size
r = non-conforming items in a sample size n
p = average defective proportion (error rate)

Inspection/testing cost $= C_t * n$ (1)
Failure cost $= (r/n) * N * C_f$ (2)

Therefore,

Total cost $C = C_t * n + (r/n) * N * C_f$ (3)

For minimum n, (dC/dn) = 0, that results in

$N^2 = (r*N*C_f)/C_t$ (4)
$n = (r/n) * N * (C_f/C_t)$ (5)

Replacing r/n = p, equation (5) becomes

$n/N = p*(C_f/C_t)$ (6)

By using equation (6) the sample size can be determined for a particular lot size if the cost ratio is known for the construction process. An example of how to determine the optimal lot size is discussed below.

For example, for a cost ratio of 3 at lower confidence level, n/N is 0.36 and at upper confidence level, n/N is 0.57. This implies that the number of samples to be inspected or tested per lot depends on the average fraction defective (p) and the ratio of cost of failure (C_f) to cost of prevention and appraisal (C_t). In this example, if n = 30, then the upper limit of the N value for a cost ratio of 3.0 is 83. If the cost ratio is lower the percentage of inspection will be lower. For higher failure cost, close to %100 inspection will be required to satisfy the confidence of owner and contractor.

3. THE WORKED OUT EXAMPLE FROM THE INDUSTRY

The MCM can be used for the calculation of optimum inspection rate for the repetitive tasks in construction. Due to mechanisation and use of same design in construction projects, construction processes are becoming repetitive. Observation of a tunnel construction project, showed that a number of tasks were subdivided into lots in a manner that they became repetitive. For example, in the selected tunnel project, the 2400-meter-long ceiling works were divided into 264 reinforced concrete slabs (each slab is approximately 12m long 7.6m wide). Cost data on this slab construction was collected, including the cost of rework and the cost of inspection/testing. The average ratio of the cost of rework and the cost of inspection/testing was found to be approximately 5 ($5000/$1000). The defective proportion (error rate) for this sort of work (e.g. reinforced concrete construction) was found from previous studies and historical data to be 0.118 (Stewart 1992). Therefore, using equation (6), the number of slabs to be inspected for the tunnel job (for p=0.118 and N =264) worked out to be 156. According to the records available all slabs were inspected and tested for this job. Therefore, if this method was used, a substantial amount of money could have been saved on inspection and testing without affecting the final quality of the product.

4. DISUCSSION AND CONCLUSION

An alternative method for calculation of optimal sample size has been developed in this study. This method is based on minimising total costs including prevention costs, appraisal costs and failure/rectification costs. An example has been presented to illustrate the application of the method. The example has shown that the number of samples to be inspected or tested per lot is not only depended on the average fraction defective but also on the cost of failure and the cost of prevention and appraisal. The example presented on the construction of repetitive slabs for a construction project, suggests that a saving can be made using the MCM by determining optimum inspection rate. In this project a number of activities were subdivided into lots. In large construction projects this is the norm for effective handling and controlling of construction activities in terms of cost and quality. Construction processes are also becoming more repetitive in residential construction due to the use of the same design and the same construction methods in a number of projects. In the Australian residential construction industry, builders are involved in construction of project homes. These project homes are of a “standard” design with inflexible contractual arrangements which make design changes costly and/or impractical. Anecdotal evidence suggests that medium to large residential builders in Australia need to complete in the range of 100 to 200 houses of (relatively) same design scale per annum to provide sufficient return to the business. Therefore, the application of the MCM can be useful for the determination of optimum inspection rate for a number repetitive trade works (e.g. foundation work, brickwork, framing, painting, etc.) involved to build these project homes.

The average error rate for a repetitive construction task is not constant throughout the project. It varies from organisation to organisation and project to project depending on a number of factors. These factors include, site management, experience and skill of the workers and inspectors, site conditions, environment and task complexity. In future research, modelling of these factors by applying appropriate tools such as fault tree analysis and event tree analysis will further enhance the effects of error rate, which may be utilised in predicting realistic inspection rate in construction.

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