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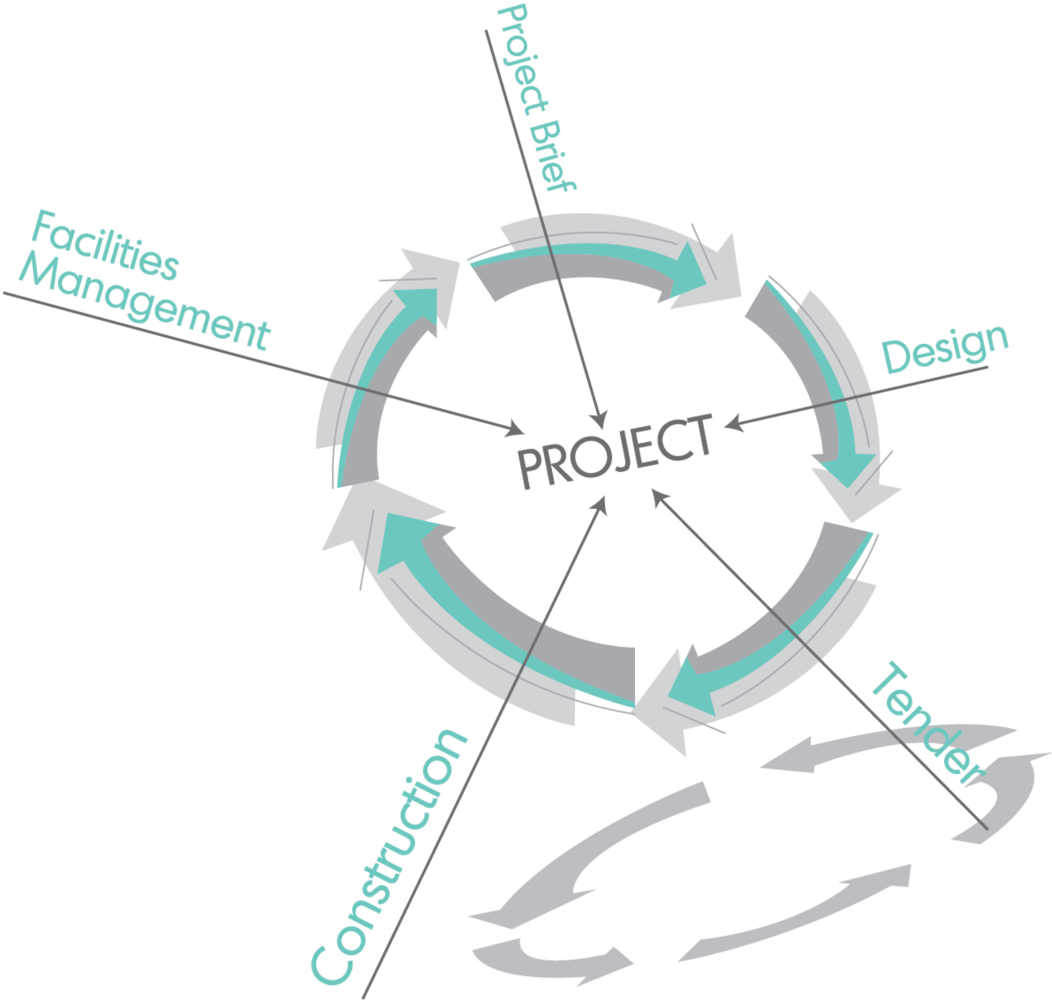

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Editorial Advisory Board

Editorial

Welcome from the Editors

Welcome to the twenty-fifth (26^{th}) issue of Malaysian Construction Research Journal (MCRJ). In this issue, we are pleased to include eight papers that cover wide range of research area in construction industry. The editorial team would like to express our sincere gratitude to all contributing authors and reviewers for their contributions, continuous support and comments.

In this issue:

The launch of The Green Technology initiative by the Malaysian Construction Industry Development Board (CIDB) to support the Malaysian Green Government Procurement (GGP) has yet to show its effectiveness in transforming the construction industry to embrace sustainable construction practices. **Padzil@Fadzil Hassan et al.,** conducted a literature review and meta-data analysis of policy papers, industry reports and research publications to gain insights into this shortcoming. The findings of the study are discussed in this paper.

Afizah Ayob et al., identified the contractors' perspectives regarding the key factors, their associated causes, current risk management implementation and mitigative measures in large construction companies in the northern states of Malaysia. The study can provide a thorough understanding of risk management and may lead to the development of a reasonable measure for risk factors, as well as can support the goal of achieving an acceptable level of competitiveness and cost-effective operation. The findings of the study are discussed in this paper.

Information Technology/Information System (IT/IS) promotes effective information exchange in multiple industries including construction industry. **Nur Mardhiyah Aziz et al.,** studied the influence of human factors in determining the success or failure of IT/IS implementation the industry. The data for the study is obtained from a preliminary interview with seven Malaysian companies representing a variety of construction industry participants and IT experts as well as a questionnaire survey of 311 construction industry practitioners. The initial 23 human factors identified from a literature review are also used for the study. The findings of the study are elaborated in this paper.

Nurul Afida Isnaini Janipha and Faridah Ismail recognized client's contribution in material purchasing activities to determine its impact towards construction quality and how they are related to one another. A preliminary survey was conducted with construction organisations to gain information on the clients' contribution and their significant involvement towards construction quality. A literature review was also done to analyse general issues related to construction environment and purchasing process. The findings of the study are explained in this paper.

Dwifitra Y Jumas et al., presented the latest research development in conceptual cost estimation (CCE) from year 1995 to year 2014, with objectives to map the CCE studies and to identify their active contributors as well as the common research methods adopted in the CCE studies. Fifty-six relevant articles obtained from 18 major journals associated with construction management studies are successfully accessed. The findings of the study are discussed in the paper.

Previous research shows that the implementation of lean construction differs according to companies' own understanding of the principles. **M.S. Bajjou and Anas Chafi** aimed to fill this gap by proposing a generic framework leading to a better understanding of the basics of lean construction. This study also aims to develop a conceptual model that shows the main principles and the most common sub-principles leading to the success of lean construction implementation. The outcome of the conceptual model was demonstrated in this paper and the most used Lean Construction sub-principles were also identified.

Luis Navas et al., compared the structural properties of Steel Framing and Molecule System to indicate the use of the more suitable one in a seismic highly vulnerable like Ecuador. This is accomplished by using analytical models to obtain standard weights of the structures, shear and moment in columns, floor drifts and periods of vibration. The results obtained from the study is elaborated in this paper.

Corrosion of steel reinforcement due to carbonation can affect the durability of reinforced concrete (RCC) structure. Therefore, **S Verma and J Kujur** simulated, predicted and validated concrete carbonation depth for different concrete mixes using a neural network. This study compared the performance curves, regression plots, predicted values and error histograms of the different concrete mixes. The results were presented and elaborated further in this paper.

Editorial Committee

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GOVERNMENT GREEN PROCUREMENT (GGP) IN MALAYSIAN CONSTRUCTION INDUSTRY: HAVE WE GOT IT RIGHT?

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Abstract
Various initiatives were mooted the banner of Green Technology Program to promote environmental sustainability in construction projects the construction industry to support the Malaysian Government Green Procurement (GGP) in 2009. However to date, the take-up has been poor. This paper critically reviews the Green Technology implementation to identify insights to the shortcomings. A thematic meta-data analysis of policy papers, industry reports and research publications was adopted as the research methodology. The emergent themes were mapped against the concepts public sector strategic management to identify the gaps in the implementation. The findings suggest the industry to re-learn its GGP implementation process if the GGP targets set is to be achieved.

Keywords: *Malaysian Construction Industry; Green Technology; sustainable construction practices; Government Green Procurement (GGP); Public Sector Strategic Management*

INTRODUCTION

The Green Technology initiative launched by the Malaysian Construction Industry Development Board (CIDB) in 2009 is a significant effort by the construction industry to support the Malaysian Green Government Procurement (GGP). However, its effectiveness in transforming the industry to embrace sustainable construction practices has yet to be evident. Arguments on the suitability of its implementation strategy are continuing, as there has been dearth of study to ascertain the causes for the under achievements. A critical literature review and meta-data analysis of policy papers, industry reports and research publications were undertaken to gain insights into this phenomenon. The aim was to establish the causes for the lack of readiness of the Green Technology initiative by analysing the elements of the implementation against the concepts public policy strategic management concepts. The finding identifies significant gaps in the design of the implementation strategy that have inhibited its effective implementation. This suggests the necessity for the industry to review and re-structure the whole implementation to be effective.

MALAYSIAN GOVERNMENT GREEN PROCUREMENT (GGP)

GGP is defined as “the acquisition of products, services and work in the public sector that takes account environmental criteria and standards to conserve the natural environment and resources, which minimize and reduce the negative impacts of human activities” (KeTTHA, 2012). The definition was chosen to underline the significance of procurement of products and services in the effort to minimize degradation of the environment and consequently reduce carbon emission within the country (SMECorp, 2010; KeTTHA, 2012). To jump start the GGP, National Green Technology and Climate Change Council (NGTCCC) was formed by the Ministry of Energy, Green Technology and Water (KeTTHA) in 2009. This formation was in line with the National Climate Change Policy introduced under 9th Malaysia Plan (MNRE, 2009).

Why GGP?

The government is the biggest procurer of products and services in any nation (Adham and Siwar, 2012; Adham et al., 2012a). Malaysia's GDP which measures at 12-15% annually was identified as having the influence to change the spending trend. This influence can be exercised directly through the procurement in government owned projects, and indirectly through policies to govern private sector procurement practices. GGP was identified as the enabler that will be able to transform the national environmental through innovation while supporting the local economy. It was envisaged that GGP could potentially open up larger new markets, improving the performance of business while at the same time, stimulate sustainable consumption and production (SCP) (KeTTHA, 2012; Lighthouse Technical, 2013; Adham et al., 2012b). It was believed that the introduction of it would create the domino effect to enable the economy to flourish. Malaysia would be able to facilitate long term saving through the production of higher quality products, healthier working condition, reduce carbon emissions and increase energy efficiency by 40% by 2020. The anticipated saving from this is estimated at RM295 billion, with the creation of 47,000 jobs in the green industry (PEMANDU, 2010; Adham et al., 2012b; Kahlenborn et al., 2014). This will transform the value chain and life cycle in all sectors of the economy that will lead to the targeted carbon emission reduction (Kataoka, 2011; Adham and Siwar, 2011; Kalubanga, 2012).

Framework for GGP Implementation

The commitment to implement GGP was underlined in the 10th Malaysian Plan (Adham et al., 2012b; CIDB, 2015). This was linked to the other economic policy and implementation projects which include the New Economic Model (NEM), and the Economic Transformation Plan (ETP), National Green Technology Policy (NGTP), National Renewable Energy Policy and Action Plan (NREPAP), and Small Medium Enterprise Master Plan (SMEMP). (Kataoka, 2011; Adham and Siwar, 2012; Adham et al., 2012a; Lighthouse Technical, 2013). Within the construction industry context, GGP has been extended in the implementation of Industrialized Building System (IBS) and Building Modelling System (BIM), Value Management/Life Cycle Costing for Asset Management, Outcome Based Budgeting (OBB). Moreover, GGP implemented the NextGen e-Procurement, National E-Tendering Initiative (NeTI), ePerunding, and the *Sistem Satu Pendaftaran Kontraktor* (SSPK) initiatives (KeTTHA, 2012).

The GGP Action Plan

The GGP Short Term Action Plan (STAP) was introduced by KeTTHA in 2010. The plan underlines the (a) Green Procurement (GP) procedure, (b) evaluate, award and follow the eco label certification, and (c) initiative of "Start with Government", as the guide for GGP (KeTTHA, 2012; Adham et al., 2012b; Kataoka, 2011). The Key Performance Indicator (KPI) to assess the progress and achievements of GGP was also established. The KPI elements are; (a) Establishing Eco Label certification, (b) establishing the procedure of GP (c) acceptance of the practice of GP in agencies, the private sector and public and (d) companies certified in green technology.

MyHijau Program

The MyHijau Program launched by the National Green Technology and Climate Change Council (MTHPI) in 2012 was intended to underpin the GGP implementation (Adham et al., 2012a; Adham et al., 2012b; KeTTHA, 2012b; KeTTHA, 2013a; KeTTHA, 2013b). MyHijau Program promotes the concept of sustainable production and consumption through 4 thrusts. These are;

(a) MyHijau Eco Label scheme
(b) MyHijau Green Procurement (which lists the characteristics of green product, service and works for GGP)
(c) MyHijau Green Directory, which contains information on green service and product for stakeholders
(d) MyHijau SME, which promotes green awareness and business matching within industries

THE CONSTRUCTION INDUSTRY GREEN TECHNOLOGY PROGRAM AND GGP

The construction industry was identified as the biggest polluter and in the emission of greenhouse gas in its fragmented industry nature (Nawi et al., 2012). To circumvent this, the Construction Industry Development Board (CIDB) in partnership with KeTTHA, Malaysian GreenTech Corporation, and the major stakeholders has been engaged in many change program and projects to encourage the industry to embrace GGP (Hassan, 2014). This includes the development of Waste Management Control System, Environmental Management Plan (EMP), Environmental Management System (EMS), ISO 14001 certification for contractors and Industrialised Building System (IBS). In the meantime, the Public Works Department (PWD) has been engaged with the Environmental Protection Works using Bill of Quantity (BQ). Several publications on how to improve environmental practices, management of construction waste, good sustainable/green practice series, Guidebook on Planning and Implementing Green Practices for Building Construction Works, Construction Industry Standard (CIS) and compilation of environmental acts in the industry was produced for the industry. To facilitate communications on the green, a centralized information centre for green technology was also established (MNRE, 2009).

The emphasis on transforming the construction in 2013, CIDB published a Guidebook on Planning and Implementing Green Practices for Building Construction Works contains the stakeholder involved, legislative requirements, planning methods, implementation guides, and few case studies for a green practices construction project in Malaysia. The development of Construction Industry Master Plan (CIMP) until 2015, reinforced the environmental sustainability of its thrust (REHDA, 2008; Hassan,2009) but in the Construction Industry Transformation Program (CITP) started in 2016 until 2020 had stressed the environmental sustainability as one of its core strategic thrust (Kalubanga, 2012).

ENVIRONMENTAL SUSTAINABILITY INITIATIVES IN MALAYSIAN CONSTRUCTION INDUSTRY

CIDB and Key Stakeholder in Implementing Green Technology Initiatives

CIDB as the coordinator in green technology of the industry (Hassan, 2012; CIDB, 2013; MATRADE, 2016) thus, facilitate the industry growth in environmental sustainability alongside with industry stakeholders had come out with 2 major strategic plans. These plans namely the (a) Construction Industry Master Plan (CIMP) started in 2006 until 2015 which regard environmental sustainability as part of the sub initiative but (b) Construction Industry Transformation Program (CITP) started in 2016 until 2020 regards environmental sustainability as one of its core with the initiative. Malaysian Carbon Reduction and Environmental Sustainable Tool (MyCREST) is established under the CIMP but reinforced and operated supporting the environmental sustainability thrust in CITP alongside with Green Procurement JKR (PhJKR) and Green Building Index (GBI) to gauge initiative's carbon emission under CITP.

Malaysian Carbon Reduction and Environmental Sustainable Tool (MyCREST)

The MyCREST aims to quantify the reduction of carbon emission in building using lifecycle view integrating socioeconomic to build environment. It is a rating tool mainly focuses on new construction, existing building, new construction without air-cond and new construction for healthcare. It caters for cradle to the cradle of building life cycle of the embodied and operational carbon. Implementing the MyCREST comprises 3 applications involving scorecard, reference guide and carbon calculator (MyCREST, 2010; CIDB, 2013).

Green Building Index (GBI)

The GBI is a tool to ease public recognizes the green building, serve as key design principles and performance parameter of a building. It was designed within the context of Malaysian climate, culture, building codes and practices. It is seen as an opportunity to design and construct a sustainable building, better connectivity with transport with the adoption of recycling and greenery involving residential and non-residential buildings. 6 criteria were chosen to quantify the green rating of a building with tax exemption can be applied (Aun, 2010).

Green Procurement JKR (PhJKR)

Intertwined with the Integrated System Management (IMS) and Holistic Asset Management (PAM), the Public Works Department (PWD) established a policy of sustainable development covers 8 major areas. These areas including Site Planning and Management, Energy Efficiency Management, Interior Environment Management, Resource and Material Management, Water Efficiency, Asset Management, Social Welfare and Green Technology Innovation (JKR, 2015).

It is best to learn that above mention rating tools were introduced in different context. GBI become the leading choice in private sector while the MyCREST offers an option of rating tool to the industry other than GBI. Whereas, PhJKR is seen focusing more to the public construction project. Recently, MyCREST is implemented in three (3) pilot government construction projects to verify its viability for future public construction project implementing GGP concept. The full result will be seen in 2020, while GBI continues to be the rating tool for the private construction project.

Importance of the Right Strategy Formulation for Effective Green Technology Implementation

It has been a challenge for the construction industry to persevere to identify the root cause for the poor Green Technology take-up. It contending with the challenge, it was learnt from Perry (1987); Lynn (2006); Eccleston and March (2011), that the critical point is appreciated that the Green Technology Program is a public policy which must be founded on the right public sector strategic management principles. It is the nucleus from which the policy goals and initiatives evolve. This is the basis from which the implementation strategy is formulated, stakeholders and their roles are identified, and where resources to be mobilised and consumed. Consequent to this, many strategic management models come to the fore. Among the prominent ones identified by this paper are the strategic planning model by Bryson (2011) and the strategic triangle by Moore (2004). Adding on to the models are the view on the necessity for public sector strategic management need to shift from traditional public governance to participatory public governance (Porter, 2013) and the importance of technology application in strategic management (Porter, 2013). In observing the worrying trend of predominant neo classical thinking infiltration in public policy strategic management thinking of late, Porter (2013) maintains the need uphold common shared value principles to ensure that no party would be disadvantaged or marginalised when the policies are implemented.

The significance of considering the micro and macro environment for transforming the market-oriented economy or industry was drawn from Briscoe (1988); Leibing (2001) and Osman (2008). The pros and cons of the application of strategic planning model and the triangle strategic management model to transform the conventional Malaysian economy into a green economy through GGP under the concept of sustainable consumption and production (SCP) was weighted. It was observed that the strategic planning approach have many disadvantages because it tends to be very mechanistic and top down strategy. The arduous challenge in applying this model is to convince all the stakeholders to commit and expand themselves in the initiative implementation. In contrast, the strategic triangle approach tends to be more appropriate because it is organic in its character and able to create the buy-in from the key stakeholders by creating common shared value which would benefit all.

METHODOLOGY

A qualitative approach was applied in acquiring, sorting and rearranging the data. A sequential qualitative model was adopted along the study to compare the existing implementation and critical discussion in public strategic management field. First, critical literature review was themed under GGP framework, public policy formulation, green practice in Malaysian construction industry and environmental sustainability tools to set the context and foundation of the study using AtlasTi software. The study was themed into Malaysian GGP, the need of GGP, its action plan and available green initiatives in the industry. Second, ten (10) selected major articles of journal, research reports, government policy papers, best practices and industry blueprints and reports on Malaysian GGP were used in meta-data analysis to analyze level of GGP readiness and gaps at policy and project management level. This was summarized in Table 1. The documents were mapped by publication year to synchronize its application to the industry. The elements obtained from the documents collected and synchronized with the study of construction economic field which significantly related to strategic management field. Third, the findings from themed literature and meta-data analysis were discussed under the backdrop of public strategic management literature discussed in literature review part.

DISCUSSION

Notwithstanding the various GGP policies and implementation strategies mooted since 2009 (KeTTHA, 2013a), there has been little evidence to suggest the achievements. To date there has been no mechanism identified that can gauge the achievement of Green Technology program. The initiatives taken by the industry stakeholder in public and private sector under the CIMP started in Green Technology Programme in 2009 until the CITP initiative is still in a bush.

In Table 1, there are visible gaps more in project management than policy level. This might be argued to different context of the document analysed, but it is suggested that the effectiveness of policy implementation cascaded down to the project management need a revision. Another significant element need to be review is merging the concept of SCP in higher learning institution specifically to the built environment programs. There is also lack of engagement with Non-Government Organisation (NGO) which may represent public aspiration at large on the SCP concept affecting their quality of environment. There are also repetitive themes factors emerge in the meta-data analysis which are the regulations, standards, promotion, education and training and practicing green procurement in project management. The focus in the industry has been emphasized in these themes indicates strategic planning principles being applied in formulating and implementing GGP. These themes can be applied as the critical success factors toward establishing the macro and micro components of GGP ecosystem under the context of Briscoe (1988); Leibing (2001) and Osman (2008) study. Hence, these factors are worthwhile to be looked into more seriously for future undertaking in formulating and implementing policy on GGP.

The question of 'have we got it right' is a rhetorical question to reflect the level of readiness in GGP implementation. Transformation into GGP in short, medium and long term requires a strategic management approach that suitable to a specific industry. Among the suggested approach is to use the public sector strategic management concept (Freeman, 1984; Leonard, 2002; Kim and Mauborgne, 2005; Bryson et al., 2010) to identify the gaps thus link the existing and new initiatives and translate it into project management. Throughout the literature and meta-data analysed, it is found that there is significant gap in formulating and implementing current GGP policy underpins in mechanistic strategy rather than organic in its process. Rethinking the governance philosophy and modes is needed. As public policy is one of strategic management major blocks, valuing environmental sustainability through public policy needs to be founded in a common shared value by engaging every stakeholder including the public and other interrelated institution or industries. Hence, transforming conventional construction procurement system into green procurement as part of GGP must also adapt a new ecosystem imbued in SCP which is absent. This ecosystem must be founded under a strategic approach which is more dynamic and organic suiting the global volatility economic, environmental and social phenomenon. It is suggested the conversion of people, process and value of triangle strategic management on the industry level and project management will help enhance the efficiency and effectiveness of GGP implementation in the construction industry. Although the GGP is intended to achieve environmental sustainability on a certain target, it also must not ignore overlapped elements of sustainability of economy and social in long term. The complexity of neo classical economic and environmental economic argument is very relevant but need a dimension of intrinsic value which should become the shared value in a market driven construction industry. These necessitate the organic strategy to be weight in current public policy implementation rather than mechanistic. Characterisation of organic strategy is deemed incessant in time, interactive flow and integrated construct. In recurrent mode, the organic strategy emphasizes behavioural aspect of decision making and emphasize on linkages of process while managing both internal and external change simultaneously. In the end, a bigger concern is the question of environmental sustainability through green procurement is rather a civic question which does not only belong to the construction industry fraternity, but to the public as well.

Table 1. Visible gaps in project management and policy level of GGP implementation

Policy Papers/Journal and Organisation	Policy Level	Project Management Level				
		Inception	Design Development	Tender	Construction	Hand Over
Construction Industry Master Plan (CIMP) Construction Industry Development Board (CIDB), (2006)	• Value chain continuous improvement • Adopt quality manpower, material, equipment and method • Knowledge enhancement and skill-upgrading for competent workers • Sharing best practice • Continuous research and development • Sustainable practice • Generate new opportunity both domestic and international market • Enhancement of professionalism					
CIDB Programmes in Green Technology Construction Industry Development Board (CIDB), (2009)	• Promotion & Awareness - Centralise Information Centre - Establish Technical Committee (TC9) - Strategic Action Plan - Green labelling concept • Regulation - Green contractor accreditation and implementation - Construction Industry Standards (CIS) • Training - ISO 14001 Certification DIY Programme - CIDB EMS Certification DIY Programme • Standards - 3 tier environmental system - Assessment Tool (MyCREST, GBI) - Research & Development (Waste minimisation, EMP, EMS ISO 14001, IBS, Environmental Protection BQ (JKR)		• Guidelines		• Eco label for construction material • Waste minimisation guide	
Mengintegrasi Kriteria Alam Sekitar dalam Perolehan Kerajaan: Satu Transformasi Adham & Siwar (2011)	• National Renewable Energy Policy and Action Plan (NREPAP) • Small Medium Enterprise Master Plan (SMEMP)					

Policy Papers/Journal and Organisation	Policy Level	Project Management Level				
		Inception	Design Development	Tender	Construction	Hand Over
Critical Success Factor of Green Purchasing International Green Purchasing Network (IGPN), (2012)	• Commitment and Support - Mandate (mandatory or voluntary) - Support SMEs - Shared best practices - Establish GGP committee - Helpdesk and Hotline - Science & technology park - Green Starter Kit (GGP, pGP, skills) - Communication Guide • Policy Through Procurement - Integrated committee policies, regulation, procurement - Communication activities (Website, Social Media - Publish guidelines - Green measures • Enabling Driver - Establish green concept organisation - Green Business Platforms (expo) - Database on Green product directory • Implementation - Electronic reporting system - Practical guideline - Method calculating GGP levels (compliance GGP criteria, sample tendering procedure) - Buying Green Handbook • Green product Information & Availability - Product life cycle analysis - News alert - Newsletter • Task Force • Target - Government specific programs - Series of Campaign - Green Awards - Eco Contest • Training - International Training centre - GGP Training Toolkit with 3 modules - Train & qualified personnel - Seminar & conferences					

Policy Papers/Journal and Organisation	Policy Level	Project Management Level				
		Inception	Design Development	Tender	Construction	Hand Over
	• Criteria of Green product - ‘Flower” Eco Label (Value Chain Criteria) - Most common type Ecolabel -ISO 14001, ISO 14024 - Eco label Products (Specification) • Budget and accounting Rules - Auditing system					
Sustainable Public Procurement United Nation Environmental Program (UNEP) (2013)	• Standards - Impact indicator • Regulations - Establish legal framework and review - Value for money contract - Establish GGP committee - International Agreements - Mandate (mandatory or voluntary) - Policies & Act - Guidelines & Regulations - Directives - Rules & Principles • Research & development - Key product life cycle analysis - Market readiness analysis - Expenditure analysis • Training - Training and capacity building - Lifestyle & education • Promotion - Ecolabel & Green Products - Share best practice - Priority to product - Report & Forum - Consumer information - Awareness & Capacity building Program - Communication activities (Website, Social Media • Practice - Develop Action Plan - Identify sustainable impact and risk of procurement - Establish ‘quick win’ product categories					

Policy Papers/Journal and Organisation	Policy Level	Project Management Level				
		Inception	Design Development	Tender	Construction	Hand Over
	- Integrated committee policies, regulation, procurement - Target commitments					
Pasaran dan Permintaan Produk Hijau di Malaysia Lighthouse Technical (2013)	• Legislations - Integrated product policy, implementation - Establishment of agency, council & Task force - Price reduction for eco label - Policy - Initiatives - Action Plan - Legal framework - Act - Circular - Regulations - Blueprint • Standards - Environmental Labelling program - Integrated (Energy & recycle mark) Certification system (Quality & environment) - Declaration Product system - Criteria, list and categories of products and services • Education & Training - Shared best practice - Strategy of Growth - Research & development - Criteria Checklist - Handbook of Buying Green • Awareness & Promotions - Network of Practice with IGPN - Technical Helpdesk - Promotion of purchase - Database product and services - Charter on promotion, technical - Green Awards	• ISO 14020 international organisational standard • Life cycle costing • Guidelines of criteria of product and services		• Green Contract law • Tendering and Bidding law		• Audit and review

Policy Papers/Journal and Organisation	Policy Level	Project Management Level				
		Inception	Design Development	Tender	Construction	Hand Over
Buku Panduan Asas Mekanisme dan Strategi Pelaksanaan Perolehan Hijau Kerajaan di Malaysia Kementerian Tenaga, Teknologi Hijau dan Air (KeTTHA), (2013)	• Regulations - Establishment of agency, council & Task force - Additional criteria to government procurement - Establish Monitoring and audit mechanism - Strategic Plan - Policy & Action Plan - Regulation Frameworks • Promotions - Pilot programs - Incentives to government supplier - Workshop - Green Awards • Education & training - Techno Entrepreneur program - Capacity development program with modules - Awareness to government procure staff and supplier • Standards - National Eco label Scheme (National Eco Label, Energy Label, GreenTAG, Best Farm Accreditation, Malaysia Organic, Wood Certification) - Determine appropriate product and service • Implementation - Integration GGP with existing initiatives					
Government Green Procurement (GGP): Guideline for Government Procurer Kahlenborn, Mansor & Adham (2014)	• MyHijau Eco Label • MyHijau Green Procurement • MyHijau Green Directory • MyHijau SME					
Construction Industry Transformation Program (CITP) Construction Industry Development Board (CIDB), (2015)	• Regulations & policy - ISO 14001 for large construction project - Enforce standard requirement & assessment framework - Environmental Management certification to G8 - Enhance Regulatory - National Energy Action Plan	• SWMP submission requirement for large project	• Energy efficient Building Design • Green Street concept • BIPV	• Increase sustainable specification in BQ in line with rating tool	• Waste categorisation • Recycling plant	• Energy monitoring and conservation guidelines

Policy Papers/Journal and Organisation	Policy Level	Project Management Level				
		Inception	Design Development	Tender	Construction	Hand Over
	• Standards - Building rating tool – MyCrest, GBI - MyEnvision rating System - Minimum energy performance standards (MEPS) - Energy Audits and management - Establish working group define environmental sustainability • Training & Education - Establish Centre of Excellence (CoE) - Return of Investment Analysis (ROI) - 'MyEnvision' Training - Training for project manager on new standard and requirement • Awareness & promotion - Collaboration with private sector - Pilot project for financial and technical viability, energy usage and carbon reduction program - Publication for public and private sector - Highlight key role of stakeholder - Appropriate mechanism and incentive (financial and non-financial) - Kick-start promotion bonus - Sustainable financing Scheme - Green tax and Carbon Tax - Landfill taxation for excessive waste - Landfill taxation mechanism		• Material planning to reduce waste • BIM			
Program Polisi Teknologi Hijau Kementerian Tenaga, Teknologi Hijau dan Air (KeTTHA), (2015)	• Ecolabel & Green Products • Establish GGP committee (Majlis Teknologi Hijau Negara: Steering Committee, Task Committee) • Pilot Projects-Green Township • Master plan & Road Map • Smart Partnership (Green Jobs; Integration green topics into all education level; Green ICT; Green partnership with Korea) • Green Technology Funding Scheme- GBI tax exemption • Education • Awareness program • E-procurement system					

(Source: CIDB, 2006, 2009, 2015; Adham & Siwar, 2011; IGPN, 2012; UNEP, 2013; Lighthouse Technical,2013; KeTTHA, 2013, 2015; Kahlenborn, Mansor & Adham, 2014)

CONCLUSION

The insight of GGP in Malaysian construction industry was presented. To conclude the review, there is a need for the study of public sector strategic management in respect of construction industry to link thus intertwine the gap existed in the Green Technology initiatives established for the industry. Redefining the public sector strategic approach, stakeholder involves, the policies established, and the process involve must be in place in enhancing transformation of government procurement system in the long run. These are believe the remedy for the lack of readiness in implementing GGP in the industry strategically.

REFERENCES

A.Kataoka, (2011) *Networks to Promote Green Purchasing for Green Economy*, International Green Purchasing Network, Tokyo, pp. 1-4

Briscoe, G., (1988) *The Economics of the Construction Industry*, The Mitchell Publishing Limited and Charted Institute of Building (CIOB)

Bryson, J.M (2011) *Strategic Planning for Public and Non Profit Organisation*, John Wiley, San Francisco

C.S. Aun, (2010) *The Green Building Index Way To Green A Green Construction Industry for Malaysia*, ISM CPD Seminar, Petaling Jaya, pp. 25-55

Construction Industry Development Board (CIDB), (2009) *CIDB Programmes in Green Technology*, Technology & Innovation Development Sector, Kuala Lumpur, pp. 1-8

Construction Industry Development Board (CIDB), (2013) *Guidebook on Planning and Implementing Green Practices for Building Construction Works*, Kuala Lumpur

Construction Industry Development Board (CIDB), (2015) *Construction Industry Transformation Program (CITP)*, Kuala Lumpur, pp. 18-31

Construction Industry Development Board (CIDB), *Malaysia Carbon Reduction & Environmental Sustainable Tool (MyCREST)*, (2010), pp. 5-31

Eccleston, C.H., and March, F. (2011) *Global Environmental Policy: Concept, Principle and Practice*, CRC Press, Florida

G. Sundaraj, (2006) *The Way Forward: Construction Industry Master Plan 2006-2015*. Construction Industry Development Board, Kuala Lumpur, pp. 48-51

H. Hasan, (2012) *Forging Strategic Business Partnerships between Malaysia and IDB Member Countries*, Malaysia Islamic Development Bank Group Investment Forum, Kuala Lumpur, pp. 1-9

H.B. Leonard, (2002) *A Short Note on Public Sector Strategy-Building*, Harvard Business School.

J.M. Bryson, F.S.Berry, K.Yang. (2010) *The State of Public Strategic Management Research: A Selective Literature Review and Set of Future Directions*. The American Review of Public Administration

Jabatan Kerja Raya Malaysia (JKR), (2015) *Polisi Pembangunan Lestari JKR Malaysia*, Kuala Lumpur, pp.26-35

K.N. Adham and C. Siwar, (2011) *Mengintegrasi Kriteria Alam Sekitar dalam Perolehan Kerajaan: Satu Transformasi*, Persidangan Kebangsaan Masyarakat, Ruang dan Alam Sekitar (MATRA), Pulau Pinang , pp. 1-12

K.N.Adham and C. Siwar, (2012) *Transformation of Government Procurement in Malaysia: Direction and Initiatives*, pp1620-1641

K.N.Adham and C. Siwar, (2012) *Opportunities and Challenges for Asian Economies in the Millennium*, the 13th International Convention of the East Asian Economic Association, Singapore

K.N.Adham, C.Siwar, and A.M. Atan, (2012) *Pelaksanaan Perolehan Hijau Kerajaan: Isu, Cabaran dan Strategi Daripada Perspektif Pegawai Perolehan Kerajaan Malaysia,* Prosiding Persidangan Kebangsaan Ekonomi Malaysia (PERKEM), pp. 291-304

K.N.Adham, C.Siwar, and S.A.A. Ghani, (2012a) *Pertimbangan Alam Sekitar Dalam Peraturan Perolehan Kerajaan di Malaysia: Analisis Arahan Perbendaharaan*, Prosiding Persidangan Kebangsaan Ekonomi Malaysia (PERKEM), pp. 808-882

K.N.Adham, C.Siwar, and S.A.A. Ghani, (2012b) *Kajian Empirikal Pembangunan Perolehan Hijau Kerajaan di Malaysia*, Kementerian Pengajian Tinggi (KPT), pp. 44-58

Kementerian Sumber Asli dan Alam Sekitar (MNRE), (2009) *Dasar Perubahan Iklim Negara*, Putrajaya

Kementerian Tenaga, Teknologi Hijau dan Air (KeTTHA), (2012b) *Sumber Elektronik*, Putrajaya pp.1-64

Kementerian Tenaga, Teknologi Hijau dan Air (KeTTHA), (2013a) *Buku Panduan Skim Eco-Label SIRIM di Malaysia*, Putrajaya pp.1-35

Kementerian Tenaga, Teknologi Hijau dan Air (KeTTHA),(2012a) *Malaysia's Government Green Procurement (GGP): A Way Forward*, Putrajaya pp.3-4

Kementerian Tenaga, Teknologi Hijau dan Air (KeTTHA),(2013b) *MyHijau Programme*, Putrajaya pp.1-6

Leibing, R., (2001) *The Construction Industry: Process, Players and Practice*, Prentice Hall Inc, New Jersey

Lighthouse Technical, (2013) *Bengkel Perlaksanaan Kajian Pasaran Produk & Perkhidmatan Hijau di Malaysia*, Petaling Jaya, pp. 1-22

Lighthouse Technical, (2013) *Bengkel Perlaksanaan Kajian Pasaran Produk & Perkhidmatan Hijau di Malaysia*, Petaling Jaya, pp. 1-22

Lynn, L.E., (2006) *Public Management,: Old and NewRoutledge*, New York

M. Kalubanga, (2012) *Sustainable Procurement: Concept and Practical Implications for the Procurement Process*, International Journal of Economics and Management Science, pp. 1-7

Malaysia External Trade development Corporation (MATRADE), (2016) Construction Industry Development Board, Kuala Lumpur

Moore, M, Khagram, S. (2004) *On Creating Value: What Private Sector Can Learn Form Public Sector Strategic Management*, Corporate Social Responsibility Initiative Paper No.3, Cambridge, MA, John F. Keneddy School of Government, Harvard University

Nawi, M.N.M., Lee, A., Mohamad Kamar, K.A., Abd Hamid, Z. (2012) *Critical Success Factors For Improving Team Integration In Industrialised Building System (IBS) Construction Projects: The Malaysian Case*, Malaysia Construction Research Journal (MCRJ),10(1), 44-62.

Osman, O., (2008) *Emerging Governance and Economic Issues in Construction Industry in Malaysia*, Penerbitan Universiti Sains Malaysia

P.F. Hassan, (2014) *Aplikasi Teknologi Hijau di Dalam Pembangunan Projek Pembinaan*, Seminar on Green Technology in Construction, Kuala Lumpur, pp. 1-40

Performance Management and Management Unit (PEMANDU), (2010) *Economic Transformation Program.* Performance Management and Management Unit, Prime Minister Department. Kuala Lumpur: Percetakan Nasional Malaysia Berhad

Perry, J.L., (1987) *Handbook of Public Administration*, The American Society of Public Administration, Washington

Porter, M.E., (2013) *Why Business Can Be Good at Solving Social Problems*, TED Talk

R.E. Freeman, (1984) *A Stakeholder Approach to Strategic Management*, Graduate School of Business Administration, Virginia

Real Estate and Housing Developers Association (REHDA), (2008) *CIMP 2006-2015: The Way Forward for the Construction Industry*, Kuala Lumpur, pp.6

Small Medium Entrepreneur Corporation (SMECorp), (2010) *APEC: Survey on Business Environment,* Gifu, Japan, pp. 4-5

W.C.Kim, R.Mauborgne, (2005) *Blue Ocean Strategy: From Theory to Practice*, California Review Management, Berkeley

W.Kahlenborn, N. Mansor, K.N.Adham, (2014) *Government Green Procurement (GGP): Guideline for Government Procurer*, Sustainable Production and Consumption (SCP), Putrajaya, pp. 3-5

CONTRACTORS' PERSPECTIVES OF RISK MANAGEMENT IMPLEMENTATION IN MALAYSIAN CONSTRUCTION INDUSTRY

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Abstract
The construction industry, similar to other industries, is subject to risk and uncertainty because of the nature of its operating environment, which may affect overall performance toward achieving desired goals. This research identifies the contractors' perspectives in regards to the key risk factors, their associated causes, current risk management implementation, and mitigative measures in large construction companies in the northern states of Malaysia. Data were obtained via interview and structured questionnaire surveys conducted on 100 G6 and G7 companies in Perlis, Kedah, and Pulau Pinang. Of 70% valid responses, the top five risks factors considered are "Delayed progress payment by client," "Changing contract terms and clauses," "Delay in solving contractual issues," "Errors and omissions in design drawings, inadequate drawings and technical specifications, and uncoordinated design disciplines," and "Poor geological and geotechnical site conditions." "Lack of communication" between all parties is the main factor causing risk. "Effective risk management implementation" to increase the competitiveness of the company was not selected as the current exercise, and local construction industry players considered "Ensure effective site management and good contractor supervision" as the mitigative measure in response to risk. These findings indicate that the Malaysian contractors' perspectives remain at the early stages of risk management and lacks standardization.

Keywords: *Key risk factors; Construction company; Risk management; Mitigative measures*

INTRODUCTION

The construction sector plays an important role in Malaysia's economic growth. It offers employment opportunities and improves people's quality of life by enhancing the necessary socio-economic infrastructure, such as roads, offices, hospitals, houses, schools, and other fundamental and advanced facilities (Rahman et al., 2013). The global construction growth for 2012–2017 is forecasted to reach a compound annual growth rate of 4.7%, with all regions and sectors enjoying at least a modicum of growth. The Asia-Pacific region enjoyed the strongest growth in 2013, reaching 5.5%, which was led by China and India (IHS Global Insight, 2013).

Risk management is unconditionally necessary for construction projects; it aims at determining potential risks linked within a project and responding to these risks to minimize them to an acceptable level (Serpella et al., 2014). Risk management is a dynamic technique that should continue throughout project life cycle, depending on either intuition or previous experience, for an enhanced level of evaluation (Abdul-Rahman et al., 2015). Furthermore, risk management in a construction project includes timely completion within the specified cost, quality and value-for-money output, and safety and environmental precautions. Although risk management is vital, it does not always mean the complete absence of risk. Nevertheless, risk must be well understood, assessed, and appropriately controlled. Therefore, most effective method of managing risks is to mitigate them to the greatest extend possible.

The risk management practices are necessary for tackling and mitigating risks to ensure the success of projects. In reference to risk in construction industry, past research likely to focus on methods to identifying risk and the strategies and the advantages of particular risk management techniques during a construction in relation to the project aims, with little discussion of the Malaysian situation in comparison. A number of studies of particular interest were conducted by Enshassi et al. (2008); Goh and Abdul-Rahman (2013); Hwang et al. (2014); Rostami et al. (2015); and Byung et al. (2015), that concluded risk management practices were a rarity within many construction industries. Although the concept of risk management has been introduced in the Malaysian construction industry, most risk management implementations are inefficiently structured, and only a few companies utilize risk management techniques. Yusuwan et al. (2008) stated that Malaysian contractors implemented substandard straightforward, simple, fast, and inexpensive procedures (e.g., listing, brainstorming, and discussing) for risk identification. Abdul-Rahman et al. (2015) conducted case studies of specific projects in Kuala Lumpur and provide a narrow perspective of the situation that risk management implementation remains at its infancy stage mainly because majority of construction employees involved in risk management are only partly aware of the accessible risk management tools that can be applied in construction projects. Most recent study in Australia, Jin et al. (2017) discovered that there was some dependency on intuition when analyzing risk. This further escalates the question as to real extent and implementation of effective risk management practices amongst Malaysian contractors.

Therefore, this study identifies risk associated with the Malaysian construction industry in the northern region of the country. The three specific objectives are (1) to identify the key risk factors and their causes, (2) determine the current risk management implementation, and (3) examine the mitigative measures from local contractors' perspectives in response to risk.

LITERATURE REVIEW

Despite the potential economic benefits, construction sectors are more susceptible to risk and uncertainties than any other sector. This susceptibility is mainly caused by the complex nature of construction business activities, long periods, financial extremities, complex processes, abominable environments, and continuous and dynamic organization structure (Flanagan and Norman, 1993; Akintoye and Macleod, 1997; Mills, 2001; and Abdul-Rahman et al., 2015). These uncertainties, including costing, time constraints, quality expectation, location, and contractual disputes in tender contractors, originate from external and internal factors. Many players in multiple areas meet with one another at various stages throughout a single project. This attribute further complicates the entire construction process, which comprises a series of time-consuming activities. The construction industry is an interesting, risky, and changeable field that warrants research.

Risk management is commonly perceived as one of the major procedures in project management. Each construction project becomes difficult, unique, continuous, and dynamic because construction performance involves various uncertainties, multiple intricacies, diverse procedures, and divergent environments (Jarkas and Haupt, 2015). Risk and uncertainty illustrate settings where the output of an activity is most likely to deviate from the determined value. Productivity, efficiency, quality, and cost are influenced by risk, which can be potentially disastrous to the outcomes of a construction project. In this case, Goh and Abdul-Rahman (2013) highlighted that financial risk and time risk are found to be the major risk factors in regards of the occurrence frequency and the impact for Malaysian construction industry. The risk occurrence probability frequently varies and the effect of risk differs from one project to another; the nature of risk changes during project life cycle. Insufficient project information, especially at the construction beginning stages, usually leads to a high risk magnitude. By contrast, when risks are recognized as a project progresses, the increased level of certainty decreases the risk level in the project (Goh and Abdul-Rahman, 2013). Therefore, determining and managing possible risk factors, which vary from project to project based on a few conditions, are important tasks in improving performance and accomplishing projects.

Effective risk management practices consist of three main processes, namely risk identification, risk analysis, and risk response (Mills, 2001; Smith, 2006). A critical phase is risk identification encompasses not just identifying key risks factors, but also the interconnected among these risks. Considering that risks vary from project to project depending on the projects characteristics, risk identification should be carried out at the initial risk management stages. It continues with categorizing the types of risks, factors causing risk, and their effect to the project. Risk analysis will screen and priorities the recognized risks. Following the risk analysis, a risk mitigation strategy is then developed. Previous research by Enshassi et al. (2008) recommended that contracting companies in Palestine should identify and adequately quantify project risk factors which could be added to quotation and time estimation. Additionally, Hwang et al. (2014) reported that positive correlation between risk management implementation and improvement in quality, cost and schedule performance of small projects in Singapore.

METHODS

The targeted respondents in this research are the G6 and G7 contractors registered with the Construction Industry Development Board (CIDB) at the northern region states of Malaysia, namely, Perlis, Kedah, and Pulau Pinang. These contractor classes are selected because they exhibit higher tendering and working capacity than other contractor classes. These large construction companies are also responsible for a substantial portion of this industry's output compared with smaller companies (Zainon et al., 2016). The paid-up capital or net capital worth of the companies exceeds half a million MYR, which is the highest among the seven classes of construction companies.

The questionnaires were divided into five sections, with Section A consisting of open-ended questions regarding the company's general background. Prior to data collection, a set of factors for Sections B (Key risk factors), C (Factors causing risk), D (Current risk management implementation), and E (Risk mitigative measures) were derived through literature review. A preliminary study was conducted by interviewing five experienced personnel (Table 1) to validate the clarity, relevancy, appropriateness of the questionnaire's contents and the findings were rationalized with the information from the literature review in order to generate the final questionnaires.

Table 1. Profile of respondents interviewed during preliminary study

Organization	State	Designation	Year of Working Experience
G6	Perlis	Project Manager	5
G6	Kedah	Project Manager	15
G7	Pulau Pinang	Site Engineer	7
G7	Pulau Pinang	Site Engineer	10
G7	Kedah	Contract Department Manager	20

Table 1 indicates that the interviewed respondents possessed extensive working experiences and sufficient technical background in handling construction project, ranging from 5 to 20 years. The respondents are senior employees of their companies and hold non-executive, executive, and managerial positions. From October to January 2016, a cover letter and 100 questionnaires were distributed to the targeted companies, comprising approximately 5% of the total population of the survey target that remains active in handling projects. During interview, respondents were asked to describe the companies they worked for, along with their role, working experience, and type of project they were previously involved in over the past 10 years. Sections B, C, D, and E consist of close-ended questions using a five-point Likert scale (1= strongly disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly agree), were then analyzed using the average index (AI) technique as shown in Eq. 1.

$$AI = \frac{\text{Number of response count } (n) \times \text{weight of answer choice } (n)}{\text{Total number of respondents}} \quad \text{Eq. (1)}$$

RESULTS AND DISCUSSIONS

General Company's Background

For Section A, approximately 70% of the respondents successfully answered and returned the forms. Of the respondents, 14% were from Perlis, 42% were from Pulau Pinang, and 44% were from Kedah, which had the highest percentage. The respondents involved in the survey possessed several years of experience in handling various types of projects. Table 2 summarizes the respondents' profile who participated in the survey.

Table 2. General company's background

Parameters	Frequency	Percentage
Organisation Type		
G6	17	24.3
G7	53	75.7
Designation Type		
Project Manager	16	26
Site Engineer	28	30
Contract Department Manager	13	21
Site Supervisor	5	9
Quantity Surveyor	8	14
Projects Type		
Civil and structure	65	94.3
Mechanical and electrical	1	1.4
Telecommunication	3	2.9
Project management	1	1.4
Year of working experiences		
1-5	17	26
6-10	8	17
10-20	20	27
More than 20	25	30

Key Risk Factors

Section B show the key risk factors considered by contractors (Table 3), with an AI value of 4.10 (SD =1.01), "Delayed progress payment by client" ranks first among the economic and financial factors explored. Although this point is related with clients' decision-making inefficacy, it may also be caused by the existing trend in the Malaysian construction industry, that is, the government sector remains the biggest client. In the public sector, progress payment must go through a series of authoritative approvals that may disrupt the construction progress. In this case, the effect on a mega project is significantly higher, especially when financial resources required generally go beyond what consortiums can handle. Delaying the payment request of contractors can cause financial overburden on the contractor who must fulfill their obligations toward subcontractors, suppliers, technical staff, and laborers. This delay may create a major "knock-on" effect on cash flow, thus affecting the financial stability of the entire chain. Accordingly, subcontractors may stop onsite work, suppliers may restrict subsequent deliveries, and technical staff and laborers may quit their current employment to pursue new jobs in other firms. Replacing contractors during project execution is also costly. The results obtained are supported by Goh and Abdul-Rahman (2013), whose research involved the identification and management of major risks in the construction industry in the states of Selangor, Kuala Lumpur, and Johore.

"Project value" is ranked second (AI value = 3.87, SD=0.79), almost all respondents agreed unanimously. This perception is true for G6 and G7 contractors because project value plays a crucial role in the success of the physical execution of construction work. Adequate project value appraised by the client is critical, especially in minimizing cost overrun while maintaining cash flow, achieving the best quality work, and ensuring financial stability to avoid project failure. "Market condition" is the third major risk considered, with an AI value of 3.84 (Table 3). The instability and inflationary rate of a country contribute to the local construction materials unavailability, which leads to price fluctuation, therefore significantly reflected in the increasing materials costs, labor, machinery, and other supplementary materials and services.

For political and legal key risk factors, "Changing contract terms and clauses" and "Delay in permits and licenses approval," with an AI value of 3.70 (SD=0.99), are the first-ranked risk factors considered by respondents. A change in contract terms is defined as work, processes, or methods that digress from actual plans and specifications. Frequent distraction and work redirection, associated with changes in instructions, not only prolong construction plans but also reduce the time available for labor activities, require additional procurement planning, and potentially lead to disputes and litigations. The consequences of this risk factor are related to social, political, cultural, and environmental influences. The increase in the development of complex and big projects, such as the longest multi-purpose SMART tunnel in Asia, has attracted a joint venture pact from international engineering designers and construction companies in 2003. Many of these foreign groups lack adequate experience in the social, political, cultural, and physical environments of Malaysia, thus resulting in continual changes to the plans, specified materials, and contract terms and conditions. These changes are likely caused by private sector clients who do not directly take part in various design projects stages. Thus, changes in contract terms are demanded after physical implementations are completed.

Table 3. Four types of key risk factors

Key risk factors	Rank	AI values	Standard Deviation (SD)
Economic and financial			
Economic instability	4	3.72	0.95
Global inflation	6	6.12	0.86
Local market condition	3	3.84	0.97
Project value	2	3.87	0.79
Delayed progress payment by client	1	4.10	1.01
Exchange rate fluctuation	7	3.57	1.00
Penalty caused by extending project duration	5	3.64	0.87
Political and legal			
Change in law and regulation	3	3.67	0.88
Public disorder	6	3.36	0.95
Local authority or government interference	4	3.65	0.84
Delay in permits and licenses approval	2	3.69	1.01
Corruption issue	5	3.60	1.13
Changing contract terms and clauses	1	3.70	0.99
Delay in solving contractual issues	1	3.70	0.98
Design and construction stage			
Type of project	2	3.83	0.88
Shortage of equipment and materials	3	3.80	0.84
Inexperienced worker assigned	5	3.66	1.01
Error in scheduling	8	3.41	0.91
Change in scope of work	6	3.52	0.86
Defective design	4	3.97	0.89
Weather issue	7	3.48	0.97
Errors and omissions in design drawings, inadequate drawings and technical specifications, and uncoordinated design disciplines	1	3.89	0.83
Safety and environmental			
Poor site management	2	3.84	0.97
Water quality issue	7	3.29	1.05
Poor geological and geotechnical site conditions	1	3.91	1.03
Labor disputes	5	3.47	1.04
Pollution issue	6	3.73	0.96
Accident	3	3.76	1.01
Incomplete or wrong environmental analysis	4	3.52	0.91

"Delays in permits and licenses approval" is perceived as one of the most dominant construction risk factors. Important approvals are often required mostly from professional engineering consultants (architects, engineers, and building draftsmen) after the completion of physical developments on a construction site. An example is the certificate of completion and compliance introduced by the Malaysian Street, Drainage and Building (Amendment) Act 2007. The inefficient approval process by these groups can be detrimental to project completion; such inefficiency is due to the consultants' hierarchical approval structure and the limited authority vested in consultants' staff, especially those at the supervisory levels, to approve completed work in accordance with standard industry practices. One classic case is the Murum hydro project in Sarawak, which commenced in 2008; the explosives supply to the site presented an early difficulty because of the tight regulations in Malaysia and delays in receiving the permit to use explosives (Pattle and Foster n.d.). This factor is a source of claim by contractors because they are responsible for obtaining permits.

"Errors and omissions in design drawings, inadequate drawings and technical specifications, and uncoordinated design disciplines," including architectural, structural, plumbing, mechanical, and electrical or complex design schemes, is ranked first (AI value = 3.89, SD=0.83) in the design and construction stage category; continuous requests for information and clarification are required, and thus constantly interrupt the construction progress. Consultation firms in Malaysia had slowly changed their practice design codes from British Standards to Eurocode, but most contractors continued to follow the former. Feasible alterations may be required in design documents, significantly causing immoderate delays in response to the contractor's application for information, which, at the same time, disrupts related work and rework, thereby postponing construction operations.

With an AI value of 3.91 (SD=1.03), "Poor geological and geotechnical site conditions" ranks first in the safety and environmental category. Unforeseen geological conditions and associated geotechnical risk are primary contributors to cost and schedule overruns (Ghenbasha et al., 2016), especially in large civil engineering projects. Despite many attempts to solve these situations by incorporating various clauses and terms in contracts, the problem persists. Unpredictable geological conditions cannot be blamed for all the cost and schedule delays. The basic difficulties faced by a designer in predicting geological and technical risks in the construction of highways, long underwater or hilly terrain tunnels, offshore industries, or dam foundations lie in the inadequate information gathered from site investigation.

Hoek and Palmiere (1998) discussed variations in the cost versus the exploration borehole length ratio to tunnel length; they highlighted that inadequate core drilling for geological investigation resulted in project cost increases in 84 tunnels around the United States. The cost of making a drilling plan and mobilizing equipment reaches several million dollars and can exceed preliminary cost estimates when the needed time is also considered. Despite comprehensive site investigation, some parameters are undetected, which eventually results into problems during project implementation. Numerous projects that have been designed to incorporate a proper interpretation of geological and geotechnical information are later summarized as completely inadequate. Only by luck and the assistance of an experienced and cooperative contractor can a project be finished with relatively few disruptions, schedule delays, and cost overruns.

Factors Causing Risk

Section C show the key risk factors causes from the respondents' perspectives (Table 4), with an AI value of 4.30 (SD=0.71), most of them agreed that "Lack of communication" between all parties involved in a project is the primary cause of risk. Communication underlies many of the methods discussed by the respondents, which include communication between different departments, formalized review procedures, and direct lines of communication between all major players in a project to help resolve matters before they turn into disputes. A basic part of communication is a transparent assessment of accurate conditions and concerns on a project. This step assures that all parties involved in the project recognize that reporting issues immediately, fully, and honestly helps the entire team to solve them.

Table 4. Factors causing risk

Factors causing risk	Rank	AI values	SD
Lack of communication	1	4.30	0.71
Financial viability (budget and overruns) are not identified	2	4.06	0.95
No consideration by company on its ability to deliver the quality of work required within the duration and budget	5	3.81	0.93
Unclear scope of work	4	3.78	0.98
Influences of third parties as multiple stakeholders and political interest	6	3.69	0.73
Lack of information on risk and responsibility	3	3.97	0.85

The CIDB, which is responsible for planning the direction of the industry, summarized in its planning report for 2006–2015 that construction project failures are due to contractors as well as multiple participants, such as architects, engineers, designers, subcontractors, and suppliers (CIDB, 2006). Thus, the project success depends on the effort of each member, because unsatisfactory work or rework by one party can cause significant failure of the entire project. Satisfaction of all parties is also central to maintaining the cohesiveness and level of teamwork needed for accomplishing a project. Additionally, overruns in the schedule of government projects in Malaysia are caused not only by the poor performance of the builders but also by the lack of communication between participating parties, inadequate client finances, and late provisions of technical drawings by the design engineer.

The attitudes of the participants during project are crucial in determining communication efficiency, collaborative work, and service quality. Fully transparent communication is difficult to achieve unless prioritizing risk mitigation is incorporated into the culture of companies. Enhancing understanding and trust among project parties is also beneficial in increasing the satisfaction levels of all parties, and thus solving many hidden problems during construction.

Current Risk Management Implementation

Section D discusses current risk management implementation among the respondents (Table 5). "Best practices implementation for risk management onsite," with an AI value of 3.80 (SD=0.97), ranks first. Compared with the five other stages of the project life cycle, that is (i) feasibility, (ii) design, (iii) tendering, (iv) construction, and (iv) handling and maintenance, the construction stage is recognized as the project stage with the highest risk frequency because it always involves many investments and stakeholders and takes a long execution time (Goh and Abdul-Rahman, 2013). More unpredicted events, such as physical (e.g., weather, earthquake, flood, etc.) and safety risks (e.g., accidents, falls, vehicle crashes, etc.), take place during the construction stage than in the five other stages.

Table 5. Current risk management implementation

Current risk management implementation	Rank	AI values	SD
Risk management consideration at different project stages	3	3.43	0.94
Risk classification before participating in bidding	2	3.54	0.96
Use of partner risk assessments and third party reviews	6	3.03	0.96
Risk management on perceived economy	5	3.12	0.92
Effective risk management to increase the competitiveness of company	4	3.35	1.01
Best practices implementation for risk management onsite	1	3.80	0.97

"Effective risk management implementation" (AI value = 3.35, ranked fourth) remains rhetorical among Malaysian contractors because of insufficient knowledge, lack of experience in analysis techniques, and difficulty in finding the probability risk distribution. In common practice, subjective judgment utilizes the experience gained from similar past projects by the decision maker in deciding the likelihood of risk exposure and outcomes. Judgment and experience may become the most useful information source in case of limited time and few resources for preparing the best practices for risk management at construction site. The approach of local contractors in risk analysis is largely based on the use of a checklist by the site manager (Ayob et al., 2018), who attempts to think of all possible risks. For these contractors, risk implementation at construction site (ranked-first, Table 5) should focus on events with a large likelihood of occurrence and significant effect. They also feel that the effective implementation practices for risk management needs considerable time, which does not suit the Malaysian culture that is perpetually in a fast pace.

Construction is subjected to a dynamic environment, which is why risk managers for all parties involved must constantly strive to enhance their estimates. However, decision making about risk at near perfect estimates is a daunting task. A previous study by Enshassi et al. (2008) showed that in the Gaza Strip, 39% of the contractors attempted to shift the consequences of accidents to insurance firms, 42% were willing to bear these consequences, and 19% wanted to share these consequences with the project owner. The existence of an insurance premium for site employees can also mitigate risk consequences of accidents and injuries. Contractors should deliberately exert additional effort to mitigate the costs of accidents and other after effects by employing effective tools and training and effective practices in the management of safety precautions (Shaari et al., 2016; Zaki et al., 2016). Poor practices of risk management reflect the weakness and incompetence of contractors, which, in long run, significantly affect the cost, work quality, and time performance.

Risk Mitigative Measures

Section E discusses the mitigative measures of the key risk factors (Table 6), where majority of the G6 and G7 contractors decided to "Ensure effective site management and good contractor supervision," with an AI value of 4.29 (SD=0.69). Managing a site can be complicated and lead to more risks, higher costs, and longer downtime in high-ticket projects. With a construction boom underway, construction companies are often maxed out in terms of experienced project managers and engineers. Contractor companies need to improve the knowledge and abilities of managers and engineers, which are crucial in the successful completion of projects (Nawi et al., 2012). Good supervision and experience matter, particularly for large projects. Officers can be stationed full time at the project site during critical periods. Notwithstanding, no contractor wants to lose its job. Accordingly, many projects are being led and managed by inadequately trained and inexperienced personnel, which inevitably causes site, claims, disputes, and termination problems.

Table 6. Mitigative measures of key risk factors

Mitigative measures of risk	Rank	AI values	SD
Enhance the communication	4	4.18	0.86
Include a clause for delays and additional payment in contract	6	3.73	0.92
Accurate economical and financial information from client	7	3.65	0.89
Engaging in activities that reduced the litigation likelihood	8	3.48	0.79
Rigorous risk assessment implementation and mitigation processes	9	3.39	0.87
Ensure that site investigations are completed and carried out according to procedure	5	4.01	0.74
Good planning and scheduling by contractors according to schedule	3	4.19	0.80
All design work is according to the standards and rules recognized by the authorities	4	4.18	0.70
Ensure that site workers are experienced and have obtained a CIBD Greed Card	2	4.26	0.84
Ensure effective site management and good contractor supervision	1	4.29	0.69

Thus, contractors have to adopt important innovative management techniques, including organizing and controlling, team building, and value engineering, which may be more efficient and effective than those currently employed. Quarterly meetings with all subcontractors may be needed to evaluate work performance, findings of site monitoring and auditing, comments from statutory authorities, employer status, and concerns and complaints from relevant parties, such as the public and nearby residents. Implementing these techniques can, more or less, guarantee the mitigation of critical risk factors, such as delays, costs, overruns, and termination.

CONCLUSION

Based on the contractors' perspectives, "Delayed progress payment by client," "Changing contract terms and clauses," "Delay in solving contractual issues," "Errors and omissions in design drawings, inadequate drawings and technical specifications, and uncoordinated design disciplines," and "Poor geological and geotechnical site conditions" are the key risk factors considered by construction companies. A great improvement in project performance is likely to be attained by emphasizing on managing these five major risk factors. Accordingly, these types of risks are caused by "Lack of communication" between all parties, which considerably affect the progress of a project in terms of costs, time, and quality. The questionnaires results indicate that many companies in the local construction industry do not practice effective risk management. "Best practices implementation for risk management onsite" is the most popular practice because it includes brainstorming and checklists, which often highly rely on subjective knowledge and experiences. The sole use of checklists cannot be considered as a formal risk management procedure. A systematic risk management implementation is noteworthy because informal risk management has been unsuccessful in providing useful risk-reporting for future project reference. Finally, "Ensure effective site management and good contractor supervision" is chosen as the mitigative measure for successful risk management. The findings of this study can provide an in-depth understanding of risk management and may lead to the development of a reasonable control measure for risk factors not only during construction activities but also along the development of the design phases of projects. The results can further support the goal of achieving an acceptable level of competitiveness and cost-effective operation. Future studies would be conducted to investigate risk management implementation in other states of Malaysia and to highlight the relationship between the resources invested in risk management and improvement in performance such as quality, cost, schedule, safety, productivity and client satisfaction, as well as the underlying causal relationship between the risk management implementation and performance improvement.

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REFERENCES

Abdul-Rahman, H., Wang, C. and Mohamad, F. S. (2015) Implementation of risk management in Malaysian construction industry: Case studies. *Journal of Construction*, 192742

Akintoye, A. S. and Macleod, M. J. (1997) Risk analysis and management in construction. *International Journal of Project Management*, 15(1):31-38

Ayob, A., Shaari, A. A., Zaki, M. F. M. and Munaaim, M. A. C. (2018) Fatal occupational injuries in the Malaysian construction sector – causes and accidental agents. IOP Conf. Ser.: Earth Environ. Sci. 140, 012095

Byung, K. G., Mohamed, A.F., Boon, H. G., Myung, K. S. and Cheng, Z. (2015) Current practice of risk management in the Malaysia Construction Industry – The process and tools/techniques. *International Journal of Structural and Civil Engineering Research*, 4(4):371-377

CIDB, (2006) *Construction Industry Master Plan 2006-2015,* Construction Industry Development Board (CIDB) Malaysia

Enshassi, A., Mohammed, A. and Abu Mosa, J. (2008) Risk management in building projects in Palestine: Contractor's Perspective. *Emirates Journal for Engineering Research,* 13(1), 29-44

Flanagan, R. and Norman, G. (1993) *Risk management and construction*, Oxford: Blackwell

Ghenbasha, M, Omar, W. M. S. W. and Ayob, A. (2016) Causes of construction delay in developing countries: A theoretical review. *The 1st International Conference on Invention & Design (ICID),* Kuala Lumpur Convention Centre, Malaysia

Goh, C. S. and Abdul-Rahman, H. (2013) The identification and management of major risks in the Malaysian construction industry. *Journal of Construction in Developing Countries*, 18(1):19-32

Hoek, E. and Palmieri, A. (1998) Geotechnical risks on large civil engineering projects - *Proceedings of the 8th Congress IAEG, eoas.ubc.ca*

Hwang, B-G., Zhao, X. and Toh, L. P. (2014). Risk management in small construction projects in Singapore: Status, barriers and impact. *International Journal of Project Management*, 32, 116-124

IHS Global Insight (2013) *Global Construction Outlook: Executive Outlook.* Retrieved 21st November, 2016,https://www.ihs.com/pdf/HIS-Global-Construction-ExecSummary-Feb2014, 40852110913052132.pdf

Jarkas, A. M., and Haupt, T. C. (2015) Major construction risk factors considered by general contractors in Qatar. *Journal of Engineering, Design and Technology*, 13(1):1656-194

Jin, X., Zhang, G., Lui, J., Feng, Y. and Zou, J. (2017) Major participants in construction industry and their approaches to risks: A theoretical framework. *Procedia Engineering.* 182, 314-320

Mills, A. (2001). A systematic approach to risk management for construction. *Structural Survey,* 19(5):245-252.

Nawi, M. N. M., Lee, A., Kamar, K. A. M. and Hamid, Z. A. (2012) Critical Success factors for improving team integration in industrialised building system (IBS) construction projects: The Malaysia Case. *Malaysian Construction Research Journal,* 1(1):45-62

Pattle, A. and P. F. Foster, Sarawak's hydro projects—building a better future with renewable energy, *IPENZ Proceedings of Technical Groups,* 37/1(LD)

Rahman, I. A., Memon, A. H. and Karim, A. T. A. (2013) Significant factors causing cost overruns in large construction projects in Malaysia. *Journal of Applied Sciences,* 13(2):286-293

Rostami, A., Sommerville, J., Wong, I. L. and Lee, C. (2015) Risk management implementation in small and medium enterprises in the UK construction industry. *Engineering, Construction and Architectural Management*, 22(1):91-107

Serpella, A. F., Ferrada, X., Howard, R. and Rubio, L. (2014) Risk management in construction projects: A knowledge-based approach. *Procedia-Social and Behavioural Sciences*, 119, 653-662

Shaari, A. A., Zaki, M. F. M., Muhamad, W. Z. W. and Ayob, A. (2016) Safety of Precast Concrete Installation for Industrialised Building System Construction. *International Journal of Applied Engineering Research*, 11(13):7929-7932

Smith, N. J., Merna, T. and Jobling, P. (2006) *Managing risks in construction project,* Blackwell Publishing, London, UK

Yusuwan, M. M., Adnan, H. and Omar, A. F. (2008) Clients' perspective of risk management practice in Malaysian construction industry. *Journal of Politics and Law,* 1(3):121-130

Zainon, A., Ayob, A., Munaaim, M. A. C., Zaki, M. F. M. and Elyas, S. F. (2016) Bid evaluation strategy among G7 construction companies in northern states of Malaysia. *Research Journal of Fisheries and Hydrobiology*, 11(3): 24-30

Zaki, M. F. M., Muhamad, W. Z. A., Ayob, A. and Suhaimi, M. Q. (2016) Preliminary study on safety during precast concrete installation in IBS construction. *Global Journal of Pure and Applied Mathematics*, 12(3):2367-2373

HUMAN AND INFORMATION TECHNOLOGY/ INFORMATION SYSTEM (IT/IS) IMPLEMENTATION SUCCESS FACTORS IN CONSTRUCTION INDUSTRY

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Abstract
Mobile computing, cloud computing and social connectivity are the three big trends materializing across multiple industries that promote effective information exchange. Being in the information-intensive industry, it is crucial for the construction organisations to embrace Information Technology/ Information System (IT/IS) to remain competitive. Failure to access accurate, complete and timely information will make the organisation unable to deliver the best result in the most productive manner. Many researchers have highlighted the IT/IS implementation failure due to the human factor. To deal with this issue, this study aims to identify the human factor that influence the success or failure in IT/IS implementation. An initial list of 23 human factors was identified from the literature review and a preliminary interview with seven Malaysian companies representing a variety of construction industry participants and IT experts. This was followed by a main study comprising a questionnaire survey of 311 construction industry practitioners including contractors, developers, construction material suppliers as well as a diverse range of construction consultancy practice which include architect, engineers and quantity surveyors. Data obtained were analysed using the Relative Importance Index, mean and the Spearman Correlation Coefficient. The analytical result revealed 7 factors as having the greatest impact on the success/failure of IT/IS implementation. The implication of the findings implies that organisation should consider the identified factor as crucial in maximising the probability of success in IT/IS implementation.

Keywords: *IT/IS success; human and IT/IS; IT/IS implementation*

INTRODUCTION

Previously, every task involved in construction industry was performed manually which took months or even years to complete. In 1980's, only several constuction companies starting to used personal computers (Núria, 2005). In late 1980's, CAD was used to support creation and viewing of data and this is followed by the introduction of 3D-CAD in the mid 1990's which was used for designing (Froese, 1999). According to Tam (1999), the World Wide Web (WWW) had been introduced for the commercial uses in 1993, but the applicationis limited to the static web pages which allows sharing of information without limits. During this period, communicating via e-mail and sharing of documents become common in construction industry (Froese, 1999). Over the years, the static web pages had evolved into an interative pages and it become the main source of information for everyone. Virtual Reality (VR) was introduced in the early 2000 (Li, 2010), and its application is not limited to design space and space modelling but also for interior design, fire risk assesment, site layout and planning and others. Since 2006, Software-as-as-Service (SaaS) has becoming accepted in construction idustry and this technology is used a lot in cloud computing (Zainon et al., 2011). The usage of cloud computing benefited the construction industry in various aspects such as structural analysis, cost estimating, project planning and also architectural design.

The information-intensive nature of the construction industry has resulted in IT/IS as essential elements for many construction businesses and operational processes. The usage of IT/IS in this sector can assist in achieving firms strategic objectives (Lin et al., 2007; and Nessa et al., 2010). Many organisations have increased their annual IT/IS investments (Bravo et al., 2014) in order to obtain the benefits of technology as already discussed by many scholars Zakaria et al. (2013); and Latiffi et al. (2014).

Unfortunately however, there are numerous example of IT/IS implementation failures are reported (Dwivedi et al., 2015). Researchers looking for the causes of failures have identified human factors as a core explanation (Hartmanna & Fischer, 2009; Kim & Kankanhalli, 2009). Given the use of IT/IS, organisation need to better understand the weaknesses in managing human so as to successfully implement IT/IS. It is held that most organisations failed to obtain the full benefits of IT/IS because they overlooked this factor. Being the major asset in every organisation, human has a strong influence on the success or failure in implementing IT/IS and therefore, greatest awareness of the human factors may help such organisations to successfully implement IT/IS. Many human factors are described in the scholarly and professional literatures but do they differ in their relative perceived importance?

In Malaysia, IT/IS has become the major components of the country's 5 years development plan (Haron & A. T., 2015) . In supporting the development of IT/IS in this country, large amount of resources and funds have been allocated by the government. Several institutes were developed such as the Malaysian Institute of Microelectronic Systems (MIMOS), the National Information Technology Council (NITC), The Multimedia Super Corridor (MSC) and the Malaysia Communication and Multimedia Commission (MCMC). All of these institutes were developed for the same purpose which is to provide ideal environment and infrastructure for IT/IS related activities in the country. Even with the strong support from the Malaysian government, the implementation of IT/IS in the country is still far behind. Research carried out by the Malaysian Productivity Corporation (MPC) in 2009 to identify the organisation readiness to use e-commerce revealed that only 17% of the organisations applied e-commerce transaction. While 35% of them believed that e-commerce is not suitable for them and another 32% admitted that they do not have the required knowledge to use it. Another 10% of the organisations indicated financial factor as the barrier to adopt e-commerce (Abdul Rahim, 2010; Hashim & Said, 2011). Zakaria et al. (2010), highlighted that organisations in Malaysia fail to implement IT/IS because they are not ready.

Despite the potential use of IT/IS, little attention has been given to examining the human factors that influence the successful implementation of IT/IS in the construction industry context (Sidawi, 2012; and Xue et al., 2012). To rectify this situation, this study aimed to identify the human related success factors. In doing this, an initial list of 23 potential factors was identified from the literature review and a preliminary study with seven Malaysian companies representing a diversity of construction industry players and IT experts. This was followed by a main study comprising a questionnaire survey of 311 construction industry practitioners including contractors, developers, construction suppliers as well as a diverse range of construction consultant which include architect, engineers and quantity surveyors.

IDENTIFYING THE HUMAN FACTORS: A LITERATURE REVIEW

The reviewed involved eighty three (83) existing journal articles on human factors in IT/IS implementation across industries. Twenty one (21) human factors were identified and illustrated in Table 1 below.

Table 1. General list of human factors that contribute to IT/IS implementation failure

FACTORS	NO OF CITATIONS
Motivation	6
Training/ skills	16
Top management support	22
Communication	17
Knowledge and experience	14
Leadership/ IT Leader	8
Willingness to process change	7
IT staff roles & responsibility	6
Organisational culture	11
Commitment	6
Management style	6
User involvement	10
Attitude	7
Team work/ Collaboration	8
Interest in IT	3
Staff behaviour towards IT/IS	5
Awareness	4
Focus and vision	4
Trust	5
Interpersonal relationship	2
Satisfaction	8

METHODOLOGY

Pilot Study

The pilot study was conducted to ascertain the extent to which the factors gathered from the literature are relevant to construction industry practices. Data collected during the pilot study focused on the human factors that have influence on the success and failure experienced by each organisation. Seven construction organisations were selected to participate in the pilot study. The selected construction organisations were from different areas of the construction industry-construction consultancy practice, contractor, material supplier and developer. All the selected organisations have an IT department. The participant mixture provided a diverse set of views and perspectives from the various professionals involved in the industry. Semi-structured interviews were employed to reflect the reality of the current situation. This allowed rich collection of data in terms of experience and perception through probing the conversation in detail, where the collected data cannot be measured in quantitative approach. Major questions were developed in the form of a general statement which was then followed by a sequence of sub-questions for further probing. The method allows the researcher to explore and clarify relevant comments made by the respondents. It also allows researcher and respondent to discuss important issues relevant to the study.

Interview sessions were undertaken with the seven (7) IT/IS managers from seven (7) construction organisations. The interviews took place in the interviewees' office and lasted between 40 to 60 minutes. The interviews were tape-recorded to secure an accurate account of the conversations and avoid losing data since not everything can be written down during interview. The semi-structured interview included sections on the following key areas; organisation background and history, reasons for adopting the IT/IS, details of IT/IS and issues in implementing IT/IS (CSFs).

The initial list of 21 human factors identified from the literature review was presented to the interviewees for confirmation and comments. All the factors were accepted as being reasonable representation of the main issues involved in implementing IT/IS in Malaysia.

Main study

Data collection

In the next phase of research, a questionnaire survey was designed using the list of 23 human factors to identify the most important perceived success factors in IT/IS implementation in Malaysia. Respondents were asked to rate the 23 human factors based on five-point Likert-type scales that vary from 1= not important to 5= extremely important. Prior to distributing the questionnaires, a content validity process was carried out involving thorough discussion with the pilot study members and several IT academicians to examine whether the instrument was relevant and representational for the purpose of this study.

Potential questionnaire respondents' organisations were selected from various databases in order to ensure diversity of view of IT/IS human success factors in Malaysia. In this research, the targeted respondents are General Manager, IT Directors, IT Managers, IT professionals and other personnel holding IT-related management level positions.

General respondent's demographic

The largest number of respondents came from integrated services (referring to an organisation that provide several services such as construction, trading, manufacturing, quarry and others) (17.7%), followed by surveying firms (17.4%), construction developer and architecture firm (13.8%), sub-contractors (8.4%), contractors (7.4%), civil and structural firms (5.1%), suppliers(1.6%) and other organisations (government, semi-government, highway concessionaires) at 7.7%, as shown in Figure 1.

Regarding the respondents' occupation, Figure 2 indicates that majority of respondents are IT Manager or Head of IT/IS Department (75.2%), followed by General Managers (8.4%), Senior IT/IS Management (11.3%) and IT/IS Executives (5.1%).

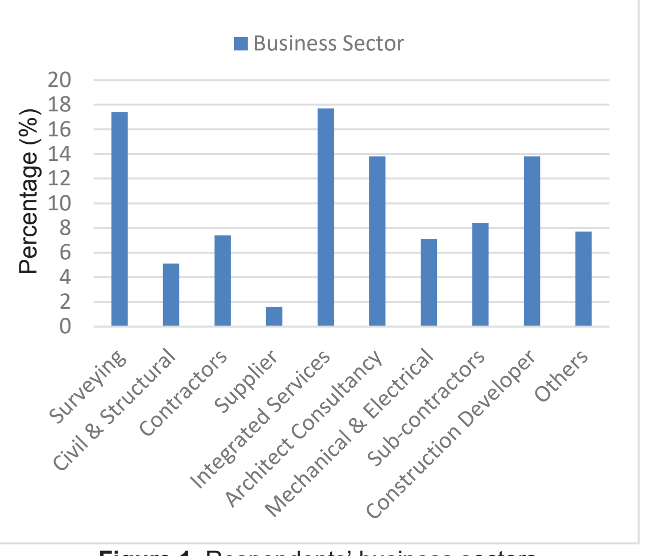

Figure 1. Respondents' business sectors

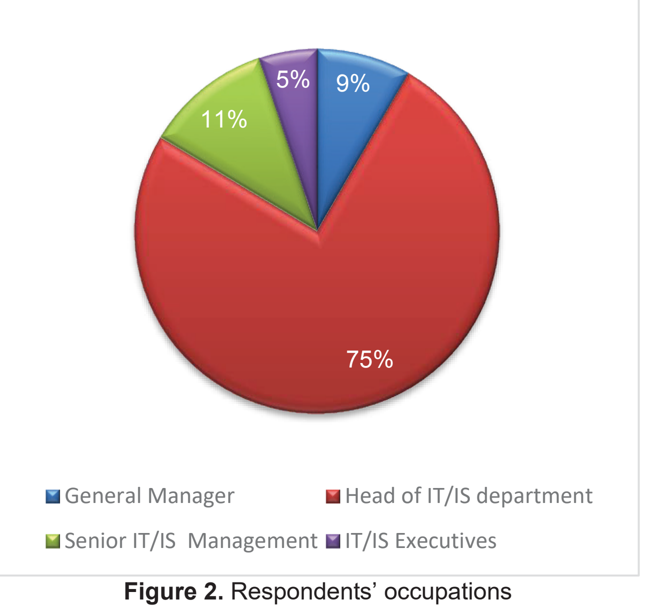

Figure 2. Respondents' occupations

Data analysis

The perceived importance of the factors are measured through a 5-point Likert scale with graded item responses ranging from "1 –Not Important" to "5 - Extremely Important", hence the issues are treated as ordinal variables. The relevant non-parametric tests were used encompass of mean and Relative Importance Index (RII) for data ranking and supported by Spearman's Rho correlation coefficient. A combination of these tests has been widely used by many researchers previously in the process of identifying factors (Leung & Wong, 2008; Otchere et al., 2013).

Relative Importance Index (RII) and mean were used to rank the factors. The RII was calculated using the following formula:

$$RII = (\sum W)/AN \quad (1)$$

W is the weighting given for each factors by the respondents range from 1 to 5, A is the highest weight (5 in this case) and N is the total number of sample (in this case N=311).

Factors that have a very high influence on the successful implementation of IT/IS were then shortlisted based on the RII value of more than 0.7 (Ezzat Othman & Harinarain, 2012; Park, 2009) and a mean value of more than 3.5 (Famakin et al., 2012; Okotie, 2012). The correlation for these factors was then tested to identify their relative importance. For this, Spearman's rho correlation coefficient was selected as it is a common non-parametric method used for correlating factors (Filed, 2009), where

$$\rho = 1 - \frac{6\sum d_i^2}{n\left(n^2 - 1\right)} \quad (2)$$

with $\sum d^2$ being the sum of the squared differences between the pairs of ranks and n the number of pairs. Using a standard table of probabilities, p, for , the usual criterion is adopted in that $p<0.05$ denotes a significant correlation of the respondents' rating of the IT/IS success factors.

The employment of such a test produces a mathematical value that exhibits the strength of a linear relationship between the factors.

ANALYSIS AND FINDINGS

A total of 311 completed questionnaires were received giving a total response rate of 31.1%. The responses received covered the whole range of business sector in Malaysia, where majority hold IT related management-level positions, with majority (75.2%) being Head of IT/IS Department. This is beneficial as managerial perspectives are important to provide valid evaluation of strategic measures, due to their technological background and IT familiarity. Over half (60%) of the respondents are also very experienced, with more than 10 years working experience in IT, while only 8% have less than 5 years working experience. This shows that the response received meet the targeted respondents and represents Malaysia.

Cronbach’s alpha coefficients (α) for the 23 human factors are in between 0.854 to 0.870- indicating the reliable and a high internal consistency. According to Hung et al., (2010), when α is greater than 0.7, the factor is considered reliable.

The results of these descriptive analyses and ranking of the factors are shown in Table 2. The central tendency of the distribution or the mean is in the range from 4.08 to 2.22, while the standard deviation value is in the range of 0.926 to 0.638. All factors involved in this analysis have a relatively normal distribution since the skewness ranged values do not exceed the absolute value of -1 to +1. The factors were then ranked using mean and RII formula.

Table 2. Descriptive analysis and ranking of human factors

Factors	Mean	RII	Rank
Top Management Support	4.084	0.817	1
User involvement	4.003	0.801	2
Motivation	3.907	0.781	3
Training/skills	3.897	0.779	4
Willingness to process change	3.897	0.779	4
Management style	3.691	0.738	6
IT Staff roles & responsibilities	3.637	0.727	7
Leadership/IT Leader	3.473	0.695	8
Commitment	3.463	0.693	9
Knowledge & experience	3.444	0.689	10
Awareness	3.389	0.678	11
Organisational culture	3.379	0.676	12
Teamwork/collaboration	3.360	0.672	13
Communication	3.302	0.660	14
Focus & vision	3.186	0.637	15
Personal Characteristic	2.984	0.597	16
Trust	2.823	0.565	17
Attitude	2.650	0.530	18
Interest in IT	2.605	0.521	19
Satisfaction	2.437	0.487	20
Employee behaviour towards IT/IS	2.367	0.473	21

Results from this test were interpreted by correlation coefficients (r). The value of r shows the strength of the correlations between two factors. When the value of p is at 5% level, it shows that the variables have a strong correlation (Filed, 2009). The null hypothesis versus the alternative hypothesis used in this study was:

H0: p (two-tailed) > .05 – the factors are not significant
H1: p (two-tailed) < .05 – the factors are significantly correlated

If the p value is more than 0.05, it means that the factors are significantly correlated. If the significant level is greater than 0.05, the hypothesis will be rejected and vice versa. Based on the above hypothesis, all factors are strongly correlated to each other. Any changes to motivation, training/skills, senior management support, willingness to process change, IT staff roles and responsibilities, user involvement and management style may have a significant effect on the success of IT/IS implementation. Table 3 presents Spearman's rho correlations among the seven factors, indicating all factors to be significantly positively correlated.

DISCUSSION

Based on the above analysis, seven human factors are identified as significantly related to the successful IT/IS implementation in Malaysia. These findings support the earlier research findings by Davis and Songer (2008); Daojin (2010); Limsarun and Anurit (2011); Doom et al. (2010); Tambovcevs (2010); Hung et al. (2010); Gorla and Lin (2010); and Rezaei et al. (2009).

Top management support was ranked first by the respondents. This factor is the most important element and is widely accepted as the compulsory element for IT/IS implementation (Abbaszadeh et al., 2010; Daojin, 2010). This factor is critical because top management is responsible in providing all the necessary resources such as financial assistance and manpower needed during the implementations of IT/IS in any organisation. Any system cannot be effectively implemented when there is a lack of support from the top management. This is consistent with findings from Palanisamy et al. (2010) in North America, involving 183 organisations which also identified top management support as the most influential factor to IT/IS acquisition. This finding is also supported by research carried out by Ifinedo (2008), involving 44 organisations in Finland and Estonia, which highlighted the significant relation between top management support and IT/IS success. Having a strong top management support is critical in every organisation. Their roles are not only limited to encouraging employees to use the system, but also ensuring its effective usage and implementation (Pollaphat & Miroslaw, 2011).

Table 3. Results of Spearman's Correlation Coefficients

		(1)	(2)	(3)	(4)	(5)	(6)	(7)
Motivation (1)	ρ	1.000	. 450	.467	.516	.314	.448	.379
Training/skills (2)	ρ	-	1.000	.486	.425	.322	.401	.280
Top Management Support (3)	ρ	-	-	1.000	.423	.342	.368	.292
Willingness to process change (4)	ρ	-	-	-	1.000	.372	.477	.323
IT Staff roles & responsibilities (5)	ρ	-	-	-	-	1.000	.282	.341
User involvement (6)	ρ	-	-	-	-	-	1.000	.164
Management style (7)	ρ	-	-	-	-	-	-	1.000

Legend:

ρ = Spearman's correlation coefficient
Significance (p) = 0.00
N = 311

The second most important factor was user involvement. User involvement is defined as the participation of actual users of the application in the development process (Havelka, 2002). This is an important factor as it requires users to use their skills, experience and knowledge to successfully implement IT/IS. This will give them the authority in making decisions, controlling their own work and being more responsible (Evans & Lindsay, 2002), thus developing a sense of ownership (McGill & Klobas, 2008). A strong feeling of ownership may increase users commitment and lead to a positive impact to successfully implement IT/IS (Havelka, 2002). It is suggested that organisations should consider the involvement of users in decision-making process due to its impact on IT/IS success rates (Habib, 2009; Lind & Culler, 2009). Indeed, a survey among 65 worldwide organisations conducted by Raman et al. (2006), revealed that lack of user involvement may affect the IT/IS utilisation leading to implementation failure.

The third factor identified by this study was motivation. This factor may be considered a driving force in achieving objectives. According to Davis and Songer (2008), strong motivation can overcome many difficulties in using new technologies. As new technologies are usually more complex, highly motivated users may adopt the new system more effectively. Therefore, managers should take initiatives to motivate users to use IT/IS. Motivating users is important as it may affect staffs reactions towards the usage of organisational system. According to Nahar et al. (2006), motivation can be improved by understanding organisational cultures, identifying needs and preference, as well as offering rewards.

Training/skills and willingness to process change shared the same value of relative index (0.779) and a mean value (3.897). The importance of training/skills in successful IT/IS implementation has been highlighted by previous researchers (Buruncuk & Gülser, 2001; and Raj et al., 2011). Appropriate training helps users to understand a system and to use the system effectively. According to Limsarun and Anurit (2011), training can be regarded as a way of educating and motivating staff to use IT/IS in their respective organisations. It also helps users to understand their new roles and responsibilities, thus creating effective environment for IT/IS implementation (Abbaszadeh et al., 2010). According to Ooi et al. (2010), training enables creation of an environment that will encourage users to use IT/IS within an organisation. Chang et al. (2010) studied 87 samples of 4 real estate organisations in Taiwan revealed that adequate training and skills enabled efficient usage of IT/IS among users. On the other hand, a study by Ranjan and Bhatnagar (2009) showed that users' willingness to process change has major influence on whether or not IT/IS system is successfully implemented. A concern is that users will naturally refuse to change due to habits they acquire over time; the resistance exists because a new system involves changes of user behaviour (Peansupap & Walker, 2005). This suggests that major action should be taken by such organisations to overcome this problem to improve efficiently, including ways to encourage users to change as such changes are beneficial in enabling users to perform their work effectively, giving clear advantage to such organisations. Davis and Songer (2008), suggested that individuals higher up the organisational hierarchy are more willing to change comparatively as they have the authority to adjust to the changes to suit their requirements.

Ranked at number six is management style. Management style refers to the approach used by the management to organise, influence and control human activities to achieve organisational objectives (Rezaei et al., 2009). The importance of management style in successfully implementing IT/IS has been highlighted by many researchers (Erdogan et al., 2008; and Xue et al., 2012) due to the fact that management style has indeed influenced the organisations' performance by facilitating internal behaviour consistency (Rahman & Kumaraswamy, 2005). Research findings by Lu and Wang, (1997) and Hussein et al. (2007), revealed that management style has a positive relationship with IT/IS implementation success. Gorla and Lin (2010) also stated that good management has the ability to lead to successful implementation of IT/IS. The survey among the agricultural industry in Iran regarding the impact of organisational factors on management information success by Rezaei et al. (2009) revealed that management style is highly correlated with IT/IS success.

IT staff roles and responsibilities is ranked at number seven. IT staff includes the IT manager, programmer, technician, analyst; who are responsible for maintaining, developing and implementing all IT/IS related activities within an organisation. The successful implementation of IT/IS depends on the roles and responsibilities of IT staff. Without them, it is difficult for organisations to implement new technologies. Findings from a survey in the health industry in Taiwan conducted by Hung et al. (2010), showed that the higher adoption rate of IT/IS in organisations will increase in parallel to the roles and responsibilities of IT/IS staff. This indicates that the adoption of IT/IS in an organisation is equivalent to the roles and responsibilities of IT/IS staffs.

CONCLUSION

The relative importance of human factors in determining the success or otherwise of IT/IS implementation in business has received much attention from researchers and practitioners over the years. An extensive literature review supported by interview with selected representatives from Malaysia has identified 23 human factors. Findings from this study shows the most important human factors are perceived to be motivation, training/skills, top management support, willingness to process change, IT staff roles and responsibilities, user involvement and management style.

This catalogue of human factors is a helpful addition to the wider literature but also offers a significant contribution to this subject especially in Malaysia. Identification of this list on its own however was not considered sufficient in contributing to improve IT/IS implementation, thus a survey was used to rank those factors to determine the most important. This study thus provides insights in a number of ways. First, a deeper appreciation of the perceived relative importance of human factors in the successful implementation of IT/IS can assist the higher education sector and professional bodies to identify relevant learning outcomes and skills requirements. This may require development of ongoing training needs. Second, given the ranking, this reveals that management style and training/skills are important as IT/IS skills per se. Indeed it appears to be the 'softer' or 'cultural' qualities that are critically important with user involvement, willingness to process change identified as important attributes for personnel. This highlights that training and support is important depending on one's role and responsibility. This means that human resources need to be sensitive of different training and support needs. Third, the ranking offers insights into how organisations may need to provide enough support for their staffs when investing in IT/IS facilities.

This study also has significant implications for managers by identifying the priorities among human factors so as to help the organisations maximise the probability of success. Thus, this will further enhance the manager's knowledge on the human factors and help organisations to identify possible difficulties and eventually to enable them to avoid the potential risks. The findings can also serve as a guideline for the organisations and form the basis for their future planning. Furthermore, human factors framework or model can be devloped which can be used by specific system such as for Enterprise Resource Planning (ERP), Database Management System (DBMS), Building Information Modelling (BIM) and others.

REFERENCES

Abbaszadeh, M. A., Ebrahimi, M., & Fotouhi, H. (2010, 2-4 Nov. 2010). Developing a causal model of critical success factors for knowledge management implementation. Paper presented at the International Conference on Education and Management Technology (ICEMT).

Abdul Rahim, Y. (2010). Overview of e-Commerce Adoption among SME in Malaysia. Paper presented at the Seminar dan Pameran Sistem Penyelesaian Elektronik, Grand Dorsett Subang.

Bravo, E. R., Santana, M., & Rodon, J. (2014). Information systems and performance: the role of technology, the task and the individual. Behaviour & Information Technology, 33(1), 1-14.

Buruncuk, G., & Gülser, Z. G. (2001a). Factors Affecting Implementation of Information Systems' Success and Failure, Department of Management Information Systems. Bebek 34342, Istanbul/Turkey: Bo_aziçi University.

Chang, K. C., Lie, T., & Fan, M. L. (2010). The impact of organizational intervention on system usage extent. Industrial Management & Data System, 110(4), 532-549.

Daojin, F. (2010, 10-11 July). Analysis of critical success factors in IT project management. Paper presented at the 2nd International Conference on Industrial and Information Systems (IIS), Dalian, China.

Davis, K. A., & Songer, A. D. (2008). Resistance to IT change in the AEC industry: An individual assessment tool. ITcon, 13, 56-68.

Doom, C., Milis, K., Poelmans, S., & Bloemen, E. (2010). Critacal success factor for ERP implementations in Belgium SMEs. Journal of Enterprise Information Management, 23(3), 378-406

Dwivedi, K., Wastel, D., Laumer, S., Henriksen, H. Z., Myers, M. D., Bunker, D., Elbanna, A., Ravishankar, M. N., Srivastava, S. C. (2015). "Research on information systems failures and successes: Status update and future directions." Information Systems Frontiers 17(1): 143-157.

Erdogan, B., Anumba, C. J., Bouchlaghem, D., & Nielsen, Y. (2008). Collaboration environments for construction: implementation case studies. Journal of Management in Engineering, 24(4), 234–244.

Evans, J. R., & Lindsay, W. M. (2002). The Management and Control of Quality (5th ed.): Thomson South Western.

Froese, T. (1999). Interwoven threads: Trends in the use of information technologies for the construction industry, A white paper prepared for the Berkely-Stanford CE&M Workshop

Gorla, N., & Lin, S.-C. (2010). Determinants of software quality: A survey of information systems project managers. Information and Software Technology, 52(6), 602-610.

Habib, Z. (2009). The Critical Success Factors in implementation of Software Process Improvement Efforts:CSFs, Motivators & Obstacles. University of Gothenburg, Gothenburg, Sweden.

Haron, A. T., Abdelmuniem, A. F. E., (2015) " A Study On Construction Industry: Building Information Modeling Current Issues " , International Journal of Management and Applied Science (IJMAS) , pp. 124-126, Volume-3, issue-4, Spl. Iss-3

Hartmanna, T., & Fischer, M. (2009). A process view on end user resistance during construction IT implementations. Journal of Information Technology in Construction.

Hashim, N., & Said, I. (2011, October 17-18). Exploring E-business applications in the construction industry: Issues and challenges. Paper presented at the Annual Summit on Business and Entrepreneurial Studies (ASBES 2011), Kuching, Sarawak.

Havelka, D. (2002). User Personnel Factors That Influence Information System Development Success. Paper presented at the IACIS 2002, Fort Lauderdale, Florida.

Hung, S.-Y., Hung, W.-H., Tsai, C.-A., & Jiang, S.-C. (2010). Critical factors of hospital adoption on CRM system: Organizational and information system perspectives. Decision Support Systems, 48(4), 592-603.

Hussein, R., Abdul Karim, N. S., Mohamed, N., & Ahlan, A. R. (2007). The influence of organizational factors on information systems success. Electronic Journal on Information Systems in Developing Countries, 29.

Ifinedo, P. (2008). Impacts of business vision, top management support, and external expertise on ERP success. Business Process Management Journal, 14(4), 551-568.

Kim, H. W., & Kankanhalli, A. (2009). Investigating end user resistance to information system implementation: A status quo bias perspective. MIS Quarterly, 33(3), 567- 582.

Latiffi, A., Mohd, S., & Brahim, J. (2014). Application of Building Information (BIM) in the Malaysian Construction Industry: A story of the First Government Project. Applied Mechanics and Materials, ISSN: 1660-9336.

Li, M. (2010). Applications of virtual reality technology in construction industry. Paper presented at the 2nd International Conference on Computer Engineering and Technology (ICCET) 2010.

Limsarun, T., & Anurit, P. (2011). The Different Perspective of Managerial and Operational Level toward Customer Relationship Management Practice in Thailand. Journal of Management Research, 3(1).

Lin, C., Pervan, G., & McDermid, D. (2007). Issues and recommendations in evaluating and managing the benefits of public sector IS/IT outsourcing. 161-183.

Lind, M. R., & Culler, E. (2009). The Relationship Between Information Technology Critical Success Factors and Project Performance. Proc Conisar, 2, 1-10.

Lu, H.-P., & Wang, J.-Y. (1997). The relationships between management styles, user participation, and system success over MIS growth stages. Information & Management, 32(4), 203-213.

McGill, T., & Klobas, J. (2008). User developed application success: sources and effects of involvement. Behaviour & Information Technology, 27(5), 407-422.

Nahar, N., Lyytinen, K., Huda, N., & Muravyov, S. V. (2006). Success factors for information technology supported international technology transfer: Finding expert consensus. Information & Management, 43(5), 663-677.

Núria, F. M. (2005). Life cycle document management system for construction.

University Politechnic of Catalunya, Catalunya

Ooi, K. B., Cheah, W. C., Lin, B., & Teh, P. L. (2010). TQM practices and knowledge sharing: An empirical study of Malaysia's manufacturing organizations. Asia Pacific Journal of Management.

Palanisamy, R., Verville, J., Bernadas, C., & Taskin, N. (2010). An empirical study on the influences on the acquisition of enterprise software decisions: A practitioner's perspective. Journal of Enterprise Information Management, 23(5), 610-639.

Peansupap, V., & Walker, D. H. T. (2005). Factors enabling information and communication technology diffusion and actual implementation in construction organisations.

Pollaphat, N., & Miroslaw, J. S. (2011). Success factors for the implementation of web-based construction project management systems: A cross-case analysis. Construction Innovation: Information, Process, Management, 11(1), 14-42.

Rahman, M. M., & Kumaraswamy, M. M. (2005). Relational selection for collaborative working arrangements. Journal of Construction Engineering and Management, 131(10), 1087–1098.

Raj, K., Dixit, G., & Garg, T. K. (2011). TQM success factors in North Indian manufacturing and service industries. The TQM Journal, 23(1), 36-46.

Raman, P., Wittmann, C., & Rauseo, N. (2006). Leveraging CRM for sales: The role of organizational capability in successful CRM implementation. Journal of Personal Selling & Sales Management, 26(1), 39-53.

Ranjan, J., & Bhatnagar, V. (2009). Principles for successful aCRM in Organizations. Direct Marketing. An International Journal, 2(4), 239-247.

Rezaei, A., Asadi, A., Rezvanfar, A., & Hassanshahi, H. (2009). The impact of organizational factors on management information system success: An investigation in the Iran's agricultural extension providers. The International Information & Library Review, 41(3), 163-172.

Sidawi, B. (2012). Management problems of remote construction projects and potential IT solutions: The case of Kingdom of Saudi Arabia. Journal of Information Technology in Construction, 17, 103-120.

Tam, C. M. (1999). Use of the internet to enhance construction communication: Total Information Transfer System. International Journal of Project Management, 17(2), 107-111.

Tambovcevs, A. (2010). ERP System Implementation: A Case Study Of The Construction Enterprise. Economics And Management, 15, 1092-1098.

Xue, X., Shen, Q., Fan, H., Li, H., & Fan, S. (2012). IT supported collaborative work in A/E/C projects: A ten-year review. Automation in Construction, 21(0), 1-9.

Zakaria, M. S., Janom, N., & Yaakub, N. I. (2010, 24-27 August). An e-Commerce Readiness Model for SMEs : A Malaysian Experience. Paper presented at the International Research Symposium in Service Management, Le Meridien Hotel, Mauritius.

Zakaria, Z., Mohamed-Ali, N., Haron, A. T., Marshall-Ponting, A. & Abd- Hamid, Z. (2013). Exploring the adoption of Building Information Modelling (BIM) in the Malaysian construction industry: A qualitative approach. International Journal of Research in Engineering and Technology, 2(8), 384-395.

Zainon, N., Rahim, F. A., & Salleh, H. (2011). The Information Technology Application Change Trend: Its Implications for The Construction Industry. Journal of Surveying, Construction and Property.2: 6- 20, 2011

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AN ANALYSIS OF CLIENTS' CONTRIBUTION IN PURCHASING ACTIVITIES AND THE IMPACT TOWARDS QUALITY CONSTRUCTION

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Abstract
Clients' contribution in the purchasing process is important because it affects the budget and the quality of construction products. Construction industry is widely seen as unpredictable in terms of quality, standards, and budgets. Improvements on the purchasing process make a significant contribution to the quality of construction industry. Therefore, it is essential to the clients, to contribute on the activities in the purchasing process and look at the right ways of delivering construction products with a good quality. Professionals are correspondence to researchers that the different in quality of construction materials has become an issue in improving the quality. Therefore, the solution to the quality of construction products lies in formal issues of clients' contribution during materials and suppliers selection in the purchasing process. This research attempts to identify the clients' contribution in the material purchasing activities, to determine the impact on theirs' contribution and to determine the relationship between clients' contributions and the impact towards construction quality. An extensive literature review was done to analyse the general issues related to the construction environment and purchasing process, at large. Preliminary survey was conducted with the representatives from construction organisations, to obtain information on clients' contribution in the purchasing activities and their significant involvement towards quality construction. The results show that the client does contribute in certain purchasing activities, and their contributions indirectly give impact to the quality of construction. Therefore, clients' contribution in the purchasing activities will guarantee the quality of the construction environment.

Keywords: *Clients' Contribution; Purchasing Activities; Quality; Construction*

INTRODUCTION

The construction industry always been observed with unpredictable issues in-terms of costs, quality standard of the construction products and time consuming (Hernandez, 2005), high fragmentation in nature, instability of site condition, low productivity of construction outputs, poor quality implementation and lack of standards and proper procurement system. This issues is due to the facts that each project has different condition of site location, personnel characteristics, design of the construction products, type of materials, weather condition, cost and time (Metri, 2005). Moreover, construction industry has a unique characteristic that related to the nature of uncertainty such as natural uncertainty, task uncertainty, organisational uncertainty, and contractual uncertainty. These uncertainties give client dissatisfaction, both private and public sectors (Hernandez, 2005; and Walker, 2002).

On the other hand, the construction materials achieve their value by considering the operational system, integrate with equipment and men and the basis of quality of material is based on quality of work. The good quality of materials can be guaranteed by quality control during the purchasing process (Wei Jia, 2012). Wang Fei and Wang Shileii (2010) justify that purchasing material is important because with a proper material price within good quality and quantity and time, will lead to good project performance, enhance the organizations economy, social and national economic benefits etc. Improved quality of a product or process will contribute towards more efficient and effective use of resources; resulting faster, better and easier work (Deming, 1993).

The largest part of current capital and production costs is contributed by purchasing of materials (Qiwen Jiang et al., 2010). Purchasing can be categorised into two roles; sourcing direct materials that relate to the main activity of the firm, and obtain indirect supplies, used in running the firm's support activities which can be divided into three levels: materials value, suppliers' value, and social value (Huanhuan Gou et al., 2011). However, Giannakis (2004) divided purchasing into six areas; research and development, financial planning and control, human relations, supply, conversion and distribution.

Studies shows that 75% of total revenue for construction companies is for purchasing material and services costs and Boverket (2005) stated purchases of material contribute to 40% of the contract sum. Therefore, the purchasing has a great impact on cost effectiveness as well as quality and time in construction. At the same time, Raja Palaniandy (2011) discovered that there is a connection between monetary problem and quality issues. It is critical for all construction organization to maintain an efficient and effective material procurement to cut excessive and unnecessary cost and obtain materials at the right cost, time and quality (Steven Ling, 2011). However, most of the construction players tend to sacrifice the significant of quality product that lead to declining of the construction quality in gaining the cost savings.

MATERIAL PURCHASING PROCESS AND CLIENTS' CONTRIBUTION

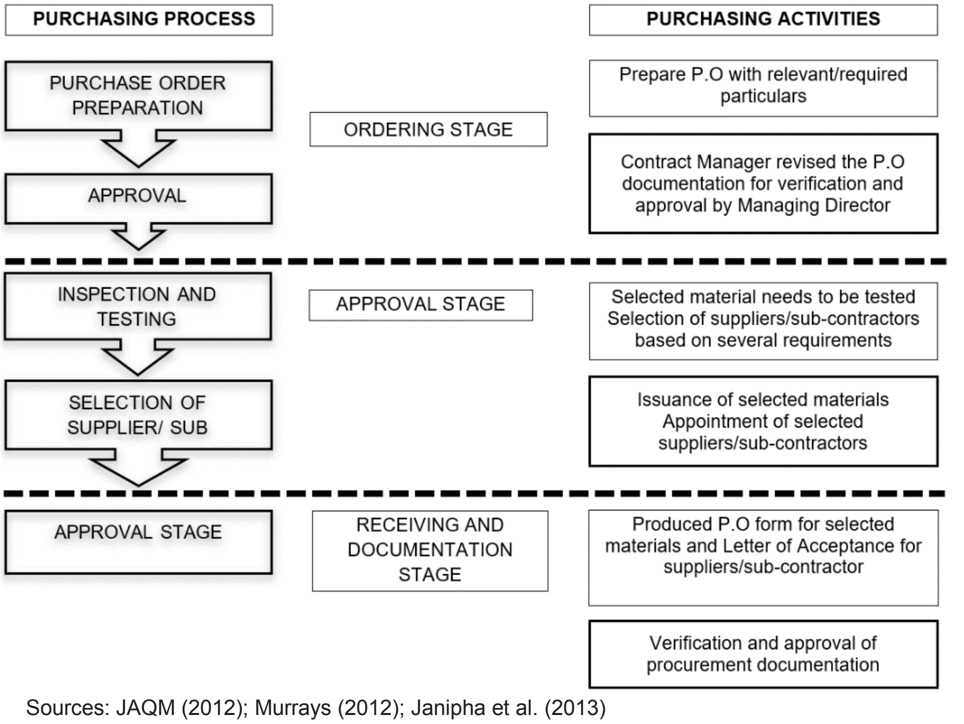
Purchasing has become an important activity to construction organisation (Jordan Academy for Quality Management, 2012). Due to the current market condition, the enhancement of productivity and quality is very important to build a sustainable local construction industry. In order to enhance productivity, there is a need to take a holistic approach to reviewing factors impacting the construction industry (Ibrahim et al., 2010). Moreover, the quality of the materials or components supplied by suppliers has an impact on the quality of final construction product or services (Chin Keng & Abdul Rahman, 2011).

Purchasing process is a process consists of the negotiation period between the purchaser and the supplier from the first communication to the final stage of signing the contract (Murray, 2013). Thus, the purchasing process quality directly affected the quality of the supply chain. Furthermore, purchasing process is the process of obtaining the best evaluated costs within the level of quality and services, minimise the risk and liability to any exposure, maximise the economies of volume (Loyola University, 2012), increase the strategic decision of supply chain and influence the companies' achievement (Karpak et al., 2001).

In order to face the challenges of the twenty-first century, the Malaysian construction industry must compete through continuous productivity improvement, more value added operations and enhanced product quality. Consequently, the construction material wastage showed the cost of materials exceeded 50 percent of the construction cost and one of the reasons is material order not meeting the specification and requirements (Ibrahim et al., 2010). (JAQM, 2012; Wu et al., 2010; Murray, 2012; Janipha and Ismail, 2013) highlighted the general issues of quality and purchasing. Moreover, quality in material purchasing process is an essential factor to increase the construction output, improve the performance and production cost and increases the quality of construction resources. The main issue of quality in Malaysian construction industry is contributed from materials supply by the suppliers (Janipha and Ismail, 2013). Additionally, Emiliani (2010) stated that the issue of purchasing is the process was usually viewed as non-specialized knowledge area that could be performs by almost any person with little or no training. Jun et al. (2012) mentioned that the level of quality purchasing has a direct relationship to the level quality of supply chain. To reinforce the quality of the purchasing process, the management of organisation is important to ensure the quality of products and to meet clients' requirements. Therefore, construction players should have serious responsibilities in delivering quality construction products to the clients, and it is essential to emphasis it through the purchasing process (Raja Palaniandy, 2011).

The collaboration with client especially on large project is crucial in purchasing process. The clients' contribution will lead on the purchasing experience and adding the purchasing value (Tufts University, 2013). In general, when the purchasing departments are looking at the procurement of materials from suppliers they will have been given some guidance, research and development, which include a variety of information about the material to be purchased (Murray, 2012). Thus, clients' contribution during this process seems to adding up input to the decision on selection to be made.

The common elements that need to be considered in the material purchasing process basically reflected the flow of material purchasing process. On the other hand, the material purchasing process comprises of four phases; requisition ordering, approval and receiving and documentation stage (JAQM, 2012; Murray, 2012; Janipha et al., 2015). Each phase has several purchasing activities started from the first communication to the signing of the contract. Figure 1 shows the purchasing activities in the material purchasing process.



Sources: JAQM (2012); Murrays (2012); Janipha et al. (2013)

Figure 1. Purchasing Process and Activities

RESEARCH METHODOLOGY

This research aims to identify and determine the clients' contribution in the material purchasing activities for Malaysian construction industry. The information and opinions sought from the respondents are mainly directed towards determining and establishing the following objectives, as refer in Figure 2.

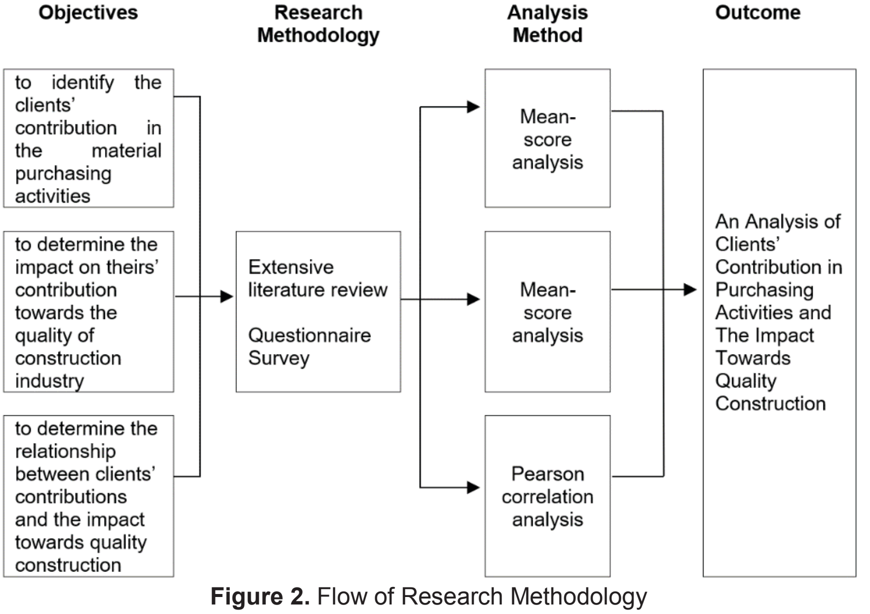


Figure 2. Flow of Research Methodology

To obtain general information on the related quality and material purchasing process issues in the construction industry, an extensive literature review was done. The activities in material purchasing process and the impact factors to the construction quality were outlined.

Additionally, to support the information in the Malaysian construction industry scope, a questionnaire survey was done. A total of 50 questionnaires were distributed amongst clients from public and private sectors, in Klang Valley. The public client refers to Public Work Department (PWD) and Semi-Government Agencies, while private clients encompasses of developers and consultants as clients' representatives.

The sampling was done based on simple random sampling. It is divided into two (2) main sections; (1) clients' contribution in purchasing activities and (2) the impact towards construction quality. For the first objective, there were eleven activities involved in the material purchasing process. A five-point Likert scale was used to measure the activities (1: least contribution to 5: highly contribute). For the second objectives, there were nine impacts were outlined for this research, and similarly five point Likert-scales were used to measure the items (1: least impact to 5: highly impact).

The data for both objectives were analysed using SPSS software. The Descriptive Statistic: Frequencies-Mean-score method was used to achieve the objectives. Later, to identify the relationship between these two objectives, the bivariate-correlation was used.

FINDINGS AND DISCUSSION

The clients' contribution in the material purchasing process activities

Table 1 indicates the clients' contribution in the material purchasing process activities. There were eleven activities involves, comprises of; Requisition Stage (1. Receive Purchase Order (P.O) form, 2; P.O verification and approval by Construction Head), Ordering Stage (3. Prepare P.O with relevant/required particulars; 4. Contract Manager revised the P.O documentation for verification and approval by Managing Director), Approval Stage (5. Selection of suppliers/subcontractors based on several requirements; 6. Selected material need to be tested; 7. Issuance of selected materials; 8. Appointment of selected suppliers/subcontractors) and Receiving and Documentation Stage (9. Produced P.O form for selected materials; 10. Verification and approval of procurement documentation; 11. Produced Letter of Acceptance for suppliers/subcontractor).

Table 1. The clients' contribution in the material purchasing process activities

Purchasing Activities	Mean Score	Std. Deviation
Receive Purchase Order (P.O) form	1.900	1.2096
P.O verification and approval by Construction Head	2.150	1.1367
Prepare P.O with relevant/required particulars	2.000	1.0760
Contract Manager revised the P.O documentation for verification and approval by Managing Director	1.750	1.0195
Selected material needs to be tested	3.800	1.0563
Selection of suppliers/subcontractors based on several requirements	3.900	0.9119
Issuance of selected materials	3.350	1.1821
Appointment of selected suppliers/subcontractors	2.450	1.2343
Produced P.O form for selected materials	2.000	1.0760
Produced Letter of Acceptance for suppliers/subcontractor	1.950	0.9986
Verification and approval of procurement documentation	3.700	0.9233

The highest contributions of clients in purchasing activities were testing of selected material and the selection of suppliers and/or sub-contractors, with a mean score of 3.800 (s=1.0563) and 3.900 (s=0.9119) respectively. Some of the materials required a submission of quality certification, testing records and certification to the clients before purchasing was made. However, there is a contradict outcome for selection of suppliers/subcontractors between current practices of purchasing and analysis. Current practices of purchasing usually allow main contractors to select their own supplier as compared to analysis, the clients' contribution in high for this activity. Another important contribution of client in purchasing process activities was verification and approval of procurement documentation (Mean Score = 3.700, s=0.9233) and the issuance of selected materials (Mean Score = 3.350, s=1.1821).

For the purchasing activities of appointment of selected suppliers and/or sub-contractor, P.O verification and approval by Construction Head, Prepare P.O with relevant/required particulars and Produced P.O form for selected materials, the respondents stated that the clients' contribution was at the moderate level. The mean score for each activity outlined were 2.450 (s=1.2343), 2.150 (s=1.1367), 2.000 (s=1.0760) and 2.000 (s=1.0760) respectively.

However, among all activities in the material purchasing process, the least contribution of the client was the revision of P.O documentation by Contract Manager for verification and approval by Managing Director, with a mean score of 1.750 (s=1.0195).

Clients' contribution is essential in the selection of material and suppliers during purchasing process to ensure the quality and standard of materials and construction output. Moreover, these purchasing activities are important to the clients since it affected the clients' budget to produce the construction output. In contrast, less contribution of clients for the revision of P.O documentation, verification and approval activities, due to the decision upon revision of P.O documentation was made by the top management of the construction companies.

Overall, there was clients' contribution throughout the material purchasing process activities. However, the clients' contribution was more to the selection of brands and type of materials to be purchased and the selection of suppliers and/or sub-contractors. Moreover, if stated in Bills of Quantities or Condition of Contracts for exceptional clauses, purchasing may be done by the clients' himself. Additionally, clients participate in factory visit, and this was to ensure the manufacturers' capability in producing the required material.

The impact factor of clients' contribution towards quality construction

Table 2. The impact factor of clients' contribution towards quality construction

Impact Factor	Mean Score	Std. Deviation
(C1) Meeting the required specification	4.250	0.7163
(C2) Overall construction cost saving	4.000	0.7947
(C3) More efficient and effective material procurement	4.000	0.9733
(C4) High quality of construction products	3.900	1.1192
(C5) High performance in the construction organisation	3.100	1.2096
(C6) Saving on the clients' budget and expenses	4.250	0.7864
(C7) Time factor; shorten length of procedure, on-time completion	3.350	0.9880
(C8) Improve supplier performance in terms of quality and delivery reliability.	2.150	1.1367
(C9) Improvement in a reduction of construction waste or production resources	3.400	1.0954

Table 2 indicated the impacts of clients' contribution in purchasing process activities which affecting the quality of construction industry. Referring to Table 2, most of the respondents indicated that clients' contribution in material purchasing process will ensure the material were within the required specification and lead to savings on the clients' budgets (Mean Score = 4.375, s=0.7163). This could be interpreted by clients usually done a manufacturing visit and indirectly ensuring the suppliers to follow the guidelines to achieve material requirements. Furthermore, the contribution of clients in material purchasing activities will give impact.

With a mean score of 4.000 (s=0.7947), the respondents stated that another high impact of clients' contribution in material purchasing process was cost saving for the overall construction productions. Since the construction output was based on clients' budgets, it will directly affect the overall construction cost. Other factors that give impact to the construction industry were more efficient and effective material procurement and high quality of construction products (Mean Score = 4.000, s=0.9733). Since the clients' contribution in purchasing activities was more to the selection of materials, their contribution gave great influence on the effectiveness of purchasing procurement and construction output.

Apart from high impact, there was few least impacts of clients' contribution that affects the quality of construction industry. The respondents indicated that high performance in the construction organisation (Mean Score = 3.100, s=1.2096) and improve supplier in terms of quality and delivery reliability (Mean Score = 2.150, s=1.1367), were the least impact to the clients' contribution towards quality of construction industry. This indicated that the client contribution in the purchasing process affected the performance and business objectives of construction organisation and suppliers.

Therefore, material purchasing process makes a significant contribution to control the quality of the organisation's resources, the clients' financial situation and the condition of construction final product. Material purchasing process is one of the essential elements to the construction industry. Hence, improving the quality of material purchasing process will ensure the final construction products are completed within the required time, cost and quality. The attitude of construction players including the client is related to the quality of construction works.

Since the quality of the construction material can be assured during material purchasing process, most of the clients and the construction organisations need to provide serious attention to the material purchasing process as to improve the quality of purchasing activities.

The relationship between clients' contributions and the impact towards construction quality

A Pearson correlation coefficient (Table 3) was computed to assess the relationship between the clients' contributions and the impact towards construction quality.

Table 3. The Relationship Between Clients' Contributions and The Impact Towards Construction Quality

Correlations											
		PA score	CI1	CI2	CI3	CI4	CI5	CI6	CI7	CI8	CI9
PA score	Pearson Correlation	1									
	Sig. (2-tailed)										
CI1	Pearson Correlation	-.267	1								
	Sig. (2-tailed)	.256									
CI2	Pearson Correlation	-.371	.277	1							
	Sig. (2-tailed)	.108	.236								
CI3	Pearson Correlation	-.501*	.075	.408	1						
	Sig. (2-tailed)	.024	.752	.074							
CI4	Pearson Correlation	-.322	.624**	.296	.580**	1					
	Sig. (2-tailed)	.167	.003	.205	.007						
CI5	Pearson Correlation	.077	.152	-.164	.224	.435	1				
	Sig. (2-tailed)	.747	.523	.489	.343	.055					
CI6	Pearson Correlation	-.594**	.631**	.505*	.138	.389	-.028	1			
	Sig. (2-tailed)	.006	.003	.023	.563	.090	.908				
CI7	Pearson Correlation	-.127	.390	-.067	-.328	-.062	-.031	.288	1		
	Sig. (2-tailed)	.593	.089	.779	.158	.796	.897	.218			
CI8	Pearson Correlation	.544*	-.372	-.291	.048	-.236	.218	-.515*	-.190	1	
	Sig. (2-tailed)	.013	.107	.213	.842	.317	.355	.020	.423		
CI9	Pearson Correlation	-.047	.201	.363	.000	.120	-.191	.122	.058	-.558*	1
	Sig. (2-tailed)	.844	.395	.116	1.000	.614	.421	.608	.807	.011	

*. Correlation is significant at the 0.05 level (2-tailed)

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

The results suggest that two (2) out of nine (9) correlations have a significant correlation at the 0.01 level (2-tailed) and one (1) correlation have a significant correlation at the 0.05 level. The correlation is significant at the 0.05 level, 2-tailed were between the clients' involvement in purchasing and the impact of improving the supplier performance in terms of quality and delivery reliability (CI8), r = .544, p = .013 and creates more efficient and effective material procurement (CI3), r= -.0501, p=.024.

Additionally, the two variables that have significant correlation at the 0.01 level (2-tailed) was between client's contribution in purchasing and the impact on saving on the clients' budget and expenses for the construction (CI6), r= -.594, p=.006.

In overall, the result suggests that by having clients' contribution in some purchasing activities, it tends to give beneficial impacts towards quality construction, particularly in savings clients' budget and to increase the business performance.

CONCLUSION

In general clients in the construction industry mainly involved in selecting and approving of major materials construction through samples and/or catalogues submitted by the proposed suppliers or sub-contractors. Material purchasing process involved with activities to purchase and sales of supplies. This process is done to achieve best practice, maximise the benefits of the system and to ensure the construction products being delivered to the client within the requirement.

Currently, clients' contribution in purchasing process is becoming more significant and strategic to decision making and has influence on the success of construction industry. The client contribution during the purchasing process is perceived to gives major impact in meeting the clients' required specifications, savings on the clients' budget and expenses and give value to the overall delivery products to the clients which lead to overall construction cost saving.

REFERENCES

Chin-Keng, T., & Abdul Rahman, H. (2011). Study of Quality Management in Construction Projects. 542-552

Deming, W. E., (1993). The New Economics for Industry, Government, Education. Cambridge University Press

Emiliani, M. (2010). Historical Lesson in PUrchasing and Supplier Relationship Management. *Journal of Management History.* , 116-136

Giannakis, M. (2004). The Role of Purchasing in the Management and Performance of Supplier Relationships: An Empirical Investigation in Service Organisations. University of Warwick

Hernandez, D. J. (2005). A Comparative Study of TQM Critical Success Factors in Manufacturing and Construction UK Industries. International Conference on Quality and Reliability, ICQR. 9-11 August, Beijing Institute of Technology, China. pp. 135-145

Huanhuan Gou, Zhenyuan Liu, Zheng Li. (2011). A Procurement Model with Material Purchasing Value Analysis in Construction Supply Chain. 2011 Chinese Control and Decision Conference (CCDC).

Ibrahim, A. R., Roy, M. H., Ahmed, Z. & Imtiaz, G. (2010). An Investigation of the Status of the Malaysian Construction Industry. *Benchmarking: An International Journal*, 17(2), 294-308.

Jordan Academy for Quality Management. (2012). *JAQM : Creating Quality Culture.* Retrieved July 11, 2012, from JAQM : Creating Quality Culture: http;//www.jaqm.net/QIPP.pdf

Janipha, N.A.I. & Ismail, F. (2013). Conceptualisation of Quality Issues in Malaysian Construction Environment. AMER International Conference on Quality of Life. 6-8 April 2013, Langkawi Pp. 53-61

Janipha, N.A.I. & Ismail, F. (2015). Clients' Involvement In Purchasing Process For Quality Construction Environment. Asia Pacific International Conference on Environment-Behaviour Studies. 24-26 February 2014, Sirius Business Park Berlin-yard field, Berlin. Pp. 53-61

Jun W, Mengya W, Lei Z., (2010). Improve the Quality Level of Purchasing Based on Six Sigma. ACPM Journal, Issue 92, pp.58-62

Karpak, B., Kumcu, E., & Kasuganti, R. (2001). Purchasing Materials In the Supply Chain : Managing a Multi-objective Task. . *European Journal of Purchasing and Supply Chain Management.* , 209-216.

Loyola University Chicago. (2012). Purchasing Manual and Procurement Procedure.

Metri, B. A. (2005). TQM Critical Success Factors for Construction Firms. Journal of Management. Vol. 10, No. 2, pp. 61-72

Murray, M. (2013). *About.com : Logistic/Supply Chain.* Retrieved January 3, 2013, from Logistic/Supply Chain: http://logistics.about.com/od/supplychaincasestudies/a/case_purch.htm

QiwenJiang, Weijun Zhong and Youyan Hu. (2010). The Construction of Conceptual Model of Working Capital Management based on SCM. Future Information Technology and Management Engineering (FITME), 2010 International Conference. 9-10 October. pp. 338 - 341

Raja Palaniandy, P. (2011). A Study on Factors Affecting Quality Deterioration in Housing Construction Industry in Klang Valley (A Case Study for Housing Construction Projects within Klang Valley). Master's Thesis. Open University Malaysia.

Steven Ling, H. K. (2011). Implementation of E-Procurement for Construction Material. Bachelor Degree Thesis. Universiti Teknologi Malaysia.

Wang Fei & Wang Shileii, (2010). Applying logistics to construction material purchasing and Supplier Evaluation. 2010 International Conference on System Science, Engineering Design and Manufacturing Informatization.

Wei Jia (2012). Application of Quality Control Techniques in Construction Projects. Advanced Materials Research Journal. Vols. 433-440,pp 1513-1518

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REVIEW OF THE TECHNIQUE APPLICATION IN CONCEPTUAL COST ESTIMATION FOR BUILDING PROJECTS: A BIBLIOMETRIC ANALYSIS

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Abstract
This paper presents the latest research development in conceptual cost estimation (CCE). The period is from 1995-2014. The methodology involves compiling all the relevant paper in the construction management related journals. Fifty-six relevant articles obtained from 18 major journals associated with construction management studies were successfully assessed. The four findings are: (1)trend of paper for CCE in building project show an upward trend with some fluctuations during the period; (2)the active contributors of the study in supplying analytical thinking and critical ideas are dominated by researcher from Turkey and Korea; (3) there is a clear positive trend for the papers that have applied quantitative approach which starts from 2005, whereas the papers applied qualitative approach began to steadily decrease; (4) the areas of cost factors that have increasingly higher growth affecting CCE are d*esign and project-specific factor*. Two broad recommendations are made to the field of study that researcher must select an appropriate historical data to be used for CCE and also each method is appropriate for certain individual situations.

Keywords: *conceptual cost estimation; building project; research trend; review; bibliometric*

INTRODUCTION

Conceptual Cost Estimation (CCE) is a fundamental in initial decision-making processes for construction project. The primary function of conceptual cost estimation is to tell the owner about the anticipated cost. It is also important for feasibility studies and impact upon final project success that can be used in project evaluations, engineering designs, cost budgeting, and cost management(Cheng et al., 2009; Cheng et al., 2010; Sonmez, 2004) or even to support bid price estimation (Gunduza et al., 2011; Wang et al., 2012).

Scholars in the construction area have thus been attracted to scrutinize the phenomena, explore method, and study the problem to improve the accuracy of cost estimation at early stage. Their contributions are to develop a systematic methodology for CCE, so as to standardize and facilitate the estimating process, making the approach more objective. In this way, the quality of the estimate produced can be more accurate and consistently developed.

Although, CCE in a building construction project is a difficult and generally a subjective process with no set standard of practice, so far, it appears to have been overlooked. Therefore the aim of this paper is to systematically analyze the findings of relevant manuscripts published in some selected journals. The objectives are to map the CCE studies and to identify their active contributors, including their countries and research center origin, and the common research methods adopted in the CCE studies.

CONCEPTUAL COST ESTIMATION METHOD

One of the purposes of CCE is to persuade key decision-makers whether to initiate or continue a project. However, essential information on the project is not sufficient at its early stages. Koo et al. (2011) suggested that it is very important to quickly, economically and accurately find particular information. The process of assumptions generate the cost of work activity or output by interpreting data or knowledge which is usually done by creating a cost model (Curran et al., 2004; Langmaak et al., 2013; Sonmez, 2011). Many researchers have studied various methodologies for predicting the cost in the initial phase with the use of limitation information. Various conceptual cost estimation methods and techniques have been done to calculate the conceptual cost estimation including neural network (Adeli & Wu, 1998; Creese & Li, 1995; Hegazy & Ayed, 1998; Kim et al., 2005) regression analysis (Kwak & Watson, 2005; Lowe et al., 2006) and case base reasoning (Chou, 2009; Koo et al., 2011; Marzouk & Ahmed, 2011). Some researchers also have integrated two of the above methods or techniques altogether (Gunduza et al., 2011; Sonmez, 2004; 2011).

Kim et al. (2004) said that regression or multiple regression analysis is very simple and powerful statistical methods that can be used as analytical and predictive techniques to examine the overall cost estimate reliability. Lowe et al. (2006) concurred that multiple regression analysis arrives at the result of a statistical analysis but its results are too linear to be used in a standardized model. On the other hand, it is not appropriate when describing non-linear relationships, which are multidimensional, consisting of a multiple input and output problem (Tam & Fang, 1999). Moreover, most of the parametric method has adopted the regression analysis (Ji et al., 2010).

A neural network is a computer system that simulates the learning process of human brain offering an alternative approach for cost estimation. Ahn et al. (2014) said that neural network can be more beneficial when involving intuitive judgment or when patterns of data become too irregular to be identified with traditional techniques. Moreover, the user does not need to exert too much effort to decide on the class of relations or the probability distribution of the variables (Sonmez, 2004). However, another study found the neural network is a black box technique and its process is time-consuming to determine the network factors that best fit the application (Adeli & Wu, 1998; Creese & Li, 1995; Hegazy & Ayed, 1998).

Another method or technique in conceptual cost estimation is Case Based Reasoning (CBR). In CBR systems, expertise is embodied in a library of past cases which contains a description of the problem, plus a solution and/or the outcome (Marzouk & Ahmed, 2011) or expert prototype system that compares historical data at the work item-level across the case library (Chou, 2009). According to Ahn et al. (2014); Marzouk and Ahmed (2011), a general CBR is able to modify, or adapt, a retrieved solution when applied in a different problem solving context. However, Watson (1997) in Ahn et al. (2014) stated the usefulness of CBR with complicated, structured symbolic data rather than purely numeric data.

To conclude regardless of which method or technique used, Riquelme and Serpell (2013) said that there is a need to select an appropriate historical construction data to be used for cost estimation. Therefore, this paper also aims to verify the correlation between the used of method or technique applied, with cost factors and historical data from similar project.

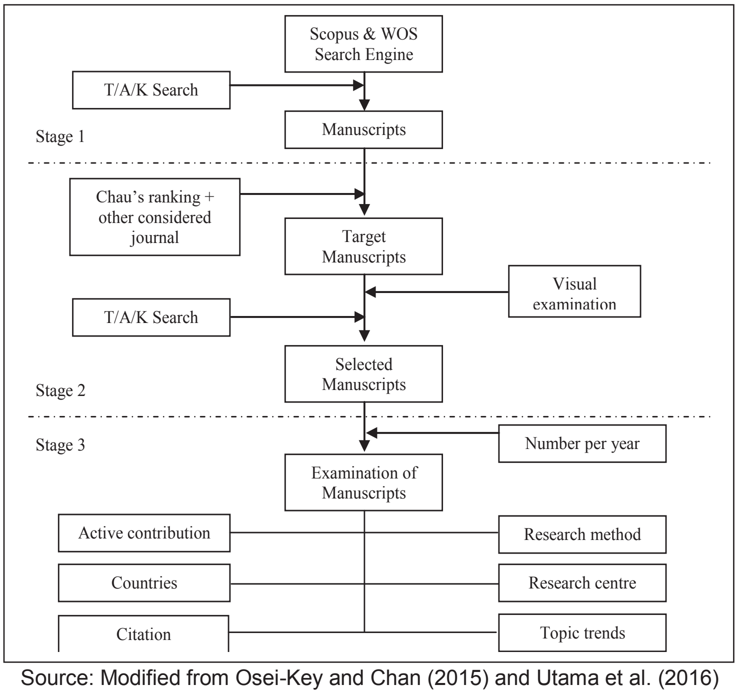
DATA AND METHODOLOGY

The data set concerns all publication as far as published in two main academic literature collections, Web of Science (WOS) and Scopus databases. Focusing only on the peer-reviewed contributions, this paper eliminated non- reviewed content (e.g., reports and books or book chapters). These databases are the most widespread databases on different scientific fields which are frequently used for searching the literature or specialized used for bibliometric data.

One of the problems related to select the scientific quality of journals is based on central assumption by the experience of author (Raan, 2005; Utama et al., 2015). However, according to Chau (1997), ranking of the top compressive live of journals highly recommended by most communities in the field that were selected. Therefore, the choice is based on the author's knowledge with a complete search encryption for databases on WOS and Scopus are given as follow:

> TITLE-ABS-KEY (*conceptual cost estimation OR cost estimation at early stage OR cost modeling for construction project OR estimating model for building project OR predicting project cost estimation) AND PUBYEAR AFT 1996 AND PUBLICATION TITLE (expert system with application OR international journal of project management OR automation on construction) TOPIC (model OR project OR cost OR project management) AND CONTENT TYPE (journal)*

Three filters were set (e.g. keyword, year and type of source) to ensure that it met the demand. All papers that had applied the qualitative and quantitative analysis techniques on CCE were selected from the related journals. Figure 1 presents the search process and Table 1 provides a breakdown of the total number of papers included in the study.



Source: Modified from Osei-Key and Chan (2015) and Utama et al. (2016)

Figure 1. The search processes

Table 1. Breakdown of the total number of selected papers by source and techniques applied

Journal Name	Number of papers	%
Journal of Construction Engineering and Management (JCEM)	11	19.64
Construction Management and Economics (CME)	8	14.29
International Journal of Project Management (IJPM)	7	12.50
Expert Systems with Applications (ESA)	6	10.71
Automation in Construction (AC)	4	7.14
Canadian Journal Civil Engineering (CJCE)	3	5.36
Building and Environment (BE)	3	5.36
Social and Behavioral Sciences (SBC)	3	5.36
Journal of Financial Management of Property and Construction (JFMPC)	1	1.79
Concurrent Engineering (CE)	1	1.79
Information and Software Technology (IST)	1	1.79
Facilities (F)	1	1.79
Technovation (T)	1	1.79
Journal of Manufacturing Science and Engineering (JMSE)	1	1.79
International Journal of Strategic Property Management (IJSPM)	1	1.79
Journal of Engineering, Design and Technology (JEDT)	1	1.79
Advances in Civil Engineering (ACE)	1	1.79
Journal of Computing in Civil Engineering (JCCE)	1	1.79
Total:	56	100
	Number of paper	%
Number (and percentage) of papers used qualitative approach	21	41.17
Number (and percentage) of papers used quantitative approach	30	58.83

DATA ANALYSIS AND RESULTS

Trend of Research Output on CCE

Preliminary retrieval of data from journal databases on CCE produced 196 articles. These appear in numerous journals publish from 1996-2015. In-depth review of the articles in selected journal, only 56 articles were truly relevant to CCE studies (refer to Table1). The statistical trend of annual number of relevant publication from 1996-2015 of selected journals is shown in Figure 2.

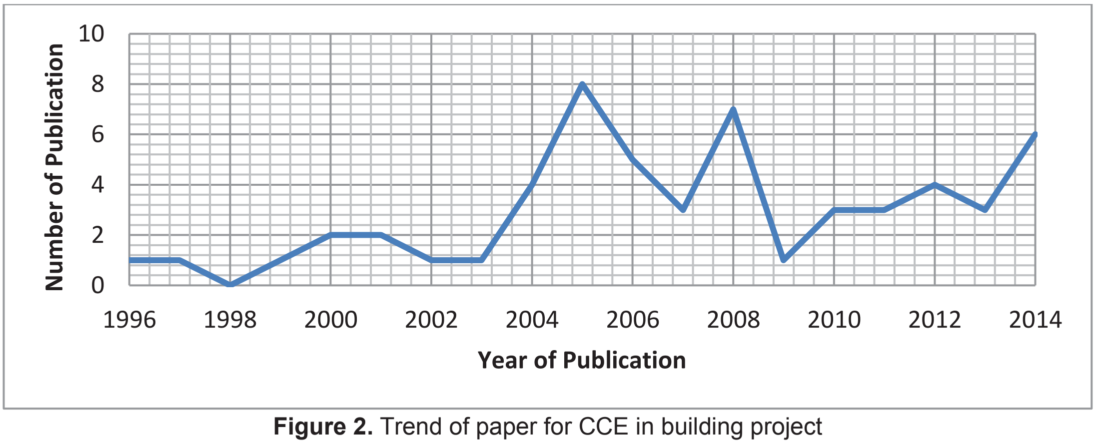


Figure 2. Trend of paper for CCE in building project

It is clear from the line graft shown in Figure 2 that the paper output trends in CCE studies fluctuated over the years from 1996 to 2014. During this period, the number of publications increased substantially over eight periods (i.e. 1998-2000; 2003-2005; 2007-2008; 2009-

2010; 2011-2012 and 2013-2014). Indeed, during 2003-2005, the number of academic papers increased dramatically from 1 paper to 7 papers. Forty-four academic papers were published over eleven year period, with average of four papers per year. Unfortunately, at the end of the trend, the number of papers jumped down from six papers to zero papers including during 1998, 2004, 2009-2011.

Active contributors to the publication

The method used to measure an individual author's contribution in multi-authored paper, and broadly adopted, is a formula initiated by Howard, Cole and Maxwell, (1987). The formula is given below:

$$Score = \frac{1.5^{n-i}}{\sum_{i=1}^{n} 1.5^{n-i}} (1)$$

Where $\boldsymbol{n}$ is the number of authors in publication; and $\boldsymbol{i}$ is the ordinal number of the specific author.

Table 2. Active contributor with at least 1 score point

Authors	Number of articles	Research Centre	Country	Score
Sonmez, Rifat	3	Middle East Technical University	Turkey	3.00
Kim, G.H.	4	Korea University	Korea	1.73
Akintoye, Akintola	2	Glasgow Caledonian University	UK	1.40
Dogan, S. Zeynep	3	Izmir Institute of Technology	Turkey	1.34
Ji, Sae-Hyun	2	Seoul National University	Korea	1.15
An, Sung Hoon	3	Korea University	Korea	1.11
Cheung, Franco K.T	2	City University of Hong Kong	Hong Kong	1.07
Stoy, Christian	2	University of Stuttgart	Germany	1.07
Gunaydin, H.M	3	Izmir Institute of Technology	Turkey	1.02
Trost, Steven M.	2	Oklahoma state university	US	1.00
Oberlender, Garold	2	Oklahoma state university	US	1.00

Of 56 papers published from 1996 to 2015, eleven researchers actively contributed to CCE study for building projects. Each researcher contributed at least two articles with one score point and more (Table 2). Although some researchers had two articles or more, they are not included in Table 2, since score point results cannot be reached a score of one. The score point was measured by using formula (1). For instance, one researcher has 4 articles. In the first paper he was 3rd author of a group of five, in the second paper, he was 3rd author of a group of three, while in the third paper, he was 3rd author of group four and the 3rd author of three in the last paper. These figures give the total contribution score as 0.17+0.21+0.18+0.21= 0.77. Thus, the author will not be included in Table 2.

Of the eleven researchers, the major research centers were Turkey and Korea with the total score of author contributor 36% and 26.8% respectively. Surprisingly, Turkey as a developing country has great interest in CCE study compared to other developed countries. The most active contributor is Sonmez, Rifaz from Middle East Technical University, Turkey with a total score of 3.00 point. Subsequently Korean author from Korea University, Kim G.H has a score of 1.73 point. Furthermore, other authors have slightly different of score value.

Table 3. Most frequently cited papers at least 50 times

Authors	Year	Journal	Cited
Akintoye, Akintola	2000	CME	363
Niazi, Adnan and Dai, Jian S.	2006	JMSE	312
Kim, G.H., An, Sung-Hoon, and Kang, Kyung, In	2004	BE	296
Iyer, K.C. and Jha, K.N.	2005	IJPM	265
Trost, Steven M. and Oberlender, Garold	2003	JCEM	241
Akintoye, Akintola and Fitzgerald, Eamon	2000	CME	213
Hughes, Robert	1996	IST	188
Gunaydin, H.M. and Dogan, S. Zeynep	2004	IJPM	155
Oberlender, Garold D. and Trost, Steven M.	2001	JCEM	145
An, Sung-Hoon, Kimb, Gwang-Hee and Kang, Kyung-In	2007	BE	130
Lowe, David J., Emsley, Margaret W. and Harding, Anthony	2006	JCEM	115
Chua, D.K.H., Kog,Y.C., Loh, P.K., and Jaselskis, E.J	1997	JCEM	108
Rush ,Christopher and Roy ,Rajkumar	2001	CE	95
Sonmez, Rifat	2004	CJCE	90
Elhag, T.M.S., Boussabaine, A.H and Ballal, T.M.A	2005	IJPM	81
Kim, G.H., Seo, D.S. and Kang, K.I.	2005	JCCE	73
Liu, Li and Zhu, Kai	2007	JCEM	69
Cheng, Min-Yuan, Tsai, Hsing-Chih and Hsieh, Wen-Shan	2009	AC	67
Aibinu, Ajibade A. and Pasco, Thomas	2008	CME	63
Chan, Swee Lean and Park, Moonseo	2005	CME	60
Yang, I-T	2005	IJPM	55
Cheng, Min-Yuan, Tsai, Hsing-Chih and Sudjono, Erick	2010	ESA	55

(Source: Google Schoolar (https://scholar.google.co.id/) accessed on July 3th, 2017)

Other important information related to the analysis of research trends is the number of citations. Generally, all journal data bases, including one such as SCOPUS and WOS, provide such information. However, according to Utama et al. (2015), these data bases gave different information about the citation count. Thus, another popular academic search engine was used to deal with this problem. The results show only 11 out of 18 journals with 22 articles contributes the list. Those journals contribute to a citation count 3,239 times, equal to a count of 147.23 cited times on average. Moreover, CME with 4 papers on the list reported 699 citations equal to 21.58% of total citation and becoming the most influential journal this study. The second influential journal is JCEM with 5 papers reported 679 citations equal to 20.96 % of total citation. Interestingly, the both journal, CME and JCEM are included in the top five of Chau's rangking.

Research Methodology Employed in CCE

In the next phase analysis, the papers were classified by type of techniques applied in CCE for building project. A total of 51 papers were compiled. From the table 1, the results indicated that there was more paper having applied quantitative approach than qualitative approach. They were 30 (about 58.83%) and 21 papers (about 41.17%), respectively. Likewise, the respective trends depicted in Figure 3 confirmed this finding.

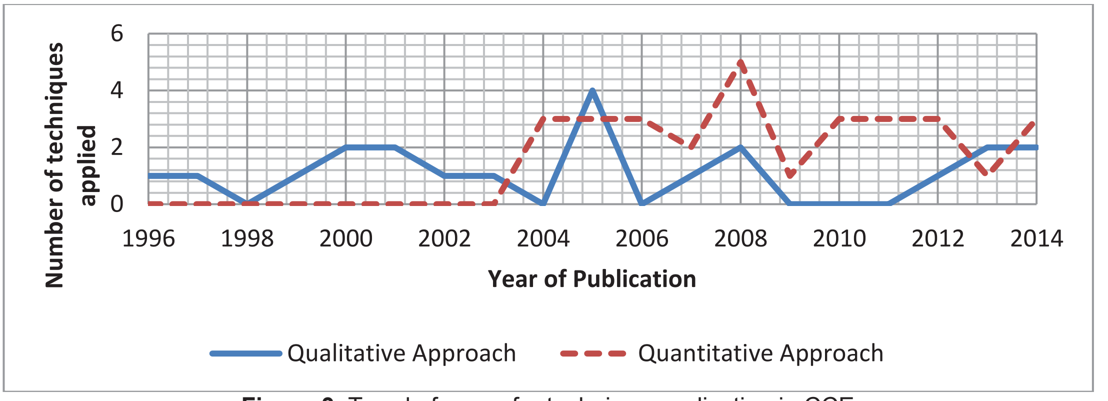


Figure 3. Trend of paper for technique application in CCE

In cost modeling, quantitative approach is defined as cost element and known structures of elements which form the basis of a cost estimate and that are measurable (Rush & Roy, 2001b). On the contrary, qualitative approach can be defined as the assumption and judgment that related to how the estimator refers the past project as a basis for the generation of a new estimate (Datta & Roy, 2010; Niazi & Dai, 2006; Rush & Roy 2001a). Based on the year of publication in Figure 2, there were not papers having applied quantitative techniques during 1996 – 2004. However, in 2005, researchers started to study CCE papers in applied quantitative approach. Furthermore, in the ten years after 2005 spent tracing the trends, production of CCE papers had more papers having in quantitative approach than qualitative approach. There was a total of 24 and 8 papers, respectively. Otherwise, in the first eight years, there were only papers in applied qualitative approach with a total of nine papers.

Through comprehensive review on research methodology, the papers were also classified by analysis method and model applied. Figure 4 shows the distribution of papers into three of categories in term of research analysis employed. In this study, the model dominantly was used in analysis for about 54%. In contrast, the descriptive and statistic were used just over 14% and 32% respectively.

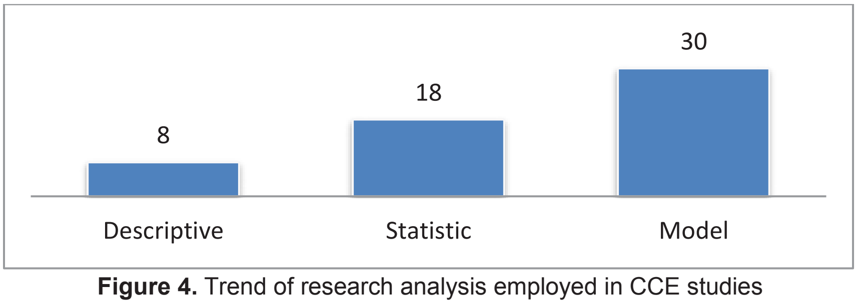


Figure 4. Trend of research analysis employed in CCE studies

As mention before, various conceptual cost estimation methods and techniques have been done to calculate the conceptual cost estimation including regression, neural network, case base reasoning (CBR), and simulation. Instead, some researchers also have integrated the two above methods or techniques altogether. Through the process, a total of 30 papers was classified into technique of models were used. From Figure 5, the result indicated that, there were not a large different between technique of models used including CBR, neural network, regression and simulation. There were 8, 7, 5 and 5 papers respectively, for integrated technique altogether.

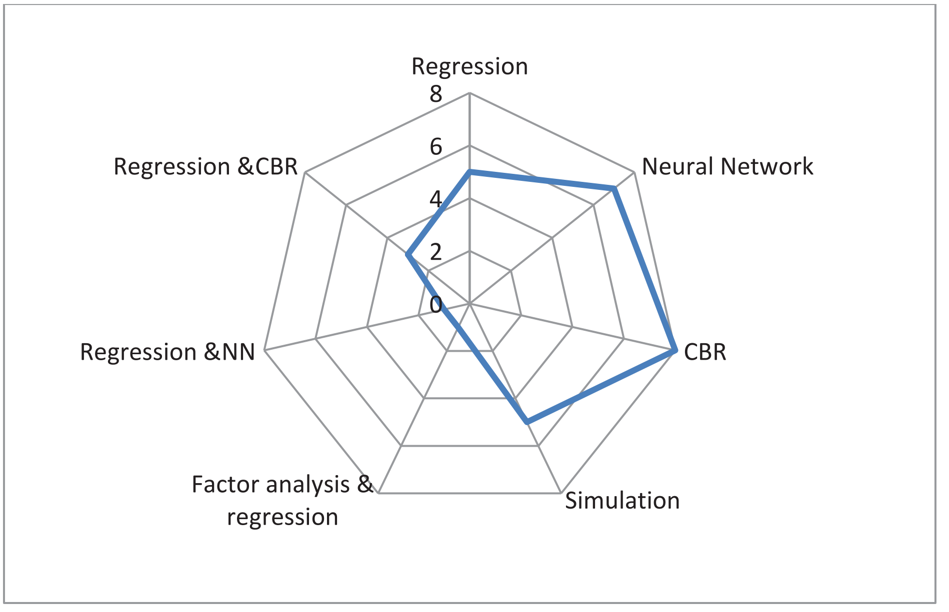


Figure 5. breakdown of the total number for model applied

Trends of research topic

To figure out the evolution of CCE research topics on factors influencing the cost estimation, researchers attempted to classify the large number of cost factors into categories of factors with similar attributes (Akintoye & Fitzgerald, 2000; Cheng, 2014; Elhag et al., 2005; Enshassi et al., 2005; Liu & Zhu, 2007; Toh et al., 2012; Trost & Oberlender, 2003). The cost factors are identified into five categories: 1) information of consultant and design parameter, 2) project's characteristics, 3) client's characteristics, 4) contract requirements and procurement methods, and 5) external factors and market conditions. In order way, the above factors can be categorized into two distinct group: 1) estimator-specific factors and 2) design and project-specific factors (Akinci & Finchers, 1998; Elfaki et al., 2014). However, through comprehensive reading of articles, the above cost factors can be combined into four categories as presented in figure 5.A four and five-year interval had been chosen for a distribution of 19 years over four consecutive periods. The main reason for using a longer interval period instead of annual period was to ensure that the depicted trend would be less erratic or smoother.

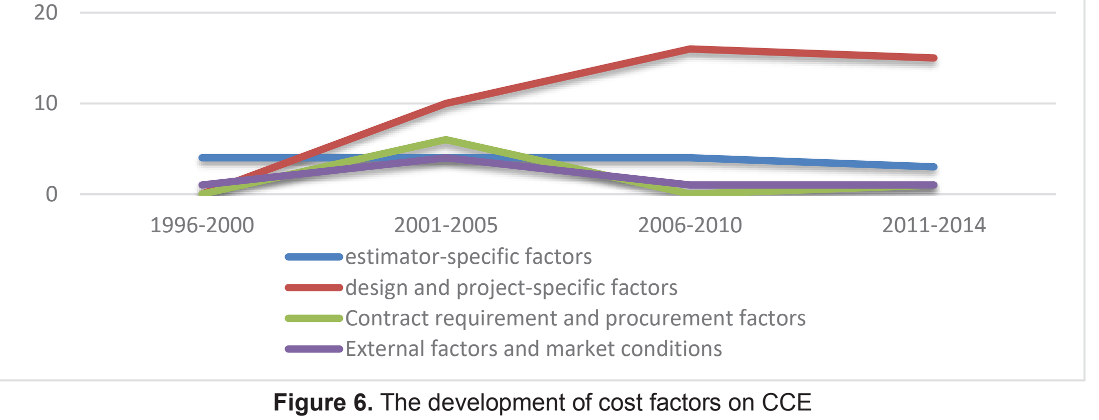


Figure 6. The development of cost factors on CCE

Figure 6 depicts how research topics in CCE changed during the period 1994-2014. The first point to note is that there is one topic which attract researcher's in particular. In the three last terms, the cost factor related to *Design and project-specific* (e.g. gross floor area, number of stories, total unit, location, roof types, foundation types, usage of basement, finishing grades, etc) piqued researcher's interest. There is a growing trend of *design and project-specific factors* being applied to research in the field of CCE with total of 41 papers in all period. On the contrary, the trend changes to *Estimator-specific factors* (e.g. experience of estimator, frequency of estimating, estimation process, estimation conditions, client characteristics, consultant and contractor attributes, etc.). In the early three terms (i.e. 1996-2000; 2001-2005; 2006-2010), the papers remained relatively steady in 4 papers and decreased one paper in the following term.

Interestingly, *Contract requirement and procurement factors* and *External factors and market conditions* have the same total of papers during all the period (1996 to 2014) with 7 papers. Compared to the two mention topics, *Contract requirement and procurement factors* (e.g. building tender price index, poor tender document, insufficient tender document analysis, etc) and *External factors and market conditions* (e.g. construction demand, bank landing, hostile socio economic, etc) tend to be overlooked in all terms. There were not many researchers incorporating these factors as a significant cost factor in CCE.

In addition, from Table 4, the results revealed one active area of cost factors, in term of having the highest numbers of papers among the seven categories of model applied. The area identified were *design and project-specific factors* (with 27 papers). This area also had the highest number of papers to which neural network and CBR techniques had been applied (in 7 papers). Regression and simulation techniques also had the same number of papers (in 5 papers). The patterns of the papers were plotted in Figure 5 depicting the trends of all papers including descriptive and statistical analysis that were applied.

Table 4. Classification of papers by model applied for area of cost factors

Area of cost factors in CCE	Estimator-specific factors	Design and project-specific factors	Contract requirement and procurement factors	External factors and market conditions
Regression (RS)		Hua, Goh (1999)		Hua, Goh (1999)
		Li, Heng and Shen (2005)		
		Lowe et al. (2006)		
		Sonmez, Rifat (2008)		
		Ji, Sae-Hyun et al. (2010)		
Neural Network	Chua, D.K.H et al. (1997)	Gunaydin and Dogan (2004)		
	Cheng, MY et al. (2009)	Kim, G.H et al. (2005)		
		Yu, Wen-Der (2006)		
		Cheng, MY et al. (2009)		
		Cheng, MY et al. (2010)		
		Sonmez, Rifat (2011)		
		Bala, Kabir et al. (2014)		
CBR	Lai, Yu-Ting (2008)	Kim, G.H et al. (2004)		Lai, Yu-Ting (2008)
	Rush and Roy (2001)	An, S. H et al. (2007)		
		Doğan, S. Z et al. (2008)		

Area of cost factors in CCE	Estimator-specific factors	Design and project-specific factors	Contract requirement and procurement factors	External factors and market conditions
		Lai, Yu-Ting (2008)		
		Koo, C.W et al. (2010)		
		Ji, Sae-Hyun et al. (2011)		
		Koo, C.W et al. (2011)		
Simulation	Khodakarami et al. (2014)	Yang, I-T (2005)		
		Kim, H.J et al. (2012)		
		Wang, W.C et al. (2012)		
		Khodakarami et al. (2014)		
Factor analysis & RR	Trost and Oberlender (2003)	Trost and Oberlender (2003)	Trost and Oberlender (2003)	
Regression & NN		Sonmez, Rifat (2004)		
Regression & CBR		Jin, RunZhi et al. (2012)		
		Jin, R.Z et al. (2014)		
		Ahn, Joseph et al. (2014)		

CONCLUSION AND RECOMENDATIONS

The three main finding are as follows:

(1) Trend of paper for CCE in building project show an upward trend with some fluctuations during the period of 1997 to 2014 (refer to Figure 1)
(2) The active contributors of the study in supplying analytical thinking and critical ideas are dominated by researcher from Turkey and Korea (refer to Table 2)
(3) There is a clear positive trend for the papers that have applied quantitative approach which starts from 2005, whereas the papers applied qualitative approach began to steadily decrease (refer to Figure 2)
(4) The areas of cost factors that have increasingly higher growth affecting CCE are *Design and project-specific factor*, e.g. gross floor area, number of storeys, total unit, location, roof types, foundation types, usage of basement, finishing grades, etc (refer to Figure 6)

Over the years, research in cost estimation at early stage (CCE) has been done. Empirical evidence from this bibliometric paper indicates that previous calls for paradigm in area of significant cost factor have changed in practice toward the adoption of more on *design and project-specific factor*. This paper also verifies there is no correlation between cost factors with model applied in CCE (refer to Table 4). The paper can apply all defined technique or method in using data analysis.

The study using one cost factors in factor *design and project-specific factor* could expound not only the significant cost variable but also the prediction interval to show the range estimating possible of accuracy. Trost and Oberlender (2003), in data analysis for their study had three cost factors as shown in Table 3. They have analyzed five significant cost factors from three above defined cost factors (11 variables with 45 elements) and there was not a conclusion on estimating possible of accuracy. This study has been also shown by Chua et al. (1997). Moreover, most papers used historical project data to develop causal models where relationships of the variables can be established in a predictable interval of accuracy.

In conclusion, it seem to agree with Riquelme and Serpell (2013) that there is a need to select an appropriate historical data to be used for cost estimation and also each method is appropriate for certain individual situations. And the analysis result could help estimators and researchers to make plans for the applications and supporting future research.

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REFERENCES

Adeli, H., & Wu, M. (1998). Regularization neural network for construction cost estimation. *Journal of Construction Engineering and Management, 124*(1), 18-27.

Ahn, J., Ji, S.-H., Park, M., Lee, H.-S., Kim, S., & Suh, S.-W. (2014). The attribute impact concept: Applications in case-based reasoning and parametric cost estimation. *Automation in Construction, 43*, 195-203.

Akinci, B., & Finchers, M. (1998). Factor affecting contractors's risk of cost overburden. *Journal of Management in Engineering, 14*(1), 67-76.

Akintoye, A., & Fitzgerald, E. (2000). A survey of current cost estimating practices in the UK. *Construction Management and Economics, 18,*161-172.

Cheng, Tsai, H.-C., & Hsieh, W.-S. (2009). Web-based conceptual cost estimates for construction projects using Evolutionary Fuzzy Neural Inference Model. *Automation in Construction, 18*, 164–172.

Cheng, M.-Y., Tsai, H.-C., & Sudjono, E. (2010). Conceptual cost estimates using evolutionary fuzzy hybrid neural network for projects in construction industry. *Expert Systems with Applications, 37*, 4224-4231.

Cheng, Y.-M. (2014). An Exploration into cost-influencing factors on construction projects. *International Journal of Project Management, 32*, 850-860.

Chou, J. (2009). Web-based CBR system applied to early cost budgeting for pavement maintenance project. *Expert Systems with Applications, 36*(2), 2947-2960.

Chua, D. K. H., Kog, Y. C., Loh, P. K., & Jaselskis, E. J. (1997). Model for construction budget performanece-neural network approach. *Journal of Construction Engineering and Management, 123*(2), 214-222.

Creese, R. C., & Li, L. (1995). Cost estimation of timber bridge using neural networks. *Cost Engineering, 37*(5), 17-23.

Curran, R., Raghunathan, S., & Price, M. (2004). Review of aerospace engineering cost modelling: The genetic causal approach. *Progress in Aerospace Sciences, 40*(8), 487-534.

Datta, P. P., & Roy, R. (2010). Cost modelling techniques for availability type service support contracts: A literature review and empirical study. *CIRP Journal of Manufacturing Science and Technology, 3*(2), 142-157.

Elfaki, A. O., Alatawi, S., & Abushandi, E. (2014). Using intelligents techniques in construction project cost estimation: 10-years survey. *Advances in Civil Engineering, 2014*, 11 pages.

Elhag, T. M. S., Boussabaine, A. H., & Ballal, T. M. A. (2005). Critical determinant of construction tendering cost: Quantity surveyors standpoint. *International Journal of Project Management, 23*, 538-545.

Enshassi, A., Mohamed, S., & Madi, I. (2005). Factors affecting accuracy of cost estimation of building contracts in the Gaza Strip. *Journal of Financial Management of Property and Construction, 10*(2), 115-125.

Gunduza, M., Ugurb, L. O., & Ozturk, E. (2011). Parametric cost estimation system for light rail transit and metro trackworks. *Expert Systems with Applications, 38*, 2873-2877.

Hegazy, T., & Ayed, A. (1998). Neural network model for parametric cost estimation of highway projects. *Journal of Construction Engineering and Management, 124*(3), 210-221.

Ji, S.-H., Park, M., & Lee, H.-S. (2010). Data Preprocessing–Based Parametric Cost Model for Building Projects: Case Studies of Korean Construction Projects. *Journal Construction Engineering Management, 138*(8), 844-853.

Kim, G. H., An, S. H., & Kang, K. I. (2004). Comparison of construction cost estimating models based on regression analysis, neural networks, and case-based reasoning. *Building and Environment, 39*, 1235-1242.

Kim, G. H., Seo, D. S., & Kang, K. I. (2005). Hybrid models of neural networks and genetic algorithms for predicting preliminary cost estimates. *Journal of Computing in Civil Engineering, 19*(2), 208-213.

Koo, C., Hong, T., & Hyun, C. (2011). The development of a construction cost prediction model with improved prediction capacity using the advanced CBR approach. *Expert Systems with Applications, 38*(7), 8597-8606.

Kwak, Y. H., & Watson, R. J. (2005). Conceptual estimating tool for technology-driven projects: exploring parametric estimating technique. *Technovation, 25*, 1430-1436.

Langmaak, S., Wiseall, S., Bru, C., Adkins, R., Scanlan, J., & Sóbester, A. (2013). An activity-based-parametric hybrid cost model to estimate the unit cost of a novel gas turbine component. *International Journal of Production Economics, 142*(1), 74-88.

Liu, L., & Zhu, K. (2007). Improving cost estimates of construction projects using phased cost factors. *Journal of Construction Engineering and Management*.

Lowe, D. J., Emsley, M. W., & Anthony, H. (2006). Predicting Construction Cost Using Multiple Regression Techniques. *Journal of Construction Engineering and Management, 132*(7), 750-758.

Marzouk, M. M., & Ahmed, R. M. (2011). A case-based reasoning approach for estimating the costs of pump station projects. *Journal of Advanced Research, 2*, 289–295.

Niazi, A., & Dai, J. S. (2006). Product cost estimation:techniques classification and methodology review. *journal of Manufacturing Science and Engineering, 128*, 563-575.

Raan, A. F. J. (2005). Fatal attraction: Conceptual and methodological problems in the ranking of universities by bibliometric methods. *Scientometrics, 1*(62), 133-143.

Riquelme, P., & Serpell, A. (2013). Adding qualitative context factors to analogy estimating of construction projects. *Social and Behavioral Sciences, 74*, 190-202.

Rush , C., & Roy , R. (2001a). Expert judgement in cost estimating: Modelling the reasoning process. *Concurrent Engineering, 9*(4), 271-284.

Rush, C., & Roy, R. (2001b). *Capturing quantitative & qualitative knowledge for cost modelling within a concurent engineering (CE) enviroment*. Paper presented at the 8th ISPE International Conference on Concurent Engineering: Research and Applications, Anaheim, California.

Sonmez, R. (2004). Conceptual cost estimation of building project with regression analysis and neural network. *Canadian Journal Civil Engineering, 31*, 677-683.

Sonmez, R. (2011). Range estimation of construction costs using neural networks with bootstrap prediction intervals. *Expert Systems with Applications, 38*(8), 9913-9917.

Toh, T. C., Ting, C., Ali, K.-N., & Aliagha, G.-U. (2012). Critical cost factor of building construction projects in Malaysia. *Procedia - Social and Behavioral Sciences, 57*, 360-367.

Trost, S. M., & Oberlender, G. D. (2003). Predicting Accuracy of Early Cost Estimates Using Factor Analysis and Multivariate Regression. *Journal Construction Engineering Management, 129*, 198-204.

Utama, W., Chan, A., Zahoor, A., & Gao, R. (2015). Review of research trend in international construction projects: a bibliometric analysis. *Construction Economic and Building, 2*(16), 71-82.

Wang, W. C., Shih, H., Tsui, Y. K., & Hsu, C. H. (2012). A factor-based probabilistic cost model to support bid-price estimation. *Expert Systems with Applications, 39* 5358–5366.

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A CONCEPTUAL MODEL OF LEAN CONSTRUCTION: A THEORETICAL FRAMEWORK

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Abstract
Lean Construction has become a global reference of a production system with the minimum of waste. However, previous research shows that there are several implementation scenarios, which differ from one company to another according to their own understanding of the Lean Construction principles. This work aims to fill this gap by proposing a generic framework leading to a better understanding of the basics of Lean Construction. In this paper, an original conceptual model has been developed based on a rigorous analysis of the most relevant Lean construction models that have been applied and tested in several countries. The outcome of this model shows that there are nine main Lean Construction principles, and which are: customer focus, supply, continuous improvement, waste elimination, people involvement, planning and scheduling, quality, standardization and transparency. In addition to that, the most used Lean Construction sub-principles have been identified based on an extensive literature review.

Keywords: *Lean Construction; Conceptual model; Framework; Principles; Sub-principles*

INTRODUCTION

The construction industry is highly characterized by the generation of waste, uncertain safety conditions and a high variability of its construction process (Koskela, 1999; Tezel and Nielsen, 2013). In addition, building construction sector is often classified at the bottom of the ranking of reports regarding the efficiency of the production management techniques (Antunes and Gonzalez, 2015). Indeed, several solutions had been implemented to overcome the costs and deadlines overruns of construction projects, such as the introduction of industrialization techniques through prefabrication, the use of new computer technologies as Building Information Modelling (BIM), as well as automated and robotic construction techniques. Despite the introduction of new advanced tools and materials in order to improve the performance of construction processes, this industry has not been able to achieve a significant change in its production system compared to other sectors such as the manufacturing industry. This is mainly due to the lack of a renovation strategy of the traditional management techniques (Johansen and Walter, 2007). A lot of researchers (Aziz and Hafez, 2013; Dupin, 2014; Harris and McCaffer, 2013) have demonstrated that these solutions alone cannot create a major revolution for the construction sector, especially in the absence of a solid basis of management.

The international competitiveness and the economic crisis permanently increase the pressure on the actors of construction projects to seek better and more innovative approach. Recently, the construction companies have begun to experience the lean manufacturing philosophy that has been applied for many years in the automotive industry and which has become the benchmark for industrial excellence in the manufacturing sector, but which is still recent in the construction industry. The term "Lean" means the optimal use of the available resources within the company. This approach uses only half of the human resources, half of the production space, and half of the investment costs in tools and new construction technologies, while keeping half of the required stock in order to ensure respect of the triptych (cost, time, quality) and to achieve the satisfaction of the customers' needs (El-Kourd, 2009; Gama et al., 2009; Natasya et al., 2013).

Originally, the Lean Manufacturing philosophy takes its origins from the culture of Toyota.(Taylor et al., 2015). In fact, Toyota Production System (TPS) was the first model of lean management that had been developed by the Japanese company after the Second World War. The Lean Construction philosophy is the adaptation of the Lean manufacturing philosophy with the characteristics and constraints of the construction industry (Kim and Park, 2006; Marhani et al., 2012; Mohd et al., 2013). (Dupin, 2014) defines Lean Construction as a management philosophy aimed at creating value for the customer by eliminating waste, supported by collaborative project management tools, as part of a systematic and rigorous approach of continuous improvement.

Several construction companies have attempted to implement Lean Construction practices in different countries all over the world (USA, UK, Germany, China, Chile, Brazil, India...). However, most of the companies have applied this management philosophy to their own understanding of Lean Construction principles. According to (Green, 1999) Lean Construction philosophy is a: “complex cocktail of ideas”, especially in the absence of a solid and iterative basis for performance improvement, waste reduction and maximizing value for the customer. Consequently, different implementation scenarios have been generated according to the internal characteristics of each company. This is due to the lack of a clear vision of the main practices/techniques/ tools that constitute the Lean Construction concept. The development of a Lean Construction Model (LCM) can provide a number of advantages for the construction companies by identifying the best practices/techniques/tools leading to a higher performance for the construction process, and also it constitutes a guide of improvement by showing the strong points to be reinforced and the weak points to be compensated. Our objective is to develop a conceptual Model that shows the main principles and the most used or common sub-principles leading to the success of Lean Construction deployment.

RESEARCH METHODOLOGY

In order to achieve the objective of this work, we are based on a rigorous and in-depth study of the state of art which has discussed the main principles of Lean Construction philosophy. Reliable databases were examined, in particular: Science Direct, Emerald Online, IEEE Xplore, Springer Link, Inderscience, World Scientific, Taylor & Francis, and Scopus. The concept of lean construction was first introduced by Lauri Koskela in the technical report “Application of the New Production Philosophy to Construction”. 24 the study is based on research papers, review papers, books, conference papers and thesis that have been published between 1992 and 2017. Choosing keywords is one of the crucial steps of research. Indeed, the keywords used are: “lean construction assessment”, “Lean Construction conformance”, “Lean Construction maturity”, “Lean construction model”, “Lean construction framework”, “Lean construction principles”, and “Lean construction implementation”. Besides that, several combinations of the above-mentioned keywords have been used to make the finding more significant.

As a first step, the research produced 751 documents on lean construction from all considered publication databases, and then an in-depth examination of the full text of each document enabled us to identify 125 relevant documents. We have selected the most recent research (59 documents published between 2015 and 2017) in order to design a conceptual model of lean construction. Figure 1 shows those references classified by year of publication.

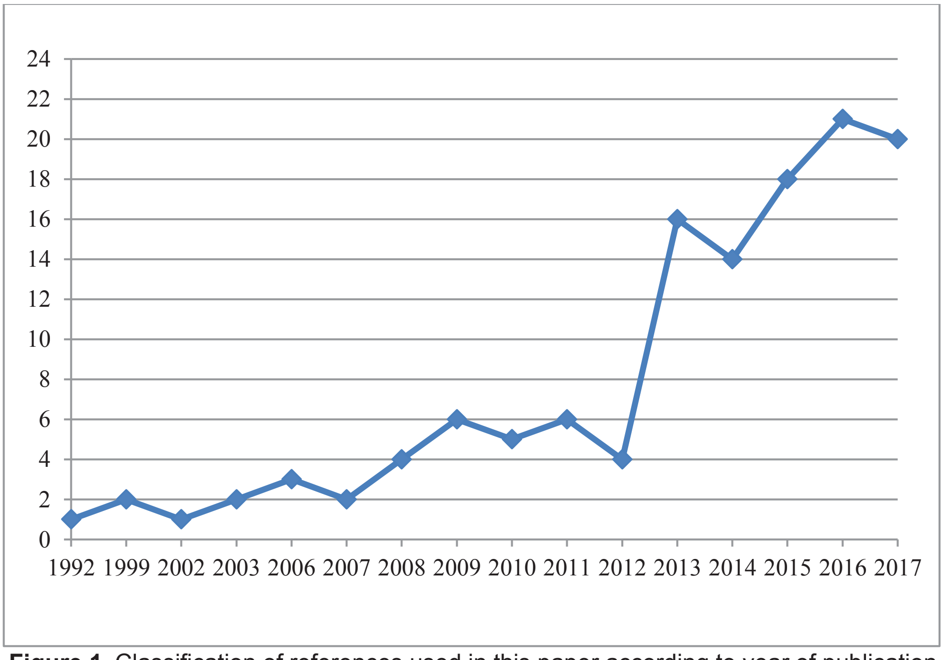

Figure 1. Classification of references used in this paper according to year of publication

LEAN PRINCIPLES IN CONSTRUCTION SYSTEM

In this study we have established a critical analysis of seven Lean Construction models in order to identify the fundamental aspects of Lean Construction theory. These models are developed in different countries which are known by their performance and maturity at the level of understanding of Lean Construction concepts (United State, United Kingdom, Germany, Italy, Brazil...). Between those models we find, for example: Lean Construction Maturity Model (LCMM) (Nesensohn et al., 2015) that is composed of eleven principles and sixty sub-principles ; The model of Lean Construction Rating (LCR) (Hofacker et al., 2008) that was developed in collaboration between two universities, the German University Karlsruhe and the Brazilian University Universidade Federal Paraná in Curitiba and which allows to distinguish between four levels of maturity within the construction companies; The model Lean Construction Conformance (LCC) (Diekmann et al., 2003) was developed by the Construction Industry Institute (CII) to verify the conformance of the management system of construction companies with Lean Construction culture. The fundamental principles on which are based the models analysed in this work are shown in Table 1.

Table 1. The main principles used in Lean Construction models

	Lean Construction models						
	(Tezel and Nielsen, 2013)	(Johansen and Walter, 2007)	(Nesensohn et al., 2015)	(Hofacker et al., 2008)	(Diekmann et al., 2003)	(Salem et al., 2006)	(Locatelli et al., 2013)
	Turkey	Germany	UK	Germany and Brazil	USA	USA	UK and Italy
Customer focus	×	×	×	×	×	×	×
Supply		×		×			×
Continuous improvement	×		×	×	×	×	×
Waste elimination	×			×	×	×	×
People involvement	×	×	×	×	×	×	×
Planning and Scheduling		×	×	×		×	×
Quality	×			×	×	×	×
Standardization	×				×	×	
Transparency	×		×	×	×	×	×

In this literature review we have identified nine principles that represent the basis of Lean Construction philosophy and which are: Customer focus, Supply, Continuous improvement, Waste elimination, People involvement, Planning and Scheduling, Quality, Standardization, Transparency. Moreover, these principles can be divided into three primary pillars:

- Systems management: it focuses on the management of systems in interaction with customers, suppliers and contractors (Customer focus, Supply, Planning and Scheduling);
- Technology management: It concerns the operational techniques aimed at optimizing the performance of the company (Transparency, Standardization, and Quality);
- Culture and behaviour: This pillar encompass all Lean Construction practices that allow the dissemination of a culture of continuous improvement during all cycle of production while ensuring an optimal use of employee skills (people involvement, continuous improvement).

These three pillars focus on eliminating waste which is the core of the lean construction philosophy, as illustrated in Figure 2.

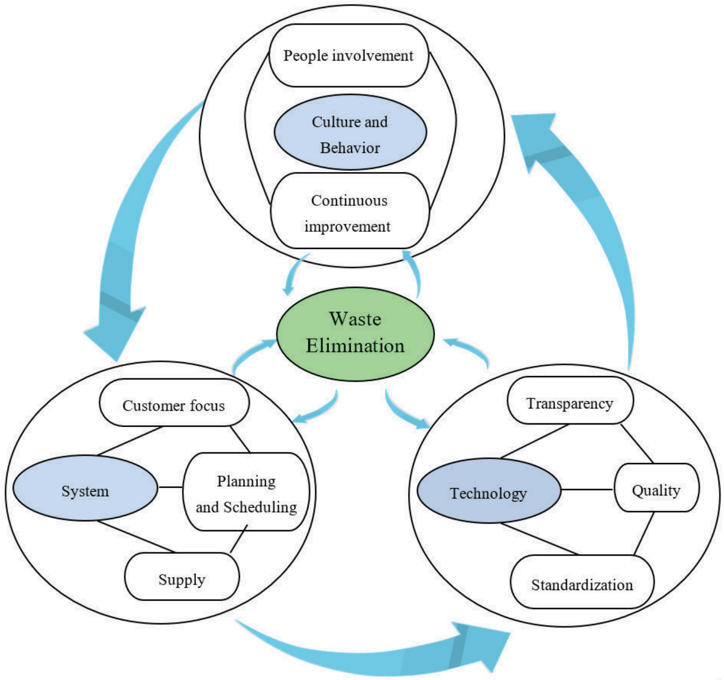

Figure 2. The major pillars of Lean Construction concept

LEAN CONSTRUCTION SUB-PRINCIPLES

The Lean construction principles can be divided into several sub-principles contributing to the strengthening of their goals. So, we have determined the most relevant and most used sub-principles. The list of sub-principles is classified into nine main principles (customer focus, supply, continuous improvement, waste elimination, people involvement, planning and scheduling, quality, standardization, transparency) by considering the number of references (frequency) that have cited them in their studies.

The highest frequency that has been found is twenty on a total of 125 main articles that have been analysed and which focus on the sub-principles and techniques most used around the world for the implementation of the Lean Construction philosophy, especially in the building projects based on the Lean Construction philosophy. Frequency scale that has been used is: 1 to 5 = Very Low (VL); 6 to 10 = Low (L); 11 to 15 = High (H); 16 to 20 = Very High (VH). The sub-principles of less than six (VL) will be omitted in the design of the conceptual model.

Customer Focus

Customer focus aims at introducing the customer into the chain of production by identifying the really necessary value while ensuring a high flexibility of the resources of the company (materials, technologies, flows, polyvalence of the workforce technical skills...). Furthermore, it contributes to maintaining a great relationship level with the customer and personnel directly in contact with him which allows executing tasks with the minimum of waste and the maximum value for the customer (Issa, 2013a). The main sub-principles of customer focus are shown in Table 2.

Table 2. The main sub-principles of customer focus

Principle	Sub-principles	Frequency	References
Customer Focus	Customer relationships	10 (L)	(Arleroth and Kristensson, 2011; Bygballe and Ingemansson, 2014; Green, 1999; Growth and Directions, n.d.; Issa, 2013a; Johansen and Walter, 2007; Jørgensen, 2006; Koskela, 1992; Natasya et al., 2013; Savolainen et al., 2015)
	Customer involvement	15 (H)	(Arleroth and Kristensson, 2011; Bashir, 2013; Bortolotti et al., 2015; Diekmann et al., 2003; Dupin, 2014; El-Kourd, 2009; Enshassi, 2008; Green, 2013; Growth and Directions, n.d.; Johansen and Walter, 2007; Jørgensen, 2006; Management, 2016; Nesensohn et al., 2015; Sadler, 2011; Tezel and Nielsen, 2013)
	Flexible resources	15 (H)	(Arashpour et al., 2015; Diekmann et al., 2003; El-Kourd, 2009; Gama, Kleber Toledo , Cavenaghi, 2009; Green, 2013; Jørgensen, 2006; Khanchanapong et al., 2014; Liu, 2013; Natasya et al., 2013; Sadler, 2011; Salem et al., 2006; Tezel and Nielsen, 2013; Vieira et al., 2010; Yu et al., 2009; Zhang et al., 2017)
	Optimise Value/Value identification	16 (VH)	(Arleroth and Kristensson, 2011; Diekmann et al., 2003; Dineshkumar and Dhivyamenaga, 2016; El-Kourd, 2009; Growth and Directions, n.d.; Hatzigeorgiou and Manoliadis, 2017; Hodge et al., 2011; Jørgensen, 2006; Mandujano et al., 2017; Mohd et al., 2013; Natasya et al., 2013; Sadler, 2011; Salem et al., 2006; Tezel and Nielsen, 2013; Tokola et al., 2015; Zhang et al., 2017)

Supply

The objective is to obtain an optimal logistic flow which allows reducing the level of the stocks, so it contains only necessary materials/equipment that will be used in the construction process (Dupin, 2014). This principle is based on several Sub-principles/Techniques/Practices such as pull system, Just-in-time, Supplier involvement, and supply chain management. The main sub-principles of supply are shown in Table 3.

Table 3. The main sub-principles of supply

Principle	Sub-principles	Frequency	References
Supply	Supply chain management (SCM)	17 (VH)	(Almeida and Salazar, 2003; Arleroth and Kristensson, 2011; Devaki and Jayanthi, 2014; Diekmann et al., 2003; El-Kourd, 2009; Green, 2013; Hodge et al., 2011; Johansen and Walter, 2007; Jørgensen, 2006; Mohd et al., 2013; Mpofu et al., 2017; Omran and Abdulrahim, 2015; Pasha and Naik, 2016; Sadler, 2011; Salem et al., 2006; Shang and Sui Pheng, 2014; Tezel and Nielsen, 2013)
	Just-in-time	18 (VH)	(Chandrasekar and Kumar, 2014; Diekmann et al., 2003; El-Kourd, 2009; Envision, 2015; Gama, Kleber Toledo , Cavenaghi, 2009; Green, 2013; Hodge et al., 2011; Hofacker et al., 2008; Management, 2016; More et al., 2016; Natasya et al., 2013; Pasha and Naik, 2016; Sadler, 2011; Salem et al., 2006; Shang and Sui Pheng, 2012; Shetty et al., 2010; Tezel and Nielsen, 2013; Vieira et al., 2010)
	Supplier involvement	8 (L)	(Dupin, 2014; Enshassi, 2008; Green, 2013; Jørgensen, 2006; Natasya et al., 2013; Sadler, 2011; Tezel, 2007)
	Supplier development	2 (VL)	(Management, 2016; Natasya et al., 2013)
	Pull system	17 (VH)	(Arleroth and Kristensson, 2011; Dineshkumar and Dhivyamenaga, 2016; El-Kourd, 2009; Gama, Kleber Toledo , Cavenaghi, 2009; Green, 2013; Growth and Directions, n.d.; Hodge et al., 2011; Hofacker et al., 2008; Johansen and

Principle	Sub-principles	Frequency	References
			Walter, 2007; Jørgensen, 2006; Mohd et al., 2013; Natasya et al., 2013; Sadler, 2011; Salem et al., 2006; Shetty et al., 2010; Tezel and Nielsen, 2013; Vieira et al., 2010)

Continuous Improvement

Several researchers (Anvari et al., 2011; Aziz and Hafez, 2013; Dupin, 2014; Khanh and Kim, 2015; Tjell and Bosch-Sijtsema, 2015) have mentioned that: "Lean is a journey, not a destination". Consequently, construction companies are forced to permanently improving their performance and renovating the traditional management techniques following a systematic and rigorous approach seeking perfection in order to resist the pressures and the competitiveness of the construction market. The main sub-principles of continuous improvement are shown in Table 4.

Table 4. The main sub-principles of continuous improvement

Principle	Sub-principles	Frequency	References
Continuous improvement	Metrics (Productivity, Quality, Safety)	11 (H)	(Arleroth and Kristensson, 2011; Dentz et al., 2014; Desale and Deodhar, 2014; Devaki and Jayanthi, 2014; Diekmann et al., 2003; Dupin, 2014; Enshassi, 2008; Fullerton et al., 2014; Senouci et al., 2016; Shetty et al., 2010; Tezel and Nielsen, 2013)
	Organizational learning	15 (H)	(Arleroth and Kristensson, 2011; Diekmann et al., 2003; Enshassi, 2008; Gama, Kleber Toledo , Cavenaghi, 2009; Growth and Directions, n.d.; Hodge et al., 2011; Hofacker et al., 2008; Jørgensen, 2006; Natasya et al., 2013; Nesensohn et al., 2015; Sadler, 2011; Salem et al., 2006; Shetty et al., 2010; Tezel and Nielsen, 2013; Vieira et al., 2010)
	First run studies (PDCA)	12 (H)	(Ansah et al., 2016; Antunes and Gonzalez, 2015; Arayici et al., 2011; Bon and Kee, 2015; Dupin, 2014; El-Kourd, 2009; Green, 2013; Johansen and Walter, 2007; Li et al., 2016; Mohd et al., 2013; Salem et al., 2006; Savolainen et al., 2015)
	Huddle meeting	11 (H)	(Arleroth and Kristensson, 2011; Bashir et al., 2013; El-Kourd, 2009; Enshassi and Zaiter, 2014; Envision, 2015; Green, 2013; Jørgensen, 2006; Maru, 2015; Mohd et al., 2013; Sadler, 2011; Salem et al., 2006)

Waste Elimination

This dimension is the core of Lean Construction philosophy. It aims at spreading a culture of elimination of various forms of waste (over-production, unnecessary transportation, Inventory, displacements, waiting, Over-Processing, Defects, unused employee creativity) (Arleroth and Kristensson, 2011; Tezel, 2007). The main sub-principles of waste elimination are shown in Table 5.

Table 5. The main sub-principles of waste elimination

Principle	Sub-principles	Frequency	References
Waste elimination	Reduce process cycle time	15 (H)	(Atout, 2016; Diekmann et al., 2003; Dupin, 2014; El-Kourd, 2009; Hodge et al., 2011; Hofacker et al., 2008; Jørgensen, 2006; Khanh and Kim, 2014; Merschbrock, 2009; Mohamad Ramly et al., 2015; Rahman and Asce, 2014; Sadler, 2011; Senaratne and Wijesiri, 2008; Shah, 2016; Tezel and Nielsen, 2013)

Principle	Sub-principles	Frequency	References
	Waste awareness/waste consciousness	17 (VH)	(Arleroth and Kristensson, 2011; Aziz and Hafez, 2013; Diekmann et al., 2003; Gulghane and Khandve, 2015; Hofacker et al., 2008; Johansen and Walter, 2007; Jørgensen, 2006; Mohd et al., 2013; Nagapan and Rahman, 2012; Natasya et al., 2013; Nesensohn et al., 2015; Sacks et al., 2009; Sadler, 2011; Shao et al., 2011; Tezel and Nielsen, 2013; Thanh Binh, 2013; Vieira et al., 2010)
	Value stream mapping (VSM)	14 (H)	(Arleroth and Kristensson, 2011; Dakhli et al., 2016; El-Kourd, 2009; "Etude comparative des outils et méthodes du Lean Construction avec les méthodes traditionnelles de planification projet et produit .," n.d.; Green, 2013; Growth and Directions, n.d.; Hodge et al., 2011; Jarkko et al., 2013; Jørgensen, 2006; Mandujano et al., 2016; Natasya et al., 2013; Shetty et al., 2010; Taylor et al., 2015; Tezel et al., 2007)
	Space utilisation	4 (VL)	(Choudhry, 2017; Hofacker et al., 2008; Society et al., 2010; Ullah et al., 2017)
	Optimize product system	6 (L)	(Arleroth and Kristensson, 2011; Diekmann et al., 2003; Dupin, 2014; El-Kourd, 2009; Green, 2013; Tezel and Nielsen, 2013)
	Disposal management	2 (VL)	(Hofacker et al., 2008; Nagapan and Rahman, 2012)

People Involvement

Contrary to the traditional construction, Lean Construction philosophy considers staff as the main promoter of change and improvement of the company. Indeed, the integration of the workforce and top management helps to increase their empowerment and makes them totally engaged in the process of improvement within the company (Harris and McCaffer, 2013).

In the case of a Lean Construction organization, personal initiative is widely encouraged. Therefore, the productivity becomes the stake of each stakeholder in the project. This strategy of collective development through the sum of personal development can be accompanied by the human resources department. The main sub-principles of people involvement are shown in Table 6.

Table 6. The main sub-principles of people involvement

Principle	Sub-principles	Frequency	References
People involvement	Workforce/workers involvement	16 (VH)	(Aziz and Hafez, 2013; Bashir, 2013; Diekmann et al., 2003; Dupin, 2014; El-Kourd, 2009; Envision, 2015; Green, 2013; Growth and Directions, n.d.; Harris and McCaffer, 2013; Mohd et al., 2013; Natasya et al., 2013; Nesensohn et al., 2015; Sacks et al., 2010; Shetty et al., 2010; Sieng, 2012; Zhang et al., 2017)
	Top management/contractor involvement	13 (H)	(Abdullah et al., 2009; Arleroth and Kristensson, 2011; Banihashemi et al., 2017; Common et al., 2000; Diekmann et al., 2003; Dupin, 2014; Growth and Directions, n.d.; Harris and McCaffer, 2013; Hook and Stehn, 2008; Höök and Stehn, 2008; Jørgensen, 2006; Nesensohn et al., 2015; Yalegama et al., 2016)
	Training/Development	19 (VH)	(Banihashemi et al., 2017; Choudhry, 2017; Diekmann et al., 2003; El-Kourd, 2009; Enshassi, 2008; Green, 2013; Growth and Directions, n.d.; Hodge et al., 2011; Hofacker et al., 2008; Mohd et al., 2013; Mpofu et al., 2017; Nagapan and Rahman, 2012; Natasya et al., 2013; Nesensohn et al., 2015; Sadler, 2011; Salem et al., 2006; Shetty et al., 2010; Tezel and Nielsen, 2013; Vieira et al., 2010)

Principle	Sub-principles	Frequency	References
	Teamwork	10 (L)	(El-Kourd, 2009; Gama, Kleber Toledo , Cavenaghi, 2009; Hofacker et al., 2008; Jørgensen, 2006; Kissi et al., 2016; Masai et al., 2015; Salem et al., 2006; Taylor et al., 2015; Tezel and Nielsen, 2013; Ullah et al., 2017)
	Health/Safety improvement	20 (VH)	(Arleroth and Kristensson, 2011; Aziz and Hafez, 2013; Diekmann et al., 2003; Dupin, 2014; El-Kourd, 2009; Enshassi, 2008; Green, 2013; Growth and Directions, n.d.; Hodge et al., 2011; Hofacker et al., 2008; Johansen and Walter, 2007; Jørgensen, 2006; Mohd et al., 2013; Nagapan and Rahman, 2012; Natasya et al., 2013; Sadler, 2011; Salem et al., 2006; Shao et al., 2011; Shetty et al., 2010; Tezel and Nielsen, 2013)
	Organizational commitment	4 (VL)	(Diekmann et al., 2003; Dupin, 2014; Enshassi, 2008; Tezel and Nielsen, 2013)

Planning and Scheduling

Lean Construction planning system is based on innovative techniques that aim to ensure the collaborative participation of all stakeholders in construction projects and to replace the traditional techniques of planning that are the main sources of the majority of cost and delays overrun (Hallman, 2013). The main sub-principles of planning and scheduling are shown in Table 7.

Table 7. The main sub-principles of planning and scheduling

Principle	Sub-principles	Frequency	References
Planning and Scheduling	Last planner system	19 (VH)	(Arleroth and Kristensson, 2011; Aziz and Hafez, 2013; Dupin, 2014; El-Kourd, 2009; Green, 2013; Growth and Directions, n.d.; Hallman, 2013; Harris and McCaffer, 2013; Hofacker et al., 2008; Issa, 2013b; Johansen and Walter, 2007; Jørgensen, 2006; Li et al., 2016; Mohd et al., 2013; Ochoa, 2014; Sadler, 2011; Salem et al., 2006; Thanh Binh, 2013; Zhang et al., 2017)
	PPC charts	14 (H)	(Arleroth and Kristensson, 2011; Bajjou et al., 2017; Green, 2013; Growth and Directions, n.d.; Habchi et al., 2016; Issa, 2013b; Jørgensen, 2006; Khanh and Kim, 2015; Lindhard and Wandahl, 2015; Mandujano et al., 2016; Maru, 2015; Sadler, 2011; Salem et al., 2006; Zhang et al., 2017)
	Collaborative planning	9 (H)	(Almeida and Salazar, 2003; Baek Minsoo, Mostaan kia, 2016; Dave et al., 2015; Growth and Directions, n.d.; Hamzeh and Bergstrom, 2010; Jørgensen, 2006; Mandujano et al., 2016; Sadler, 2011; Sarhan, 2013)

Quality

The quality management system allows keeping construction processes under control and ensuring the identification of root causes of defects based on Lean techniques such as Poka-Yoke devices, five why, Ishikawa Diagram , Pareto diagram (Almeida, 2002; Arleroth and Kristensson, 2011). The main sub-principles of quality are shown in Table 8.

Table 8. The main sub-principles of quality

Principle	Sub-principles	Frequency	References
Quality	Total Quality Management	14 (H)	(Albliwi et al., 2017; Arleroth and Kristensson, 2011; Aziz and Hafez, 2013; Growth and Directions, n.d.; Hofacker et al., 2008; Johansen and Walter, 2007; Jørgensen, 2006; Mohd et al., 2013; Natasya et al., 2013; Sadler, 2011; Salem et al., 2006; Shao et al., 2011; Shetty et al., 2010; Ullah et al., 2017)

Principle	Sub-principles	Frequency	References
	Error proofing (Poka-Yoke)	11 (H)	(Bajjou et al., 2017; Diekmann et al., 2003; Hodge et al., 2011; Jørgensen, 2006; Mohd et al., 2013; Salem et al., 2006; Sarhan, 2017; Shetty et al., 2010; Tezel and Nielsen, 2013; Tezel, 2007)
	Response to defect/Root causes analysis (Ishikawa, Pareto, The five why's)	12 (H)	(Almeida, 2002; Arleroth and Kristensson, 2011; Aziz and Hafez, 2013; Diekmann et al., 2003; El-Kourd, 2009; Green, 2013; Hofacker et al., 2008; Jørgensen, 2006; Mohd et al., 2013; Salem et al., 2006; Shetty et al., 2010; Tezel and Nielsen, 2013)
	Fail-safe for quality	6 (L)	(Aziz and Hafez, 2013; El-Kourd, 2009; Enshassi and Zaiter, 2014; Green, 2013; Salem et al., 2006; Tezel, 2007)

Standardisation

Standardization can be described as a set of analysis tools that lead to a set of Standard Operating Procedures (SOP). SOP encompasses all tasks established by the operator such as process steps, work sequences, cycle time, control processes… The standardization is the best technique to design an efficient way in order to establish the techniques of building in the shortest possible time and with the minimum of efforts (Hook and Stehn, 2008; Wang and Ma, 2014). The main sub-principles of standardization are shown in Table 9.

Table 9. The main sub-principles of standardization

Principle	Sub-principles	Frequency	References
Standardization	Optimize work content	9 (L)	(Arleroth and Kristensson, 2011; El-Kourd, 2009; Green, 2013; Hook and Stehn, 2008; Jørgensen, 2006; Nagapan and Rahman, 2012; Tezel and Nielsen, 2013; Vieira et al., 2010; Wang and Ma, 2014)
	Defined work process	11 (H)	(Arleroth and Kristensson, 2011; Aziz and Hafez, 2013; Diekmann et al., 2003; El-Kourd, 2009; Green, 2013; Johansen and Walter, 2007; Mohd et al., 2013; Sadler, 2011; Salem et al., 2006; Tezel and Nielsen, 2013; Vieira et al., 2010)
	Takt time	6 (L)	(Arleroth and Kristensson, 2011; Dupin, 2014; Gama, Kleber Toledo , Cavenaghi, 2009; Harris and McCaffer, 2013; Hodge et al., 2011; "Simulation and Lean Principles: A Case Study in a Public Service in Brazil," n.d.)
	Work sequence	3 (VL)	(Green, 2013; Growth and Directions, n.d.; Johansen and Walter, 2007)

Transparency

Transparency aims to maintain a simple, clear and flexible workflow through visual management and 5S approach which helps to improve the construction site organization and to ensure the reliability of communication between the different partners (Sacks et al., 2009; Tezel et al., 2010). The main sub-principles of transparency are shown in Table 10.

Table 10. The main sub-principles of transparency

Principle	Sub-principles	Frequency	References
Transparency	Visual management	16 (VH)	(Arleroth and Kristensson, 2011; Diekmann et al., 2003; Dupin, 2014; El-Kourd, 2009; Gama, Kleber Toledo , Cavenaghi, 2009; Green, 2013; Growth and Directions, n.d.; Hodge et al., 2011; Hofacker et al., 2008; Johansen and Walter, 2007; Natasya et al., 2013; Sacks et al., 2009; Shetty et al., 2010; Tezel and Nielsen, 2013; Tezel et al., 2010; Vieira et al., 2010)
	Work place organization	16 (VH)	(Arleroth and Kristensson, 2011; Aziz and Hafez, 2013; Diekmann et al., 2003; Dupin, 2014; El-Kourd, 2009; Enshassi and Zaiter, 2014; Green, 2013; Hofacker et al., 2008; Johansen and Walter, 2007;

Principle	Sub-principles	Frequency	References
			Jørgensen, 2006; Mohd et al., 2013; Natasya et al., 2013; Sacks et al., 2009; Sadler, 2011; Tezel and Nielsen, 2013; Tezel et al., 2010)
	Building Information Modelling (BIM)	3 (VL)	(Green, 2013; Growth and Directions, n.d.; Sadler, 2011)

DEVELOPMENT OF A CONCEPTUAL MODEL

We have determined the sub-principles most commonly used in the construction industry around the world based on a rigorous study of the most reliable references in the field of Lean Construction. Thus, the frequency of each sub-principle that has been mentioned by previous researchers was used as a basic analysis to design the conceptual model of Lean Construction. The proposed conceptual model shows thirty-three sub-principles divided into nine main principles, as shown in figure 3.

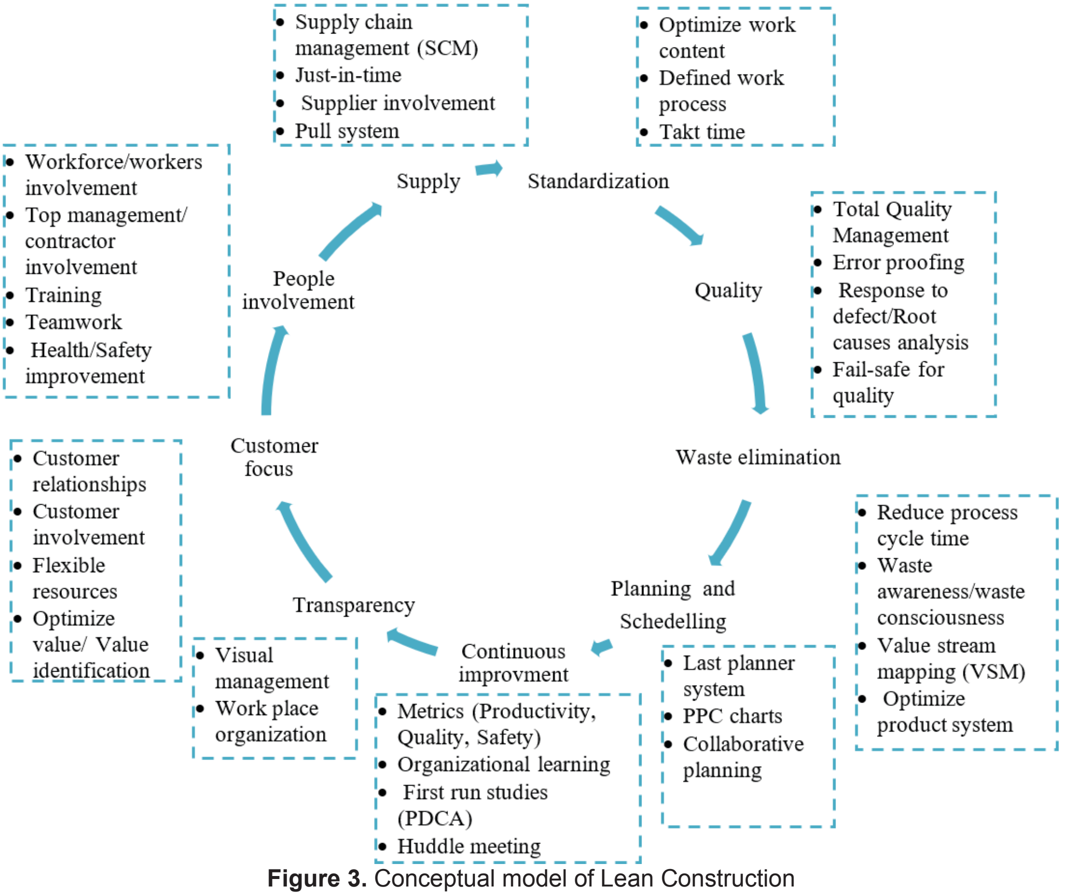

Figure 3. Conceptual model of Lean Construction

It has been found that there are some sub-principles which are rarely used in the implementation of the Lean construction approach as: Supplier developments, Space utilization, Disposal management…consequently, the sub-principles with a very low (VL) frequency have been omitted in the design of the conceptual model.

We can notice that there are sub-principles widely used in the construction projects and widely cited by researchers which make them fundamental in every implementation of Lean Construction as Just-in-time, pull system, Waste awareness/waste consciousness, Training/Development, Health/Safety improvement, Last Planner System (LPS)…

Generally, the construction system is an input-output model. This system contains as input the components needed to start the transformation stage in order to reach the construction product at the end respecting the deadline, the cost of the project and minimizing all types of waste.

As illustrated in Figure 4, we have developed an input-output model adapted to the construction context. This model is based on the main principles which we have determined by analysing the most reliable models dealing with the implementation of the Lean Construction philosophy. People Involvement and Supply constitute the basis of the input phase because they ensure all the sources necessary to begin the transformation phase (employees, materials, equipment...).

The transformation process contains four main principles: Quality, Planning & Scheduling, Standardization, and Transparency. These principles are intended to respect the triptych (quality, cost, time) while ensuring the best conditions of work for labours.

Customer focus plays a major role in the output phase by transferring information and feedback to the input phase. This operation remains valid throughout all the cycle of the project (design, Construction, delivery) which make it possible to reduce the generation of construction infrastructure not requested by the customer (overproduction), or the appearance of defects in the construction product at the delivery phase (defects).

Waste elimination and continuous improvement are integrated throughout the construction cycle, starting from the beginning to the end of the project. They are important for the performance of construction projects during the three stages of the project (Input phase, Transformation phase, Output phase). In addition, these two concepts make it possible to ensure the permanent improvement of the tryptique (quality, cost, time) and to replace the traditional management techniques by a rigorous and systematic approach of waste reduction. Figure 1 also shows the practical relationship between the principles of Lean Construction and all forms of waste (Transportation, Motion, Inventory, Waiting, Overproduction, Defects, defects, over processing, unused employee creativity, accidents).

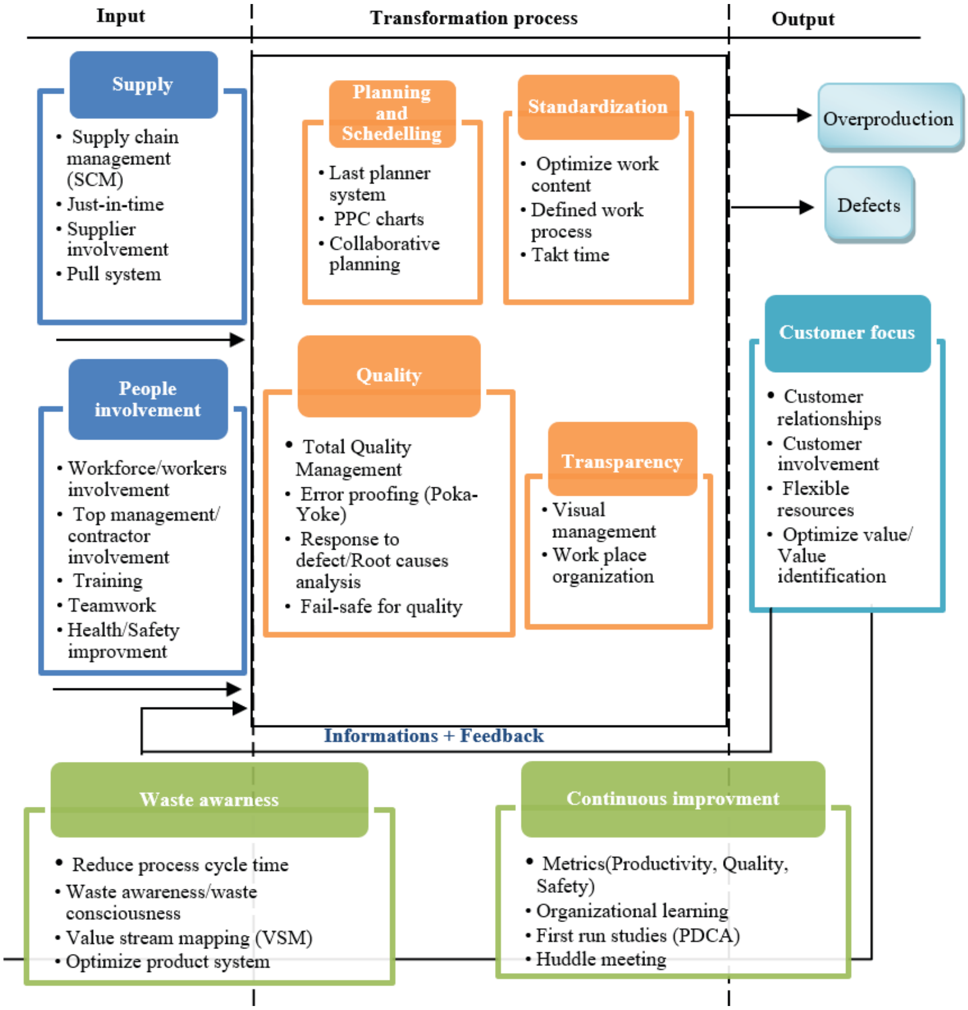

Figure 4. Input-output model of lean construction principles

CONCLUSION

This work was aimed to provide a conceptual model that shows the main principles of Lean Construction, as well as the key sub-principles that contribute to their reinforcement. Initially, the most relevant principles have been identified based on models that have been applied in several countries (USA, UK, Turkey, Italy, Germany, and Brazil). The principles are regrouped into four pillars that represent the basis of the Lean Construction concept, which are Systems management, Technology management, Culture and Behaviour, and Waste elimination. Similar sub-principles with the same characteristics are divided into nine principles (customer focus, supply, continuous improvement, waste elimination, people involvement, planning and scheduling, quality, standardization, transparency). A total of thirty-three main sub-principles have been found. This research contributes to the clarification of the implementation image of the Lean Construction approach. So, scholars and practitioners may benefit from this study as it aims to provide a general guideline leading to a better understanding of the basics of Lean Construction philosophy. In perspective, future empirical research will be done in the next stage to improve the proposed framework.

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REFERENCES

Abdullah, S., Razak, A., Bakar, A., Hassan, A., Sarrazin, I., 2009. Towards producing best practice in the Malaysian construction industry: the barriers in implementing the Lean Construction Approach. *Building* 1–15.

Albliwi, S.A., Antony, J., Arshed, N., Ghadge, A., 2017. Implementation of Lean Six Sigma in Saudi Arabian organisations. *Int. J. Qual. Reliab. Manag*. 34, 508–529. doi:10.1108/IJQRM-09-2015-0138

Almeida, J. C. (2003). *Strategic Issues in Lean Construction and the Higher Education Construction Market Sector* (Doctoral dissertation, Worcester Polytechnic Institute).

Almeida, J. C., & Salazar, G. F. (2003, July). Strategic issues in lean construction. In *Proceedings of the 11th Annual Conference of the International Group for Lean Construction, Blacksburg, VA, USA* (Vol. 2224, p. 110)

Ansah, R.H., Sorooshian, S., Mustafa, S. Bin, Duvvuru, G., 2016. Lean Construction Tools. Proc. 2016 Int. Conf. Ind. Eng. Oper. Manag. Detroit, Michigan, USA, Sept. 23-25 784–793.

Antunes, R., Gonzalez, V., 2015. A Production Model for Construction: A Theoretical Framework. *Buildings* 5, 209–228. doi:10.3390/buildings5010209

Anvari, A., Zulkifli, N., Yusuff, R.M., Mohammad, S., Hojjati, H., Ismail, Y., 2011. A proposed dynamic model for a lean roadmap. *African J. Bus. Manag*. 5, 6727–6737. doi:10.5897/AJBM10.1278

Arashpour, M., Wakefield, R., Blismas, N., Maqsood, T., 2015. Autonomous production tracking for augmenting output in off-site construction. *Autom. Constr*. 53, 13–21. doi:10.1016/j.autcon.2015.03.013

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C., O'Reilly, K., 2011. Technology adoption in the BIM implementation for lean architectural practice. *Autom. Constr*. 20, 189–195. doi:10.1016/j.autcon.2010.09.016

Arleroth, J., Kristensson, H., 2011. Waste in Lean Construction – A case study of a PEAB construction site and the development. Thesis in the Master of Supply Chain Management. Chalmers University of technology.

Atout, M.M., 2016. Delays Caused by Project Consultants and Designers in Construction Projects. *Int. J. Struct. Civ. Eng. Res.* 5. doi:10.18178/ijscer.5.2.102-107

Aziz, R.F., Hafez, S.M., 2013. Applying lean thinking in construction and performance improvement. *Alexandria Eng. J.* 52, 679–695. doi:10.1016/j.aej.2013.04.008

Baek Minsoo, Mostaan kia, A.B., 2016. Construction Research Congress 2016 739. *Constr. Res. Congr*. 739–748.

Bajjou, M.S., Chafi, A., Ennadi, A., Hammoumi, M. El, 2017. The Practical Relationships between Lean Construction Tools and Sustainable Development: A literature review. J. *Eng. Sci. Technol. Rev*. 10, 170–177. doi:10.25103/jestr.104.20

Bajjou, M.S., Chafi, A., En-Nadi, A., 2017. A Comparative Study between Lean Construction and the Traditional Production System. *Int. J. Eng. Res. Africa* 29, 118–132. doi:10.4028/www.scientific.net/JERA.29.118

Banihashemi, S., Hosseini, M.R., Golizadeh, H., Sankaran, S., 2017. Critical success factors (CSFs) for integration of sustainability into construction project management practices in developing countries. *Int. J. Proj. Manag*. doi:10.1016/j.ijproman.2017.01.014

Bashir, A.M., 2013. A framework for utilising lean construction strategies to promote safety on construction sites. PQDT - UK Irel. 1. Ph.D. Thesis. University of Wolverhampton. 257 pp.

Bashir, A.M., Suresh, S., Oloke, D. a., Proverbs, D.G., Gameson, R., 2013. The Application of Lean Construction Tools in United Kingdom Construction Organisations: Findings From a Qualitative Inquiry. *Aei 2013* 64–73. doi:10.1061/9780784412909.007

Bon, A.T., Kee, T.S., 2015. Implementation of Lean Manufacturing for Productivity Improvement in Malaysia 58–63.

Bortolotti, T., Boscari, S., Danese, P., 2015. Successful lean implementation: Organizational culture and soft lean practices. *Int. J. Prod. Econ*. 160, 182–201. doi:10.1016/j.ijpe.2014.10.013

Bygballe, L.E., Ingemansson, M., 2014. The logic of innovation in construction. *Ind. Mark. Manag.* 43, 512–524. doi:10.1016/j.indmarman.2013.12.019

Chandrasekar, A., Kumar, M.L., 2014. Effective Utilization of Lean Management in Construction Industry. *Int. J. Eng. Innov. Technol*. 3, 29–33.

Choudhry, R.M., 2017. Achieving safety and productivity in construction projects. *J. Civ. Eng. Manag.* 23, 311–318. doi:10.3846/13923730.2015.1068842

Common, G., Johansen, E., Greenwood, D., 2000. A survey of the take-up of lean concepts among UK construction companies. Proc. 8th Int. Gr. Lean Constr. Annu. Conf. Bright. United Kingdom.

Dakhli, Z., Lafhaj, Z., Benrard, M., 2016. Application of Lean to the bidding phase in building construction: a French contractor's experience. *Int. J. Lean Six Sigma* 8. doi:10.1108/IJLSS-03-2016-0010

Dave, B., Kubler, S., Främling, K., & Koskela, L. (2016). Opportunities for enhanced lean construction management using Internet of Things standards. *Automation in Construction*, *61*, 86-97. doi:10.1016/j.autcon.2015.10.009

Dentz, J., Nahmens, I., Mullens, M., 2014. Lean Production Applying in Factory *Homebuilding* 11, 81–104.

Desale, S. V., & Deodhar, S. V. (2014). Identification and eliminating waste in construction by using lean and six sigma principles. *International Journal of innovative Research in Science, Engineering and technology*, *3*(4).

Devaki, M.P., Jayanthi, R., 2014. Barriers to Implementation of Lean Principles in. *Int. J. Eng. Res. Technol*. 3, 1189–1192.

Diekmann, J. E., Balonick, J., Krewedl, M., & Troendle, L. (2003). Measuring lean conformance. In *Proc. 11th Ann. Conf. Intl. Group for Lean Construction*.

Dineshkumar, B., Dhivyamenaga, T., 2016. Study on Lean Principle Application in Construction Industries 9, 1–5. doi:10.17485/ijst/2016/v9i2/86366

Dupin, P., 2014. Patrick Dupin, Le lean appliqué à la construction, comment optimiser la gestion de projet et réduire coûts et délais dans le bâtiment.: Groupe Eyrolles, 2014.

El-Kourd, R. (2009). A study of lean construction practices in Gaza Strip. Ph.D. Thesis. Faculty of Civil Engineering Department.

Enshassi, A., Mohamed, S., & Abushaban, S. (2009). Factors affecting the performance of construction projects in the Gaza strip. *Journal of Civil engineering and Management*, *15*(3), 269-280.

Enshassi, A., Zaiter, M.A., 2014. Implementation of lean tools on safety in construction projects in palestine. 22nd Annu. Conf. Int. Gr. Lean Constr. Underst. *Improv. Proj. Based Prod.* IGLC 2014 1205–1218.

Medina Morales, N. (2015). Lean Construction on-site: Knowing how lean construction and job satisfaction are related to labor productivity.

Castanedo F. Etude comparative des outils et méthodes du Lean Construction avec les méthodes traditionnelles de planification projet et produit, Ph.D. Thesis, Lorraine university.

Fullerton, R.R., Kennedy, F. a., Widener, S.K., 2014. Lean manufacturing and firm performance: The incremental contribution of lean management accounting practices. *J. Oper. Manag.* 32, 414–428. doi:10.1016/j.jom.2014.09.002

Gama, K. T., & Cavenaghi, V. (2009, May). Measuring performance and Lean Production: a review of literature and a proposal for a performance measurement system. In *Proceedings of the Production and Operation Management Society (POMS) 20th Annual Conference*..

Swefie M.G, 2013. Improving Project Performance Using Lean Construction in Egypt: A Proposed Framework. Ph.D. Thesis. The American University in Cairo.

Green, S.D., 1999. the Dark Side of Lean Construction : Exploitation and Ideology. Proc. IGLC-7 21–32.

Madanayake, U. H. (2015). Application of Lean Construction Principles and Practices to Enhance the Construction Performance and Flow. The 4 world construction symposium sustainable development in built environment : green growth & innovative directions.

Gulghane, A. A., & Khandve, P. V. (2015). Management for Construction Materials and Control of Construction Waste in Construction Industry: A Review. *Int. Journal of Engineering Research and Applications*, *5*(4), 59-64.

Habchi, H., Taoufiq, C., Aziz, S., 2016. Last planner® system: implementation in a moroccan construction project. IGLC 2016 - 24th Annu. Conf. Int. Gr. Lean Constr. 193–202.

Hallman, M., 2013. Implementing Last Planner on Construction Sites. Ph.D. Thesis ; Chalmers Univ.

Hamzeh, F., Bergstrom, E., 2010. The Lean Transformation : A Framework for Successful Implementation of the Last Planner TM System in Construction. Int. Proc. 46th Annu. Conf. Assoc. Sch. Constr. 8 pp. doi:10.13140/RG.2.1.4590.8001

Harris, F., McCaffer, R., 2013. Modern Construction Management. doi:10.1515/9783990434550

Kennerley, M., & Neely, A. (2002). Performance measurement frameworks: a review. *Business performance measurement: Theory and practice*, 145-155.

Hodge, G.L., Ross, K.G., Joines, J.A., Thoney, K., 2011. Production Planning & Control: The Management of Operations Adapting lean manufacturing principles to the textile industry Adapting lean manufacturing principles to the textile industry. *Prod. Plan. Control* 22, 237–247. doi:10.1080/09537287.2010.498577

Hofacker, A., Fernandes, B., Gehbauer, F., Carmo Duarte Freitas, M., Mendes, R., Santos, A., & Kirsch, J. (2008). Rapid lean construction-quality rating model. *Manchester: sn*.

Hook, M., Stehn, L., 2008. Lean Principles in Industrialized Housing Production : The Need for a Cultural Change Lean Culture. *Lean Constr. J.* 20–33.

Höök, M., Stehn, L., 2008. Applicability of lean principles and practices in industrialized housing production. *Constr. Manag. Econ.* 26, 1091–1100. doi:10.1080/01446190802422179

Issa, U.H., (2013a.) Implementation of lean construction techniques for minimizing the risks effect on project construction time. *Alexandria Eng. J.* 52, 697–704. doi:10.1016/j.aej.2013.07.003

Issa, U. H. (2013b). Implementation of lean construction techniques for minimizing the risks effect on project construction time. *Alexandria Engineering Journal*, *52*(4), 697-704..

Jarkko, E., Lu, W., Lars, S., Thomas, O., 2013. Discrete Event Simulation Enhanced Value Stream Mapping : An Industrialized Construction Case Study. *Lean Constr. J*. 10, 47–65.

Johansen, E., Walter, L., 2007. Lean Construction: Prospects for the German construction industry. *Lean Constr. J*. 3, 19–32.

Jørgensen, B., 2006. Integrating lean design and lean construction: processes and methods.

Khanchanapong, T., Prajogo, D., Sohal, A.S., Cooper, B.K., Yeung, A.C.L., Cheng, T.C.E., 2014. The unique and complementary effects of manufacturing technologies and lean practices on manufacturing operational performance. *Int. J. Prod. Econ*. 153, 191–203. doi:10.1016/j.ijpe.2014.02.021

Khanh, H.D., Kim, S.Y., 2015. A survey on production planning system in construction projects based on last planner system. *KSCE J. Civ. Eng*. 0, 1–11. doi:10.1007/s12205-015-1412-y

Khanh, H.D., Kim, S.Y., 2014. Evaluating impact of waste factors on project performance cost in Vietnam. *KSCE J. Civ. Eng*. 18, 1923–1933. doi:10.1007/s12205-014-1219-2

Kim, D., Park, H.-S., 2006. Innovative construction management method: Assessment of lean construction implementation. *KSCE J. Civ. Eng.* 10, 381–388. doi:10.1007/BF02823976

Kissi, E., Boateng, E.B., Adjei-Kumi, T., Badu, E., 2016. Principal component analysis of challenges facing the implementation of value engineering in public projects in developing countries. *Int. J. Constr. Manag.* 3599, 1–10. doi:10.1080/15623599.2016.1233088

Koskela, L., 1999. Management of production in construction: a theoretical view. Proc. IGLC-7 241–252.

Koskela, L., 1992. Application of the new production philosophy to construction. Tech. Report 37–62.

Li, S., Wu, X., Zhou, Y., & Liu, X. (2017). A study on the evaluation of implementation level of lean construction in two Chinese firms. *Renewable and Sustainable Energy Reviews*, *71*, 846-851.

Lindhard, S., Wandahl, S., 2015. Exploration of correct LPS practices in scheduling of large, complex, and constrained construction projects. *Int. J. Proj. Organ. Manag*. 7, 56. doi:10.1504/IJPOM.2015.068005

Liu, X.L., 2013. Study on Technology of Green Construction Material-Saving and Material Resources Utilization. *Adv. Mater. Res*. 827, 374–379. doi:10.4028/www.scientific.net/AMR.827.374

Locatelli, G., Mancini, M., Gastaldo, G., & Mazza, F. (2013). Improving projects performance with lean construction: State of the art, applicability and impacts. *Organization, technology & management in construction: an international journal*, *5*(Special), 775-783.

Mandujano, G., Mourgues, C., Alarc, L.F., Kunz, J., 2017. Modeling Virtual Design and Construction Implementation Strategies Considering Lean Management Impacts 0, 1–22. doi:10.1111/mice.12253

Mandujano, M.G., Alarcón, L.F., Kunz, J., Mourgues, C., 2016. Identifying waste in virtual design and construction practice from a Lean Thinking perspective: A meta-analysis of the literature. *Rev. la construcción* 15, 107–118. doi:10.4067/S0718-915X2016000300011

Marhani, M.A., Jaapar, A., Bari, N.A.A., 2012. Lean Construction: Towards Enhancing Sustainable Construction in Malaysia. Procedia - Soc. Behav. Sci. 68, 87–98. doi:10.1016/j.sbspro.2012.12.209

Maru, A.A., 2015. Lean Construction in Civil Engineering and Project Management : Case Study Analysis of UT Arlington College. *Am. J. Civ. Eng*. 3, 70–74. doi:10.11648/j.ajce.20150303.13

Masai, P., Parrend, P., Zanni-Merk, C., 2015. Towards a formal model of the lean enterprise, in: Procedia Computer Science. doi:10.1016/j.procs.2015.08.122

Merschbrock, C., 2009. Lean production construction: prospects for the Icelandic construction industry 1–110.

Mohamad Ramly, Z., Shen, G.Q., Yu, A.T.W., 2015. Critical Success Factors for Value Management Workshops in Malaysia. *J. Manag. Eng*. 31, 1. doi:10.1061/(ASCE)ME.1943-5479.0000288.

Muhammad, W. M. N. W., Ismail, Z., & Hashim, A. E. (2013, April). Exploring lean construction components for Malaysian construction industry. In *Business Engineering and Industrial Applications Colloquium (BEIAC), 2013 IEEE* (pp. 1-6). IEEE..

More, V.D., Charhate, S., Sinha, M., 2016. Lean Construction Techniques in Indian Construction Industry : Some Analysis 7, 59–65.

Mpofu, B., Ochieng, E.G., Moobela, C., Pretorius, A., 2017. Profiling causative factors leading to construction project delays in the United Arab Emirates. Eng. Constr. *Archit. Manag*. 24, 346–376. doi:10.1108/ECAM-05-2015-0072

Nagapan, S., Rahman, I. A., Asmi, A., Memon, A. H., & Latif, I. (2012, December). Issues on construction waste: the need for sustainable waste management. In *Humanities, Science and Engineering (CHUSER), 2012 IEEE Colloquium on* (pp. 325-330). IEEE.

Natasya, A., Wahab, A., Mukhtar, M., Sulaiman, R., 2013. A Conceptual Model of Lean Manufacturing Dimensions. Procedia Technol. 11, 1292–1298. doi:10.1016/j.protcy.2013.12.327

Nesensohn, C., Bryde, D., Pasquire, C., 2015. A measurement model for lean construction maturity. Proc. IGLC 23 - 23rd Annu. Conf. Int. Gr. Lean Constr. Glob. Knowl. - Glob. Solut. 9, 652–660.

Ochoa, J.J., 2014. Reducing plan variations in delivering sustainable building projects. *J. Clean. Prod*. 85, 276–288. doi:10.1016/j.jclepro.2014.01.024

Omran, A., Abdulrahim, A., 2015. Barriers To Prioritizing Lean Construction in the Libyan Construction Industry. *Fascicule* 1, 53–56.

Pasha, S.S., Naik, B.H., 2016. An Analysis of Lean Construction Practices in Tamilnadu Construction Industry 16391–16398. doi:10.15680/IJIRSET.2016.0509117

Rahman, M.M., Asce, M., 2014. Barriers of Implementing Modern Methods of Construction 69–77. doi:10.1061/(ASCE)ME.1943-5479.0000173.

Sacks, R., Radosavljevic, M., Barak, R., 2010. Requirements for building information modeling based lean production management systems for construction. Autom. Constr. 19, 641–655. doi:10.1016/j.autcon.2010.02.010

Sacks, R., Treckmann, M., Rozenfeld, O., 2009. Visualization of Work Flow to Support Lean Construction. J. Constr. Eng. Manag. 135, 1307–1315. doi:10.1061/(ASCE)CO.1943-7862.0000102

Sadler, L., 2011. The adaptation and implementation of lean production in the New Zealand construction industry 1–97.

Salem, O., Solomon, J., Genaidy, A., Minkarah, I., 2006. Lean Construction: From Theory to Implementation. *J. Manag. Eng*. 22, 168–175. doi:10.1061/(ASCE)0742-597X(2006)22:4(168)

Sarhan, J. G., Xia, B., Fawzia, S., & Karim, A. (2017). Lean construction implementation in the Saudi Arabian construction industry. *Construction Economics and Building*, *17*(1), 46-69.

Sarhan, J. G., Xia, B., Fawzia, S., & Karim, A. (2017). Lean construction implementation in the Saudi Arabian construction industry. *Construction Economics and Building*, *17*(1), 46-69.

Savolainen, J., Kähkönen, K., Niemi, O., Poutanen, J., Varis, E., 2015. Stirring the Construction Project Management with Co-creation and Continuous Improvement. Procedia Econ. Financ. 21, 64–71. doi:10.1016/S2212-5671(15)00151-3

Senaratne, S., & Wijesiri, D. (2008). Lean Construction as a Strategic Option: Testing its Suitability and Acceptability in Sri Lanka. *Lean Construction Journal*.

Senouci, A., Ismail, A., Eldin, N., 2016. Time Delay and Cost Overrun in Qatari Public Construction Projects. Procedia Eng. 164, 368–375. doi:10.1016/j.proeng.2016.11.632

Shah, R. K. (2016). An Exploration of Causes for Delay and Cost Overruns In Construction Projects: Case Study of Australia, Malaysia & Ghana. *Journal of Advanced College of Engineering and Management*, *2*, 41-55.

Shang, G., Sui Pheng, L., 2014. Barriers to lean implementation in the construction industry in China. *J. Technol. Manag. China* 9, 155–173. doi:10.1108/JTMC-12-2013-0043

Shang, G., Sui Pheng, L., 2012. The adoption of Toyota Way principles in large Chinese construction firms. J. Technol. Manag. China 7, 291–316. doi:10.1108/17468771311325185

Shao, B.L., Chen, Z., Wang, F., 2011. How to Use Lean Construction to Control the Implicit Quality Costs in Construction Projects. Adv. Mater. Res. 368–373, 3102–3105. doi:10.4028/www.scientific.net/AMR.368-373.3102

Shetty, D., Ali, A., Cummings, R., 2010. International Journal of Lean Six Sigma Survey-based spreadsheet model on lean implementation Survey-based spreadsheet model on lean implementation. Int. J. Lean Six Sigma Iss Int. J. Lean Six Sigma Iss Int. J. Lean Six Sigma Iss Int. J. Lean Six Sigma 1, 310–334.

Sieng, L.K., 2012. The barriers of lean construction implementation in building construction project of Malaysia 16, 1–109.

Simulation and Lean Principles: A Case Study in a Public Service in Brazil, n.d.

Society, A.C., Library, A.S., Green, B.I., 2010. Surf's up: green construction industry. IEEE Eng. Manag. Rev. 38, 102–103. doi:10.1109/EMR.2010.2047153

Šuman, N., Semič El-Masr, M., 2013. The Integrated Approach for Introducing Innovation in construction Industry. Organ. Technol. Manag. Constr. An Int. J. 5, 834–843. doi:10.5592/otmcj.2013.2.2

Taylor, P., Ko, C., Kuo, J., 2015. Making formwork construction lean 37–41. doi:10.3846/13923730.2014.890655

Tezel, A., Nielsen, Y., 2013. Lean Construction Conformance among Construction Contractors in Turkey. J. Manag. Eng. 236–250. doi:10.1061/(ASCE)ME.1943-5479.0000145

Tezel, A., Ph, D., Koskela, L., Tzortzopoulos, P., Formoso, C.T., Alves, T., 2007. Visual

Management in Brazilian Construction Companies : Taxonomy and Guidelines for Implementation 31. doi:10.1061/(ASCE)ME.1943-5479.0000354.
Tezel, B.A., 2007. a Statistical Approach To Lean Construction Implementations of Construction Companies in. Construction.
Tezel, B.A., Koskela, L.J., Tzortzopoulos, P., Formoso, C.T., Alves, T., Neto, B., Viana, D., Mota, B., 2010. Process transparency on construction sites: Examples from construction companies in Brazil. Proc. 18th Annu. Conf. Int. Gr. Lean Constr. 296–305.
Thanh Binh, N., 2013. Applying Lean Construction to Construction Project. Adv. Mater. Res. 834–836, 1976–1983. doi:10.4028/www.scientific.net/AMR.834-836.1976
Tjell, J., Bosch-Sijtsema, P.M., 2015. Visual Management in Mid-sized Construction Design Projects. Procedia Econ. Financ. 21, 193–200. doi:10.1016/S2212-5671(15)00167-7
Tokola, H., Niemi, E., Kyrenius, P., 2015. Robotics and Computer-Integrated Manufacturing How Lean transformation affects scheduling. Robot. Comput. Integr. Manuf. 1–8. doi:10.1016/j.rcim.2015.09.012
Ullah, F., Thaheem, M.J., Siddiqui, S.Q., Khurshid, M.B., 2017. Influence of Six Sigma on project success in construction industry of Pakistan. TQM J. 29, 276–309. doi:10.1108/TQM-11-2015-0136
Vieira, L., Souza, L. De, Amaral, M., 2010. Application of the rapid lean construction quality rating model to engineering companies. 20th Annu. Conf. Int. Gr. Lean Constr.
Wang, J., Ma, R.Q., 2014. Based on Lean Construction Standardization Management Analysis of the Performance Evaluation Index System. Adv. Mater. Res. 933, 879–883. doi:10.4028/www.scientific.net/AMR.933.879
Yalegama, S., Chileshe, N., Ma, T., 2016. ScienceDirect Critical success factors for community-driven development projects : A Sri Lankan community perspective 34, 643–659.
Yu, H., Tweed, T., Al-Hussein, M., Nasseri, R., 2009. Development of Lean Model for House Construction Using Value Stream Mapping. J. Constr. Eng. Manag. 135, 782–790. doi:10.1061/(ASCE)0733-9364(2009)135:8(782)
Zhang, L., Chen, X., Suo, Y., 2017. Interrelationships among critical factors of work flow reliability in lean construction 3730. doi:10.3846/13923730.2016.1217921

AN EVALUATED COMPARISON BETWEEN THE MOLECULE AND STEEL FRAMING CONSTRUCTION SYSTEMS – IMPLICATIONS FOR THE SEISMIC VULNERABLE ECUADOR

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Abstract
The use of new constructive methods with light materials has generated a great acceptance in the field of construction around the world in recent years, among which are the Steel Framing and Molecule System, which are characterized by their structural lightness and relevant seismic behaviour. We have compared the structural properties of these two construction methods with the purpose to choose the use of the more adequate one in a seismic highly vulnerable like Ecuador. To accomplish this, the analytical models used obtained standard weights of the structures, shear and moment in columns, floor drifts as well as periods of vibration. The determined benefits were an improved seismic behaviour, a superior control of the construction processes, optimization of the time during the construction of such type of structures using the recommendations of the Ecuadorian national norm of construction.

Keywords: *Steel Framing system, Molecule system, Spaced structures, Stereo structures, Seismic resistance, Ecuador*

INTRODUCTION

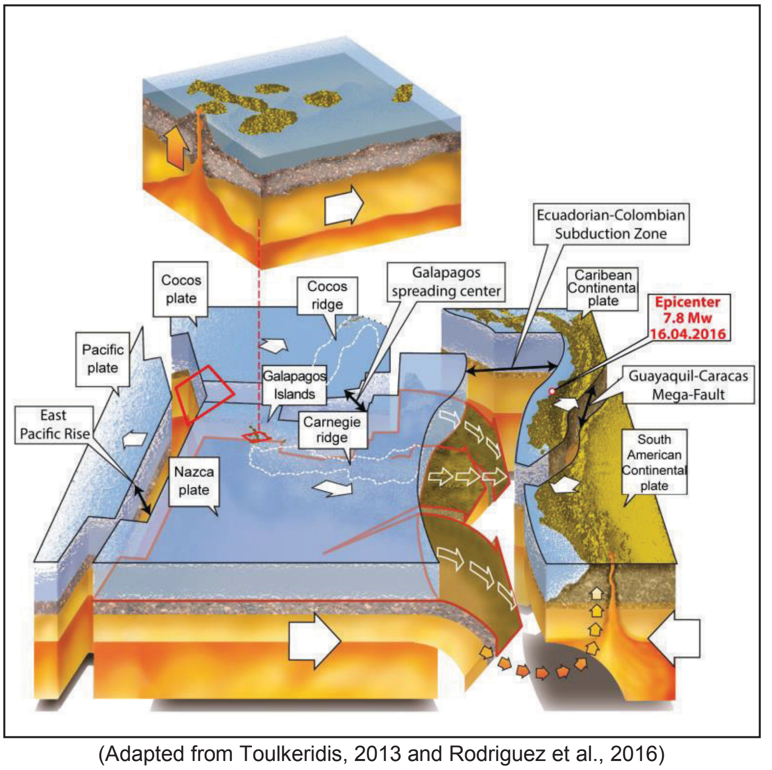
The confined masonry wall construction is a structural system, which has been generally widely used for the construction of houses in Latin America and particularly in Ecuador. Such type of structural system is characterized by its slenderness and by the elements manufactured for its construction as the bricks or blocks are united with mortar cement (Shing et al., 1990; Lourenço et al., 1998; Carrillo et al., 2007). In past the construction of masonry has always been given a minimum seismic importance, however during a telluric movement the first part that collapses are the masonry causing even fatalities (Tomaževič and Klemenc, 1997; Tomazevic, 1999; D'Ayala and Speranza, 2003; Klingner, 2006; Saatcioglu and Brzev, 2007; Zhao et al., 2009). Even more so, with the associated weight they may generate debris that becomes an additional burden to the structure. Such scenario already happened in several masonry like during the earthquake of Ecuador in April 16, 2016, as well as in Venezuela during the earthquakes in Cumaná and Cariaco in 1997 and in Tucacas in 2009 (González et al., 2004; Audemard, 2006; 2007; Vielma et al., 2016) and in Mexico with the earthquake of July 28, 1957 and later in 1985 where several confined masonry collapsed (Duke and Leeds, 1959; Rosenblueth, 1960; Mendoza and Auvinet, 1988; Tena-Colunga et al., 2009).

In order to avoid this kind of inconvenient, a variety of construction and anti-seismic systems (Sarris et al., 2010; Jaafar et al., 2016), as there are tapistic earthquake walls, which have a filling of tamped earth layers (Minke, 2001), anti-seismic reinforcements in structures such as flexible and friction sliding insulators (Rababeh et al., 2014; Hamid et al., 2014), combined with shock absorbers, which serve as seismic insulation for the structure (Hashash et al., 2001), or also seismic heatsinks that absorb energy by the action of the earthquake (Raj et al., 1995).

We have chosen to analyse and evaluate two alternative constructive systems, which may fulfil the seismic resistance needs of construction for Ecuador such as the "Steel Framing System" characterized by the use of steel profiles, and the "Molecule Structural System" which is characterized by its structure is formed by Aluminium bars. These construction systems could replace reinforced concrete elements such as beams and columns, in addition to masonry, and the structure could become lighter and have better seismic behaviour.

GEODYNAMIC SETTING AND SEISMICITY OF ECUADOR

The northern Andes in Ecuador are part of the 7000 km long classical example of an active continental margin along the South American continent with several volcanic sequences of Mesozoic and Cenozoic ages (De Mets et al., 1989; Trenkamp et al., 2002; Toulkeridis, 2013; Toulkeridis and Zach, 2017). Variations of the volcanic sequences are displayed within the observed geotectonic structures and have evolved due to different subduction geometries along the margin as well as the subduction angle of the subducting plate underneath Southern and Central America (Kellogg and Vega, 1995). In the north, the Cocos plate is subducted underneath the Central American plate, while further to the south the Nazca Pazific plate, is subducted with an angle slightly oblique to the southern American continent producing an overall active tectonic regime with transpression due to its convergence (Shumway, 1954; Daly, 1989; Gutscher et al., 1999). This Nazca Plate incorporates the aseismic Carnegie Ridge, which was produced by the passage of the ESE moving Nazca Plate over the Galapagos hot spot (Shumway, 1954; Lonsdale, 1978; Freymuller et al., 1993; Jaillard et al., 1995; Toulkeridis, 2011).



(Adapted from Toulkeridis, 2013 and Rodriguez et al., 2016)

Figure 1. Geodynamic setting and associated continental and oceanic plates as well as plate boundaries of the surrounding of Ecuador, the Galapagos Islands and the Carnegie Ridge.

The propagation of deformation towards the continent seems to be influenced also by the collision (and mechanical coupling) of the Carnegie Ridge below the South American continent (Gutscher et al., 1999; Dumont et al., 2014). Deformation is partitioned in a NNE-SSW trending strike-slip and reverse faults (Hughes and Pilatasig, 2002). The South American continent itself is composed of two different continental plates, the Caribbean and South American continental plates, of which contact is represented by a transformal or strike-slip fault named Guayaquil-Caracas Mega-Fault or Shear, which extends from the Gulf of Guayaquil in Ecuador until Venezuela (Kellogg and Vega, 1995; Dumont et al., 2005).

As result of both, the collision and subsequent subduction between the Nazca oceanic and the Caribbean with the South American continental plates as well as the movement of the referred Mega-Fault, extreme destruction by a variety of landslides, earthquakes and tsunamis have been manifested in past along the subduction trench and along and aside the fault with high losses of both, life and infrastructure (Barazangi and Isacks 1976; Mendoza and Dewey, 1984; Atakan, 1995; Tibaldi et al., 1995; Pararas-Carayannis, 2012; Chunga, and Toulkeridis, 2014; Parra et al., 2016). Therefore, strong earthquakes with catastrophic results for life and infrastructure occur in regular form in the Ecuadorian territory. In a time period of almost five centuries since 1587 until recent times more than 140 earthquakes destructed parts of cities and urban areas, with a total fatality sum of more than 80,000 deaths (Kahn, 2005; Toulkeridis et al., 2017a).

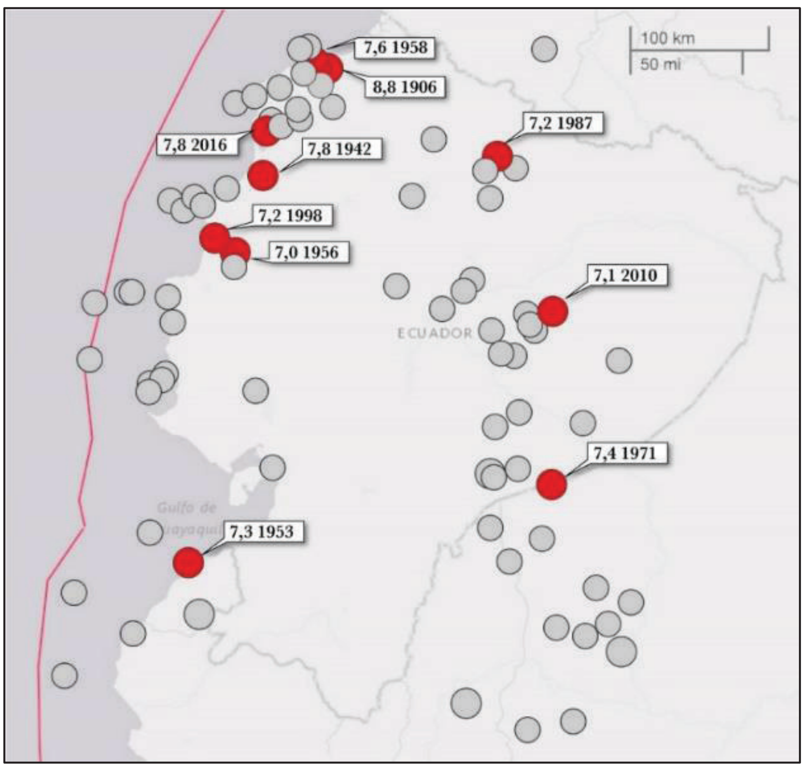


Figure 2. Seismicity of Ecuador from 1900-2017, with epicentres superior 6,0 on the Richter Scale based on the archive and catalogue of the United States Geological Survey (USGS/NEIC, 2017).

Of these telluric movements, more than 96 (+X) earthquakes had an intensity of VI to VII, another 25 (+X) earthquakes had an intensity of VIII while some 12 (+X) had an intensity equal or higher IX on the international Mercalli Scale. Remarkable of these seismic events have been those at 1797 (XI), 1868 (X) and that of 1949 (X) (Engdahl and Villasenor, 2002; Beauval et al., 2010; USGS/NEIC, 2017). From 1900 until 2017, some 65 seismic events occurred in the area of Ecuador surpassing 6,0 and reaching up to 8,8 in 1906 on the Richter Scale (USGS/NEIC, 2017). The three last earthquakes with a high number of fatalities have been a 6.8 Mw in 1949 with 6,000 deadly victims (Ganse and Nelson, 1982; Housner, 1984), a 6.9 Mw in 1987 with more than 1100 deaths (Berz, 1988; Tibaldi et al., 1995; Schuster et al., 1996), and a 7.8 Mw in 2016 with 663 fatalities (Ye et al., 2016; Toulkeridis et al., 2017; 2018).

METHODOLOGY

For the development of this study we have divided into two parts namely (A) the seismic response of conventional masonry and (b) the description of constructive systems. Both type of structures is used in the recommendations of the Ecuadorian national norm of construction (NEC, 2015), which are based on international standards of the American Iron and Steel Institute (AISI, 2008) and the Standard for Cold-Formed Steel Framing-Prescriptive Method for One and Two-Family Dwellings (AISI S230, 2010).

Seismic Response of Conventional Masonry

The structural system mostly used in the construction of houses in many parts of the world is still based on masonry walls. In this type of structures, the walls are the only vertical element resistant, so they must withstand the effects of vertical loads (gravitational) and horizontal (earthquakes), being subjected to normal and shear forces as well as bending moments (Papazoglou and Elnashai, 1996; Schlune et al., 2011).

Conventional masonry has been originated from empirical rules and designed only to support gravitational action, using the dead load to stabilize structures against lateral loads produced by winds and earthquakes (Bonett, 2003). However, earthquakes of magnitude greater than 6 on the Richter scale that have taken place in Ecuador in recent years, like in 2016 (Toulkeridis et al., 2017), demonstrate that unreinforced masonry structures are the most affected, resulting even to the loss of human lives (Figure 3).

In fact, recent studies determined relatively low resistances of masonry (Taghdi et al., 2000; Felice and Giannini, 2001; Myers et al., 2004; Juhásová et al., 2008). In Ecuador, the resistant structure is formed mainly by porticos, being inevitable that the more rigid elements are the walls, which means that in a strong earthquake they will break. Paradoxically, these elements may be beneficial since the walls receive part of the earthquake and prevent the collapse of the structured structure. An alternative is to change the masonry to other types of elements or, as proposed in this article, to change the structural system to one of supporting walls.

Photos courtesy Sissy Nikolaou

Figure 3. Masonry cracked after the earthquake on April 16, 2016 in Manta, Manabí, Ecuador.

Description of the Construction Systems

The Ecuadorian government carried out the reconstruction of the affected areas due to the earthquake of April 16, 2016, using construction alternatives, which are fast, cheap, efficient and mainly earthquake resistant (Andes, 2016). This is where a new construction system has been implemented in the country known as Steel Framing Construction System (Winch, 1998; Hajjar, 2002). The Steel Framing is a construction technique with prefabricated materials, which shall reduce the problems of foundation and seismicity, with a supposed construction time of about 90 days (Ciudadano, 2016). Furthermore, it is a lightweight construction system that allows any type of interior or exterior finish. This system totally or partially replaces the traditional structure (masonry, concrete, etc.) with panels formed with light galvanized steel profiles (Veljkovic and Johansson, 2006; Serrette et al., 2007).

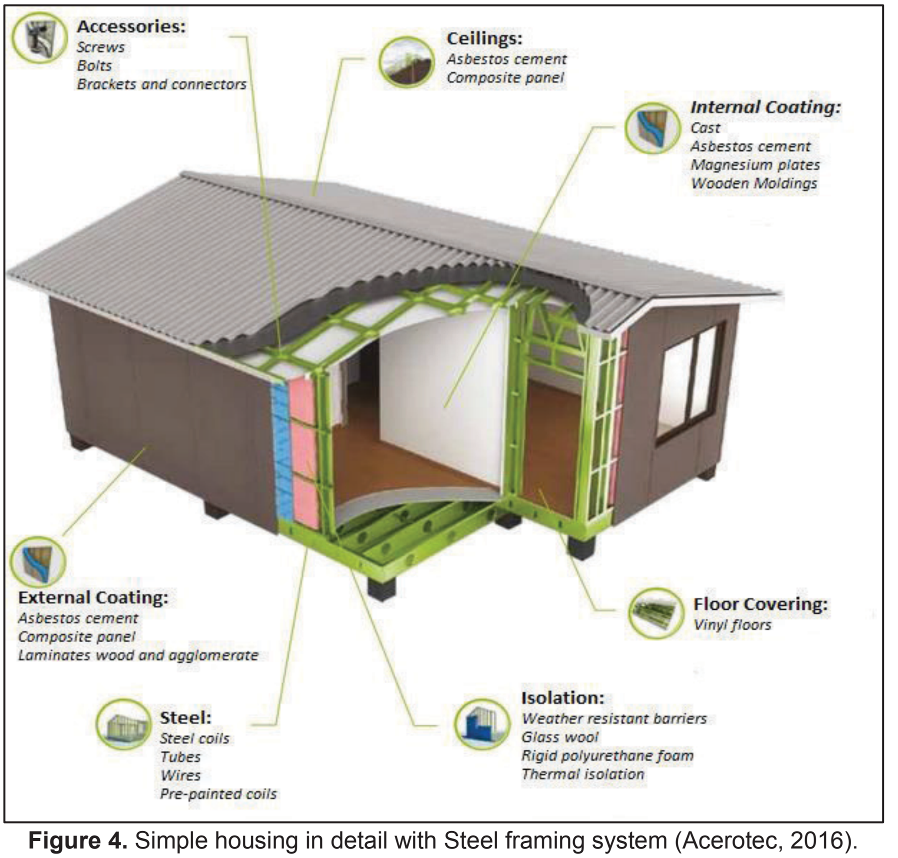


Figure 4. Simple housing in detail with Steel framing system (Acerotec, 2016).

The Steel Framing System has a variety of fundamental characteristics. They are structures built using high strength galvanized lightweight steel frameworks whose profiles in this study have been designed with the Steel 572 grade 40 with an ultimate tensile strength of 415 MPa and tensile strength yield of 290 MPa. (Bolin and Smith, 2011; MatWeb, 2017; Steel Mills of the World, 2017). It has been emphasized that the international standards of construction with the Steel Framing system establish the quality of the steel to be used, which is a guarantee of durability, and it is known that one of the main qualities of steel is to resist better the tensions compared to other materials (AceroTEC, 2016). Other advantages that may be mentioned are the flexibility of the design, reduction of construction times and costs (Dannemann, 2005; Thompson, 2014) Furthermore, Steel Framing is a set consisting of vertical resistant plates, which allows the construction masses to be distributed in these planes with the particularity that they are generally reduced masses, much smaller than traditional masonry constructions (Dannemann, 2005; Thompson, 2014).

The characteristics confer to this constructive system three additional fundamental advantages that are: the inertial seismic forces are relatively small, the resistances of the structural planes contribute efficiently to the stability of the set and in turn confer an additional advantage of a relative high rigidity, as will be verified in later calculations (Gaviria et al., 2013). The foundation depends on the geological study, as they are made suitable to the need of the land using, being mostly structural steel and reinforced concrete. Figure 4 illustrates in detail a simple housing with the Steel Framing system and Figure 5 the assembly of elements to form the Steel Framing (Cayo Palm Beach S.A., 2016; AceroTEC, 2016).

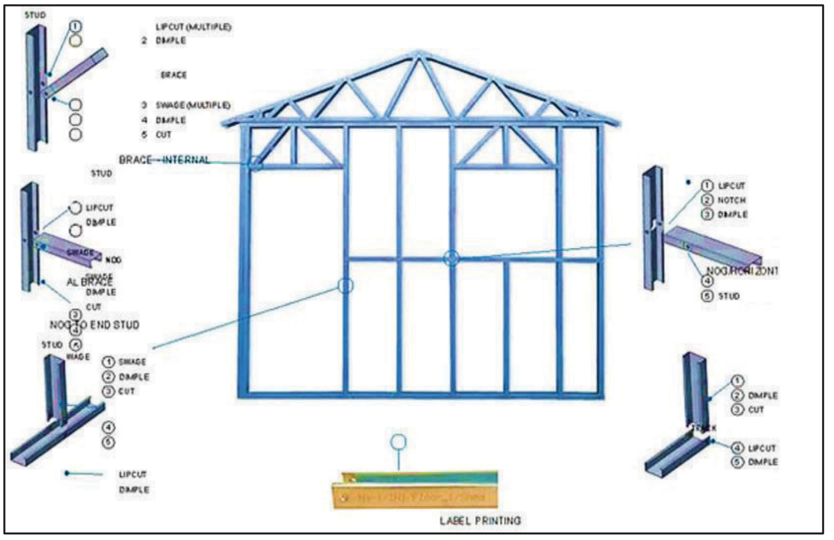
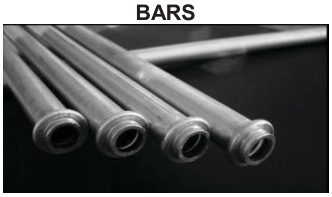
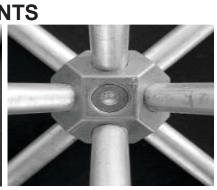


Figure 5. Assembly of elements to form the Steel framing system in a simple house (CAYO PALM BEACH S.A., 2016)

Table 1. Stereo structure Elements**.** Fuente: (Konstandt, Casa Molecule, 2016)

ELEMENTS	CHARACTERISTICS
BARS 	They are cylindrical rigid elements of minimum section that allow conducting axial traction or compression forces along its axis.
JOINTS  	They are the joining points of the bars, and can be constituted by one, two or three elements that have the purpose connect firmly attach the bars.

On the other hand, the Molecule Constructive System mentions that the molecule or molecular is a simplified system, which is able to construct any type of structure using only two elements, being an aluminium tube and a knot, of which it may form any three-dimensional figure (Christopoulos et al., 2008; Konstandt, 2010). In addition, this constructive system is relatively fast, takes up little space and something fundamental is that its weight is relatively low. This structural system allows an optimum anti-seismic behaviour and supports strong winds, since it has the capacity to join other nuclei (nodes) (Konstandt, 2010), which allows the interaction of the structure in a better way, transmitting the efforts over an entire area of application and avoiding that they are concentrated in a single point.

With the aforementioned, the Molecule Structural System is defined as a reticulated spatial structure composed of bars and knots forming a strong and light system. These structures consist of at least two external parallel meshes and an internal connective mesh. Table 1 lists the elements that make up the Molecule System's Stereo structure (Konstandt, 2010).

Figure 6 illustrates the direct assembly of the elements that is made to the Molecule Structural System, while Figure 7 demonstrates the panels used as coatings for the Molecule structure. These types of coatings may be asbestos cement, since their main physical characteristics are to be light and resistant, in addition to be of easy and fast installation.

Figure 6. Assembly of elements of the Molecule Structure

Figure 7. Coating panels for the Molecule Structure (Konstandt, 2012)

RESULTS AND DISCUSSION

The results are determined by a variety of parameters and calculations used, such as (a) the General Geometry of Structures, (b) the Specific Geometry of Structures, (c) the Load Analysis, (d) Results of seismic design parameters, (e) the Seismic Response Spectrum, (f)) The weight of each Constructive System, (g) the Comparison of the floor drifts of each Constructive System, (h) the Results of the Vibration Periods of the structures, (i) the Act on the structures and finally, (j) the PUSHOVER Nonlinear Static Analysis applied to the two Structural Systems.

General Structure Geometry

Due to an architectural design, the general geometry of the structure is presented in Figure 8 and 9, with the respective floor dimensions and heights (meters), which will be used for both, the Molecule and Steel Framing construction systems.

Specific Geometry of Structures

For the specific geometry one achieves the material of the elements, elasticity modules, sections corresponding to each construction system. In the case of the specific geometry of the Steel Framing system, an explanation is given of the general dimensions of the structural elements used for its design shown in Table 2, which have also been used in standard calculation reports in Ecuador. These elements have been coupled to the constructive method to properly combine the theoretical and practical part of engineering. The type of material used for the structural elements is steel with the parameters used of A-572 Grade 40 and $E=2100000$ kg/cm^2.

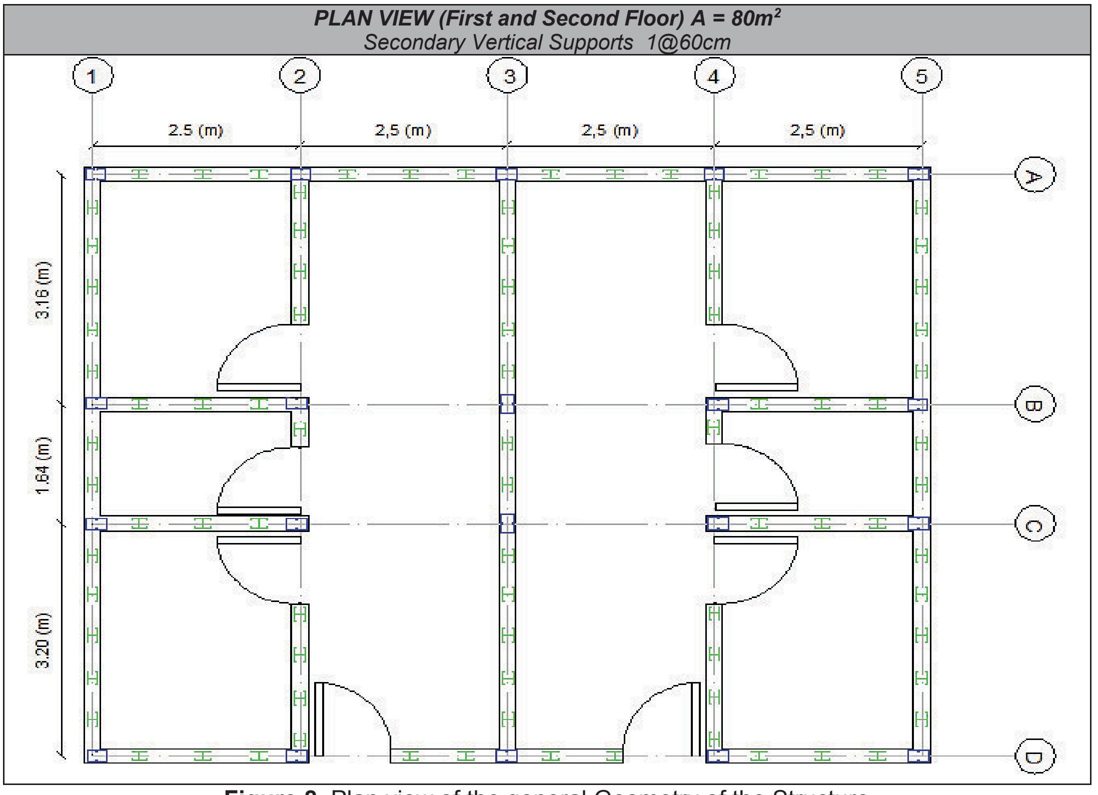


Figure 8. Plan view of the general Geometry of the Structure

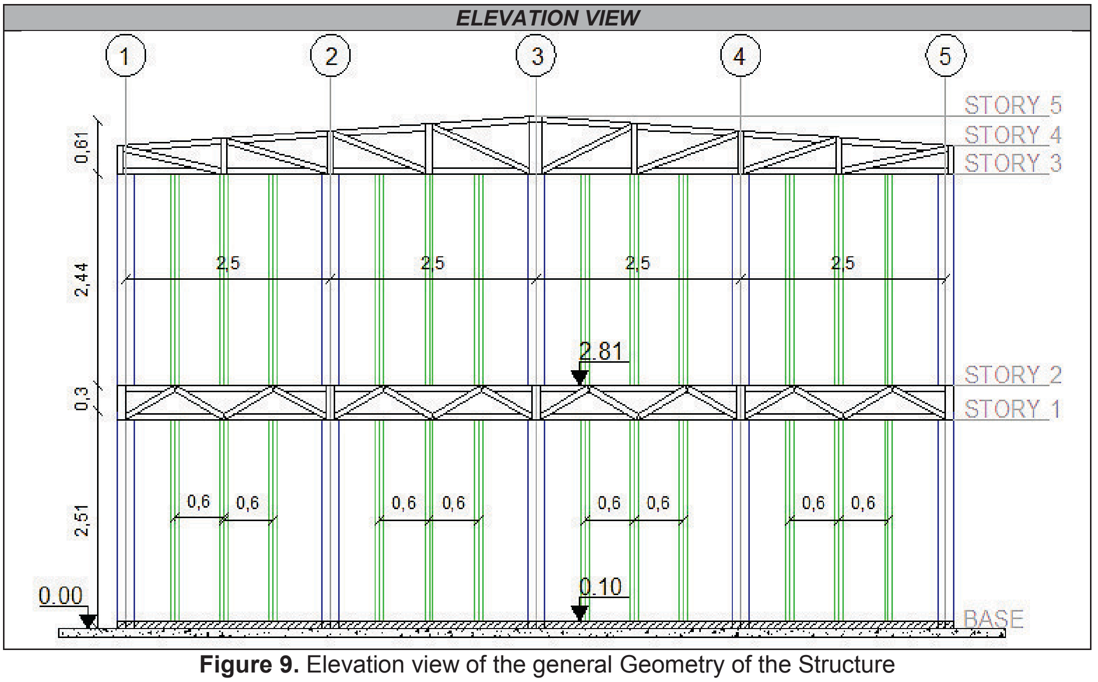


Figure 9. Elevation view of the general Geometry of the Structure

Table 2. Calculated Structural Elements of the Steel framing system distributed in denomination, frame sections and the corresponding observations of each.

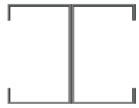
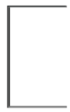
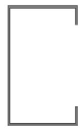
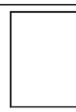
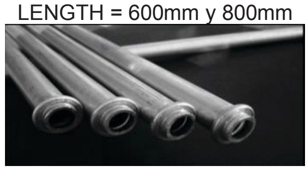
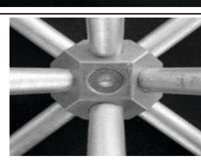
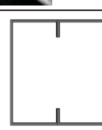
DENOMINATION	FRAME SECTIONS	OBSERVATIONS
STUDS GROUND FLOOR	2G 76x38x12x1.4 	I = 387620 mm^4
TRACKS GROUND FLOOR	C 80x36x1.2 	I = 180863.1 mm^4
TOP / BOTTOM CHORD TRUSS MEZZANINE	C 80x36x1.2 	I = 180863.1 mm^4
TRUSS MEZZANINE	G 76x38x12x1.4 	I = 193810 mm^4
STUDS TOP FLOOR	G 64x50x12x0.75 	I = 90272.9 mm^4
TRACKS TOP FLOOR	C 68x38x0.75 	I = 82829.2 mm^4
TOP / BOTTOM CHORD TRUSS DECK	C 68x38x0.75 	I = 82829.2 mm^4
TRUSS DECK	G 64x50x12x0.75 	I = 90272.9 mm^4

Table 3. Structural Elements of the Molecule system distributed in denomination, frame sections and the corresponding observations of each.

DENOMINATION	FRAME SECTIONS	OBSERVATIONS
PANELS TOP FLOOR AND GROUND FLOOR	EXTERNAL DIAMETER = 30mm THICKNESS = 3mm LENGTH = 600mm y 800mm 	ALUMINIUM BARS
JOINTS		ELEMENT TO JOIN THE BARS
PRINCIPAL COLUMNS GROUND FLOOR and TOP FLOOR	2G 76x38x12x1.4 	I = 387620 mm^4

DENOMINATION	FRAME SECTIONS	OBSERVATIONS
TOP / BOTTOM CHORD TRUSS MEZZANINE	C 80x36x1.2	I = 180863.1 mm^4
TRUSS MEZZANINE	G 76x38x12x1.4	I = 193810 mm^4
TOP / BOTTOM CHORD TRUSS DECK	C 68x38x0.75	I = 82829.2 mm^4
TRUSS DECK	G 64x50x12x0.75	I = 90272.9 mm^4

Table 3 lists the general dimensions of the structural elements used for the design of the Molecule System. It should be mentioned that some of these elements were also applied in the Steel Framing system.

Load Analysis

The structural analysis by vertical load contemplates the basic conditions of dead load and live load, which will help for a correct design of limbs and bars to know its maximum limit of fatigue and to determine its correct dimensions for the definitive design (McCormac et al., 2000). The values for the load analysis will be used according to the regulations of the NEC-SE-CG (NEC, 2015).

Table 4. Loads on the structure

DEAD LOAD		
ELEMENT	**DEAD LOAD**	**UNITS**
Mezzanine	170	Kg/m^2
Deck	20	Kg/m^2
gypsum	25	Kg/m^2
LIVE LOAD		
LEVEL	**LIVE LOAD**	**UNITS**
Mezzanine	200	Kg/m^2
Deck	70	Kg/m^2

In the design, we considered the weight of the structure that depends on the weight of each element depending on the material used, these loads are considered in the structural model directly. Table 4 lists the additional dead loads which correspond to the weight of the finishes basically, and the corresponding live loads according to NEC (2015). The analysis has been performed for static and dynamic lateral loads based on the seismic response spectrum as recommended by NEC (2015).

Seismic Parameters of the Design

The seismic parameters of the design are presented that are rule in Ecuador for constructions of buildings. These values were adapted from NEC (2015), while the design parameters used in our study are listed in Table 5.

Where, ***n:*** Ratio between the spectral acceleration Sa (T=0.1s) and the PGA for the selected return period; ***Fd, Fa, Fs:*** soil amplification coefficients, ***z:*** maximum expected rock acceleration for the designed earthquake, ***r:*** factor used in the elastic design spectrum, whose values depend on the geographic location of the project, ***I:*** Coefficient of Importance (NEC-SE-DS, 2015).

We have also used the Calculation of the Coefficient of Reduction of Structural Response (R). There are several theories for the calculation of the reduction factor, such as the one proposed by Bertero (1986) using the following expression: $R = R_s * R_u * R_{VG} * R_{SR}$, or the proposal of Witthaker et al. (1987) by means of the expression: $R = R_s * R_u * R_\delta$, and the proposal that mentions the (ATC-19, 1995), which considers the R factor equal to the product of: $R = R_\mu * R_\Omega * R_R$.

Table 5. Seismic parameters of design for the structure (NEC-2015).

Location:		*Manabí (Ecuador)*	
Type of ground:		*E*	
Zone:		*VI*	
z	0.50	***r***	1.50
Fd	1.50	***I***	1.00
Fa	0.85	***R***	2.50
Fs	2.00	***ϕE***	1.00
n Manabí	1.80	***ϕP***	1.00

Where, R_μ =Ductility reduction factor, being the factor of reduction of the seismic forces due to the non-linear behaviour of the system under analysis; R_Ω =Resistance factor; R_R =Redundancy factor. The values of these variables are: $R_\mu = 2.5$; $R_\Omega = 1.5$; $R_R = 1$; which gives as final result $R = 3.75$ and were obtained by analysing Figure 10. However, in the Ecuadorian Construction Standard (NEC-SE-DS, 2015) it is mentioned that for cold-formed steel structures the maximum value of R must be 2.5, and this value is used for the analysis of the Mathematical models of the two realized structural systems.

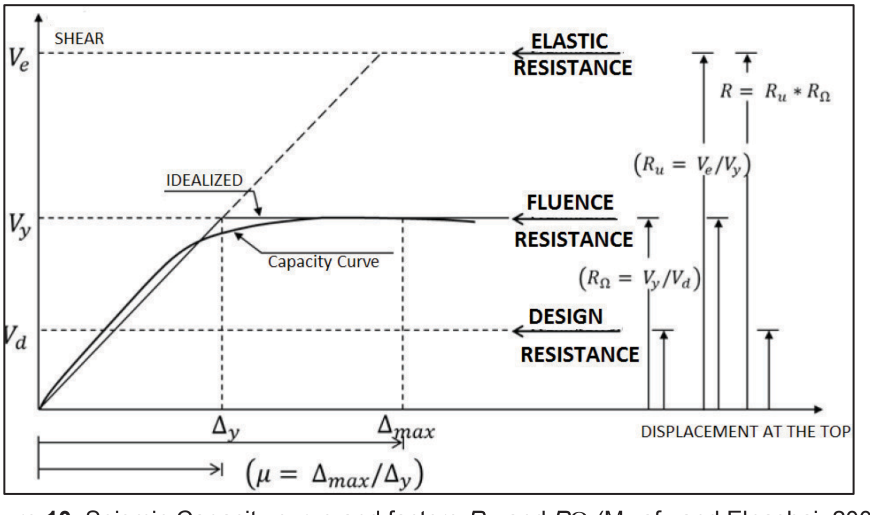


Figure 10. Seismic Capacity curve and factors $R\mu$ and $R\Omega$ (Mwafy and Elnashai, 2002)

The calculation of the elevation and plant configuration factors for the structure was also performed. The factor of ϕE is fundamental since it corresponds to the elevation configuration and refers to the mezzanine height and the vertical configuration of affected systems. The value taken for the analysis in this study is ϕE = 1.00, being constant at all levels. The factor Φp is fundamental because it corresponds to the ideal plant configuration in a structural system. This structure being regular has a Φp = 1. These values are mainly used for the construction of buildings in Ecuador that are found in the regular standard (NEC-SE-RE, 2015).

Analysis of the Seismic Response Spectrum

Seismic action can be defined by elastic response spectra and the vulnerability or fragility of the building through the capacity spectrum (Vargas et al., 2013). These spectra are functions that depend on the period T and are defined as the average of the ratios between ordinates of the response spectrum at the site (Ordaz et al., 2003). Figure 11 illustrates a comparison between the spectrum (structure periods vs. accelerations) for an E-type soil (Manabí) found in NEC (2015) and has been determined as "Elastic" and the spectrum "Inelastic", which is the variant of the elastic spectrum, reduced by the R factor explained above. Furthermore, in the same Figure 11 at the value of R = 2.5 it decreases to the inelastic spectrum by 60% with respect to the elastic spectrum, which means that there is a greater reduction in the value for the calculation of the shear force found in the Base of the structure, known as basal biting.

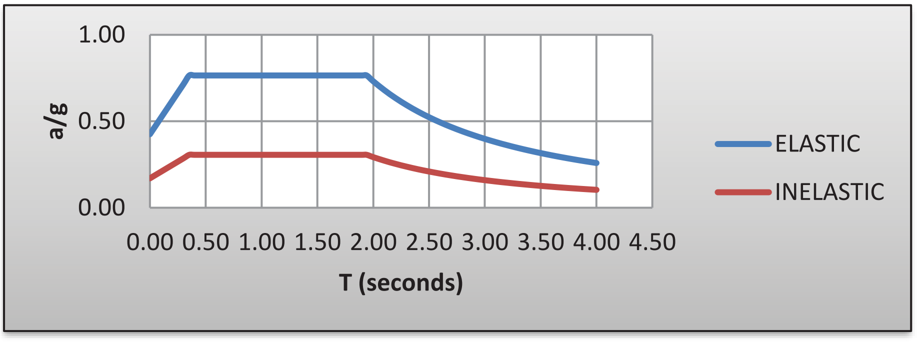


Figure 11. Graph corresponding to the Design Spectrum of Manabí (NEC, 2015)

Determination of the Weight of each Structure

Figure 12 demonstrates the mathematical models for both structural systems that were developed by a software of design and structural calculation, while Table 6 lists the total weights per floor and weight calculated for the Steel Framing and Molecule systems.

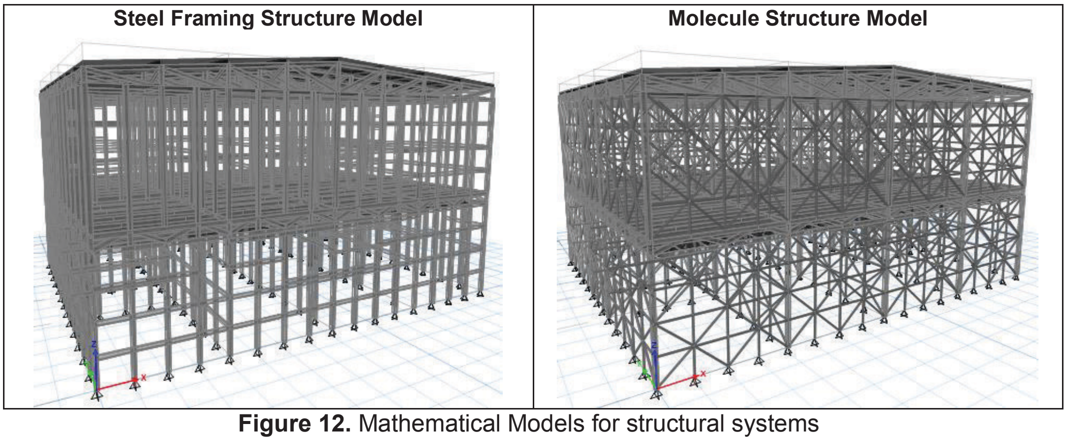


Figure 12. Mathematical Models for structural systems

As appreciated in Table 6, the weight of the Molecule structure decreased down to11.02% with respect to the weight of the Steel Framing structure, which indicates that the molecule system is lighter (Figure 12). It should be noted that both systems are designed with main steel columns. However, the existing difference occurs due to the fact that the elements that are attached to these steel columns in the structure Steel Framing are steel bars, while in the Molecule structure are aluminium bars, which finally results towards the mentioned weight differences.

Table 6. Weights of the Structures

STEEL FRAMING		Molecule Structure	
STORY	UZ	STORY	UZ
	kg		kg
Story 5	295,02	Story 5	313,77
Story 4	56,24	Story 4	64,98
Story 3	960,8	Story 3	670,39
Story 2	4671,55	Story 2	4411,02
Story 1	1061,56	Story 1	808,57
Total	***7045,17***	***Total***	***6268,73***

Floor Drifts

For the analysis of the seismic performance of a structure and structural failures of the elements, the measurement of drift between floors and the maximum rotation of the plastic hinges (Guerra et al., 2012; Daza, 2003) are generally taken as control parameters. According to NEC (2015) it is established that the maximum drift limit for any floor will not exceed the limits of the inelastic drift, in which the maximum drift is expressed as a percentage of the floor height. For metal structures, the Maximum drift is 2%. (ΔM=0.02), $\Delta M = \Delta elastic * R * 0.75$ (NEC, 2015). From the analysis obtained from the calculation in each of the structures listed in Table 7, it is evident that the produced drifts are less than the maximum permissible by the standard, which guarantees that the structures will not suffer severe damages in the case of occurrence of the designed or expected earthquake.

Table 7. Story Drifts

STEEL FRAMING STRUCTURE			MOLECULE STRUCTURE		
Story	Load Case/Combo	Inelastic Drift	Story	Load Case/Combo	Inelastic Drift
Story 5	sismoy 1	0,0001	Story 5	sismoy 1	0,0001
Story 4	sismox 1	0,0004	Story 4	sismoy 2	0,0001
Story 3	sismoy 1	0,0007	Story 3	sismox 1	0,0002
Story 2	sismoy 1	0,0022	Story 2	sismoy 1	0,0002
Story 1	Sismoy 1	0,0071	Story 1	sismox 2	0,0006

The maximum drift in the Steel Framing structure is at level 1 with 0.0071 and the maximum drift in the Molecule structure is located on the 1st floor with 0.0006 (Table 7). Thus, the two structures are lower with respect to the maximum drift for metal structures. It should be taken into account that the Molecule structure has less floor drift than the Steel Framing structure because the Molecule System acts as an armour throughout the structure due to the joints generated by the aluminium bars, which also function as co-braces between each main metal column.

Vibration Periods

The dynamic response of a structure during the action of an earthquake depends on the relationship between the period of vibration of the seismic waves and its own period of vibration (Caicedo, 2014). The analysis of the structure period is necessary to determine its response to seismic movements that may occur. For a correct study of structural stiffening systems in buildings, it is necessary to use the maximum periods of vibration as parameters of comparison (Rodriguez, 2007). The analysis of the vibration periods of the two structural systems are presented in Table 8.

The vibration periods in the Molecule Structure are much smaller than those of the Steel Framing Structure and it is due to the above explained that in the Molecule System the aluminium bars act as a reinforcement and between steel columns (Table 8). It should be noted that the periods obtained for the Steel Framing structure have been corroborated by calculations made by a construction company that has implemented this system in Ecuador.

Table 8. Periods of Vibration

STEEL FRAMING STRUCTURE							MOLECULE STRUCTURE					
Case	Mode	Period seconds	UX	UY	RZ		Case	Mode	Period seconds	UX	UY	RZ
Modal	1	***0,319***	0,0002	0,879	0,121		Modal	1	***0,112***	0.0000	0,9881	0,0000
Modal	2	***0,274***	0,9989	0,000	0,000		Modal	2	***0,101***	0,9886	0,0000	0,0000
Modal	3	***0,203***	0,0001	0,120	0,879		Modal	3	***0,080***	0,0000	0,0000	0,9930
TOTAL			***1,00***	***1,00***	***1,00***		***TOTAL***			***1,0***	***1,0***	***1,0***

Comparison between Axial Forces of each structure

Axial forces are forces that act on the entire axis of the structural elements and allow them to work under compression or traction, in addition to the design and dimensioning of structural elements (Timoshenko et al., 1998; McCormac et al., 2000; Nilson et al., 1999). Figure 13 shows the axial force diagrams produced in both structures. We focused on the lower column located in the central axis to perform a more specific analysis, with which it may be concluded that in the Steel Framing structure a much lower axial value has been produced than in the Molecule structure.

Non-Linear Static Analysis PUSHOVER applied to both Structural Systems

The nonlinear PUSHOVER analysis helps to determine the seismic demand in the structures and their behaviour to lateral forces applied in the same until their fluence (López, 2016). The PUSHOVER analysis is based on the theory of structural dynamics with invariant force distribution (Chopra, 2002). Figure 14 demonstrates the comparison between the PUSHOVER curves of the Steel Framing System and Molecule System.

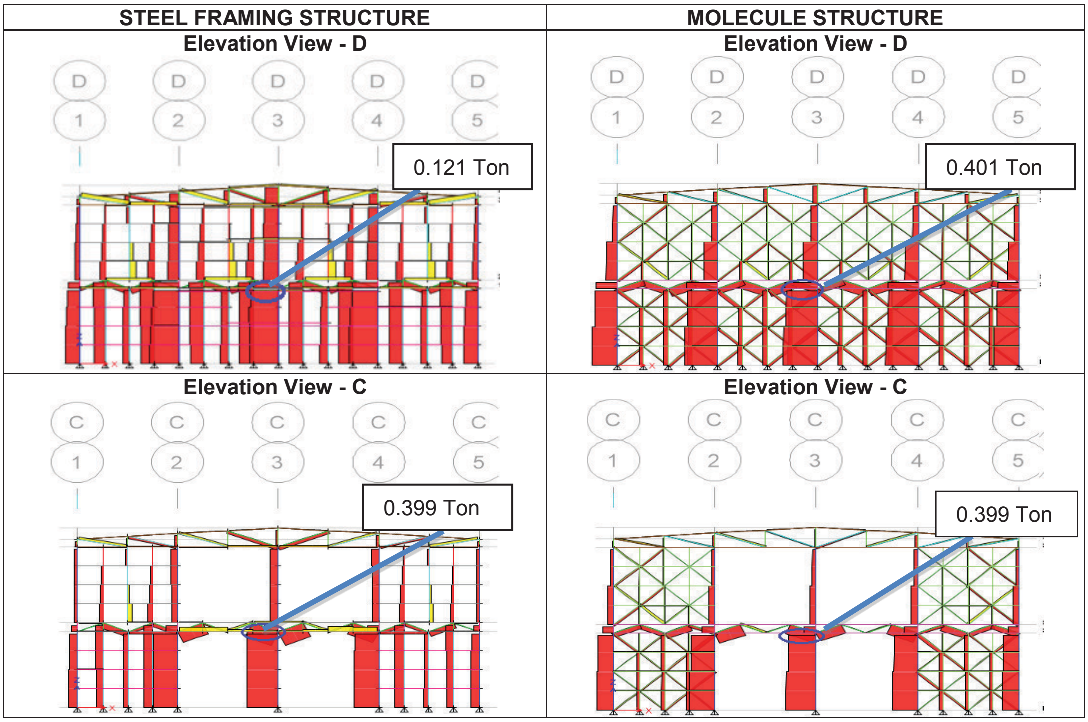


Figure 13. Axial Force in frames of the structures

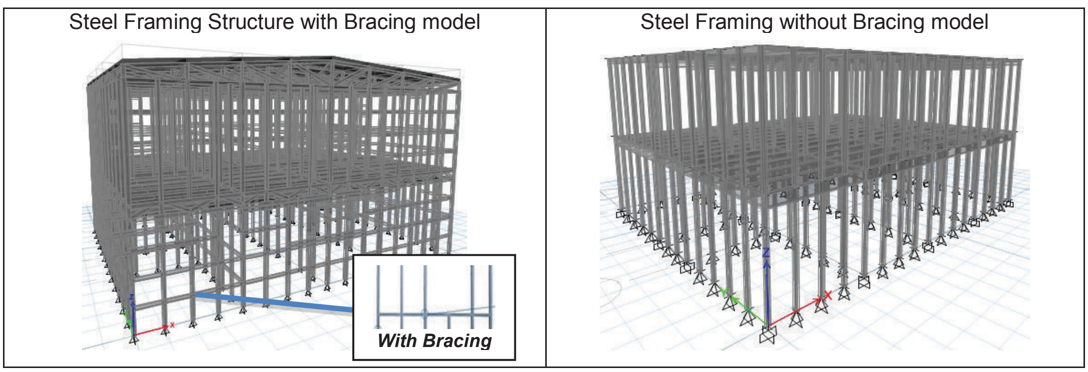


Figure 14. Mathematical Models for structural systems

In Figure 15, the pushover curve for the Steel Framing structure with braces is able to withstand more shear force than the structure without coarsening, although the displacement of the two structures does not make much difference. It should be emphasized that the braces prevent the main columns from buckling, since they function as stiffeners. The pushover curve for the Steel Framing structure shows that it can withstand greater force than the Molecule system, although the displacement of the two structures may be similar (Figure 17).

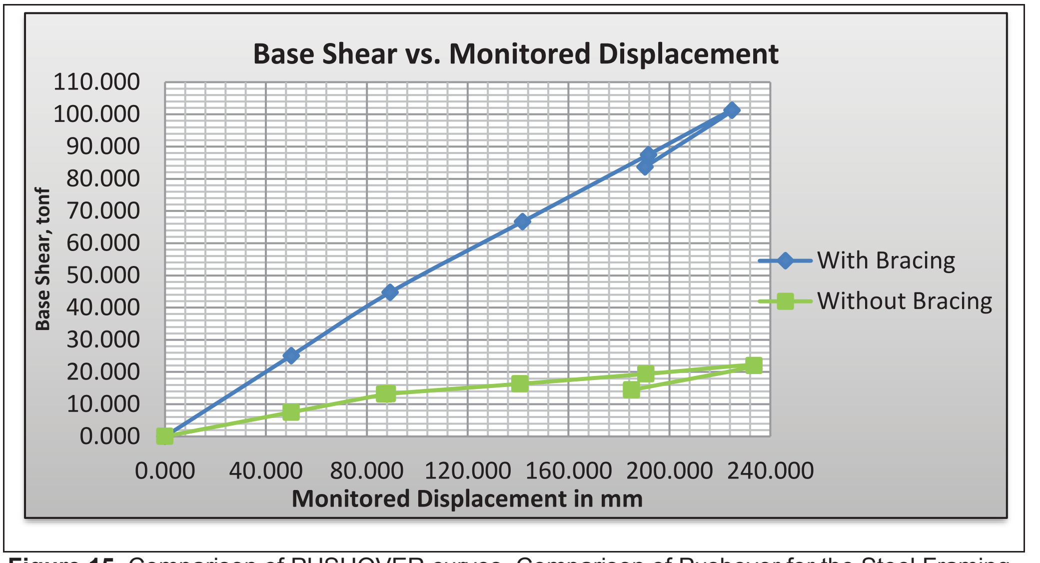


Figure 15. Comparison of PUSHOVER curves. Comparison of Pushover for the Steel Framing Structure with and without Bracing

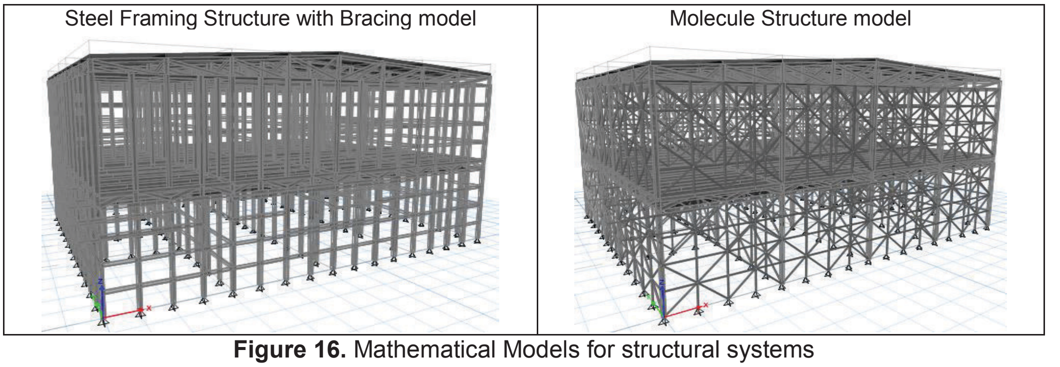


Figure 16. Mathematical Models for structural systems

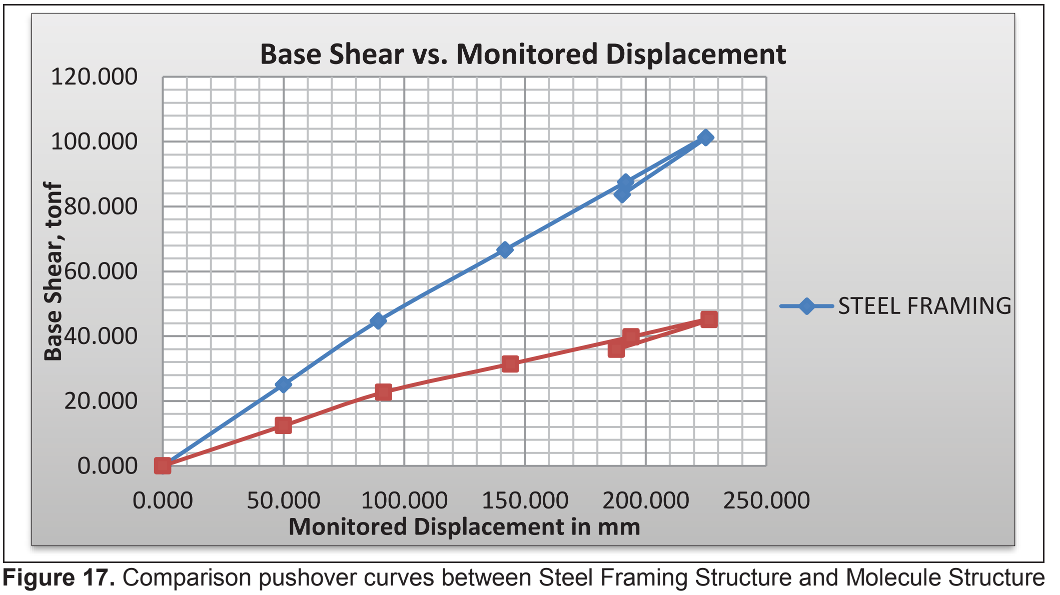


Figure 17. Comparison pushover curves between Steel Framing Structure and Molecule Structure

CONCLUSIONS

The designs of the structures comply with all the requirements in force in the Ecuadorian Construction Standard (NEC, 2015), and international construction, because the results obtained are within the permissible ranges both in terms of safety of gravitational loads and seismic based on a structural calculation using mathematical models.

The Molecule System is 11% lighter than the Steel Framing structure, because the elements that connect the steel columns in the Steel Framing structure are steel bars, whereas in the Molecule structure are of aluminium bars, which affects significantly the difference of weights.

The Molecule structure has less floor drift than the Steel Framing structure, because the Molecule System acts as a reinforcement throughout the structure due to the joints generated by the aluminium bars that also function as co-ordinates between each main metallic column. In addition, the analysis of the PUSHOVER determined that the structures work by hyperestaticity.

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REFERENCES

AceroTec (2016). Acero Tec. http://www.acerotec.com.ec/index.php/sistema-lsf/conoce-el-sistema

AISC, A. I. (2010). Specification for Structural Steel Buildings ANSI/AISC 360-10.

AISI (American Iron and Steel Institute), 2008. Cold-formed Steel Design Manual. D100-08 ed. American Iron and Steel Institute. Washington, DC

Atakan, K. (1995). Mass wasting triggered by the 5 March 1987 Ecuador earthquakes. *Earthquake Engineering*, 29, 21-42.

Audemard, F. A. (2006). Surface rupture of the Cariaco July 09, 1997 earthquake on the El Pilar fault, northeastern Venezuela. Tectonophysics, 424(1), 19-39.

Audemard, F. A. (2007). Revised seismic history of the El Pilar fault, Northeastern Venezuela, from the Cariaco 1997 earthquake and recent preliminary paleoseismic results. *Journal of Seismology*, 11(3), 311-326.

Barazangi M. and Isacks B.L. (1976): Spatial distribution of earthquakes and subduction of the Nazca Plate beneath South America. *Geology* 4: 686–692.

Beauval, C., Yepes, H., Bakun, W. H., Egred, J., Alvarado, A. and Singaucho, J. C. (2010). Locations and magnitudes of historical earthquakes in the Sierra of Ecuador (1587–1996). *Geophysical Journal International*, 181(3), 1613-1633.

Berz, G. (1988). List of major natural disasters, 1960–1987. *Natural Hazards*, 1(1), 97-99.

Bolin, C. A., and Smith, S. T. (2011). Life cycle assessment of borate-treated lumber with comparison to galvanized steel framing. *Journal of Cleaner Production*, 19(6), 630-639.

Brzev, S. (2007). Earthquake-resistant confined masonry construction. NICEE, National Information Center of Earthquake Engineering, Indian Institute of Technology Kanpur.

Carrillo, J. and González, G. (2007). Influencia de la mampostería no reforzada en el comportamiento inelástico de pórticos de concreto. *Dyna*, 74(152), 217-226.

Cayo Palm Beach S.A. (2016). CAYO PALM BEACH S.A. Steel Framing System. http://cayopalmbeach.com.ec/#!/sistemasteelframe

Christopoulos, C., Tremblay, R., Kim, H. J. and Lacerte, M. (2008). Self-centering energy dissipative bracing system for the seismic resistance of structures: development and validation. *Journal of Structural Engineering*, 134(1), 96-107.

Chunga, K. and Toulkeridis, T. (2014). First evidence of paleo-tsunami deposits of a major historic event in Ecuador. *Science of Tsunami Hazards*, 33: 55-69.

Ciudadano (2016). At 26.09.2016 Radio Huancavilca. http://radiohuancavilca.com.ec/noticias/2016/08/05/otras-157-unidades-educativas-siglo-xxi-se-sumaran-la-inversion-del-gobierno-esmeraldas-manabi-santo-domingo/

D'Ayala, D. and Speranza, E. (2003). Definition of collapse mechanisms and seismic vulnerability of historic masonry buildings. *Earthquake Spectra*, 19(3), 479-509.

Daly, M.C. (1989). Correlations between Nazca/Farallon plate kinematics and forearc basin evolution in Ecuador. *Tectonics* 8 (4), 769–790.

Dannemann, R. (2005). Manual de Ingeniería de Steel Framing. 1ª ed., Ed. Instituto Latinoamericano del Fierro y Acero. Santiago de Chile, Chile. 147pp

Daza, L. (2003). Nuevo enfoque para determinar el factor de modificación de respuesta. *Revista internacional de desastres naturales, accidentes e infraestructura civil*, 3(1), 33-48.

De Mets, C., Gordon, R.G., Argus, D.F. and Stein, S. (1989). Current plate motions. *Geophys. J.* 101, 425–478.

Duke, C. M. and Leeds, D. J. (1959). Soil conditions and damage in the Mexico earthquake of July 28, 1957. *Bulletin of the Seismological Society of America*, 49(2), 179-191.

Dumont, J. F., Santana, E. and Vilema, W. (2005) Morphologic evidence of active motion of the Zambapala Fault, Gulf of Guayaquil (Ecuador). *Geomorphology*, 65(3), 223-239.

Dumont, J. F., Santana, E., Bonnardot, M. A., Pazmiño, N., Pedoja, K. and Scalabrino, B. (2014). Geometry of the coastline and morphology of the convergent continental margin of Ecuador. *Geological Society London Memoirs*, 41(1), 327-338.

Engdahl, E.R. and Villasenor, A. (2002). Global Seismicity: 1900–1999, in International Handbook of Earthquake and Engineering Seismology, Part A, Chapter 41, pp. 665–690, eds Lee, W.H.K., Kanamori, H., Jennings, P.C. and Kisslinger, C., Academic Press.

Felice, G. D. and Giannini, R. (2001). Out-of-plane seismic resistance of masonry walls. *Journal of earthquake engineering*, 5(02), 253-271.

Freymuller, J.T., Kellogg, J.N., Vega, V. (1993): Plate motions in the north Andean region. *Journal of Geophysical Research*, 98: 21853– 21863.

Ganse, R. A., and Nelson, J. B. (1982). Catalog of significant earthquakes 2000 BC to 1979, including quantitative casualties and damage. *Bulletin of the Seismological Society of America*, 72(3), 873-877.

Gaviria, C. A. M., Guerrero, A. P. Z. and Thomson, P. R. (2013). Modelo no lineal en elementos finitos para muros livianos con entramados de acero sujetos a carga lateral/A nonlinear finite element model of lightweight walls with cold formed steel members under lateral load. *Revista Facultad de Ingeniería Universidad de Antioquia*, (69), 136-151.

González, J., Schmitz, M., Audemard, F., Contreras, R., Mocquet, A., Delgado, J. and De Santis, F. (2004). Site effects of the 1997 Cariaco, Venezuela earthquake. *Engineering Geology*, 72(1), 143-177.

Guerra, C. and Quintana, M. (2012). Desempeño sísmico de un edificio aporticado de 5 pisos diseñado con el reglamento nacional de edificaciones, pero aceptando una deriva máxima de 1%. Trabajo para optar el título de ingeniero civil, Pontificia Universidad Católica Del Perú, Lima, Perú.

Gutscher, M.A., Malavieille, J.S.L. and Collot, J.-Y. (1999). Tectonic segmentation of the North Andean margin: impact of the Carnegie ridge collision. *Earth Planet. Sci. Lett*. 168, 255–270.

Hajjar, J. F., (2002). Composite steel and concrete structural systems for seismic engineering. *Journal of Constructional Steel Research*, 58(5), 703-723.

Hamid, N. H. A., Mohamad, N. M., Hamid, Z. A., & Ghani, S. H. A. (2014). Seismic behaviour of precast shear key wall under in-plane lateral cyclic loading. *Malaysian Construction Research Journal*, 15(2), 63-73.

Hashash, Y. M., Hook, J. J., Schmidt, B., John, I. and Yao, C. (2001). Seismic design and analysis of underground structures. *Tunnelling and underground space technology*, 16(4), 247-293.

Housner, G. (1984). An historical view of earthquake engineering. *Revista de Ingeniería Sísmica*, (31), 1-16.

Hughes, R. A., Pilatasig, L. F. (2002): Cretaceous and Tertiary terrane accretion in the Cordillera Occidental of the Andes of Ecuador. *Tectonophysics*, 345: 29–48.

Jaafar, M. S., Hamid, N. H. A., & Mahmood, N. H. (2016). The behaviour of rocking multi-column pier of unskewed bridge under seismic performance using quasi-static lateral cyclic loading. *Malaysian Construction Research Journal*, *19*(2), 29-37.

Jaillard, E., Ordoñez, M., Benitz, S., Jimenez, G., Montengro, N. and Zambrano, G. (1995). Basin development in an accretionary, oceanic-floored fore-arc setting: southern coastal Ecuador during Late Cretaceous–Late Eocene times. In: S.S.R.a.W.H.J., Tankard, A.J. (Eds.), Petroleum Basins of South America. *American Association of Petroleum Geologists*, pp. 615–631.

Juhásová, E., Sofronie, R. and Bairrão, R. (2008). Stone masonry in historical buildings—Ways to increase their resistance and durability. *Engineering Structures*, 30(8), 2194-2205.

Kahn, M. E. (2005). The death toll from natural disasters: the role of income, geography, and institutions. *Review of economics and statistics*, 87(2), 271-284.

Kellogg, J.N. and Vega, V. (1995). Tectonic development of Panama, Costa Rica and the Colombian Andes: Constraints from Global Positioning System geodetic studies and gravity. *Geol. Soc. Am. Special Paper,* 295, 75–90.

Klingner, R. E. (2006). Behavior of masonry in the Northridge (US) and Tecomán–Colima (Mexico) earthquakes: Lessons learned, and changes in US design provisions. *Construction and Building Materials*, 20(4), 209-219.

Konstandt, M. (2010). Estructuras Espaciales, Estereoestructuras. http://www.molecule.com.ar/pdf/Estereoestructuras-Teoria1.pdf: 4pp

Lonsdale, P. (1978). Ecuadorian Subduction System. *Bulletin of the American Association of Petroleum Geologists*, 62: 2454– 2477.

Lourenço, P. B., Rots, J. G., and Blaauwendraad, J. (1998). Continuum model for masonry: parameter estimation and validation. *Journal of Structural Engineering*, 124(6), 642-652.

Mat Web (Mat Web Material Property Data) (2017). http://www.matweb.com

McCormac, J. C., Csernak, S. F., and Díaz, L. Á. L. (2000). Diseño de estructuras de acero. Alfaomega Grupo Editor.

Mendoza C. and Dewey J.W. (1984): Seismicity associated with the Great Colombia – Ecuador Earthquakes of 1942, 1958, and 1979: Implications for barriers models of earthquake rupture. *Bull. Seism. Soc. Am*. 74 (2): 577–593.

Mendoza, M. J. and Auvinet, G. (1988). The Mexico earthquake of September 19, 1985—behavior of building foundations in Mexico City. *Earthquake Spectra*, 4(4), 835-853.

Minke, G. (2001). Manual de construcción para viviendas antisísmicas de tierra. Forschungslabor für Experimentelles Bauen Universidad de Kassel.

Myers, J. J., Belarbi, A. and El-Domiaty, K. A. (2004). Blast resistance of FRP retrofitted un-reinforced masonry (URM) walls with and without arching action. *The Masonry Society Journal*, 22(1), 9-26.

NEC (Norma Ecuatoriana de la Construcción) (2015). Estructura de Acero, Cargas No Sísmicas.

Ordaz, M., Miranda, E., and Avilés, J. (2003). Propuesta de espectros de diseño por sismo para el DF. *Revista Internacional de Ingeniería de Estructuras*, 8(2), 189-207.

Papazoglou, A. J. and Elnashai, A. S. (1996). Analytical and field evidence of the damaging effect of vertical earthquake ground motion. *Earthquake engineering and structural dynamics*, 25(10), 1109-1138.

Pararas-Carayannis, G. (2012): Potential of tsunami generation along the Colombia/Ecuador subduction margin and the Dolores-Guayaquil Mega-Thrust. *Science of Tsunami Hazards*, 31, 3: 209-230.

Parra, H., Benito, M. B. and Gaspar-Escribano, J. M. (2016). Seismic hazard assessment in continental Ecuador. *Bulletin of Earthquake Engineering*, 14(8), 2129-2159.

Rababeh, S., Al Qablan, H., Abu-Khafajah, S. and El-Mashaleh, M. (2014). Structural utilization of wooden beams as anti-seismic and stabilising techniques in stone masonry in Qasr el-Bint, Petra, Jordan. *Construction and Building Materials*, 54, 60-69.

Raj, K., Moskowitz, B. and Casciari, R. (1995). Advances in ferrofluid technology. *Journal of magnetism and magnetic materials*, 149(1-2), 174-180.

Rodríguez Espinosa, F., Toulkeridis, T., Salazar Martinez, R., Cueva Girón, J., Taipe Quispe, A., Bernaza Quiñonez, L., Padilla Almeida, O., Mato, F., Cruz D´Howitt, M., Parra, H., Sandoval, W. and Rentería, W., 2017: Economic evaluation of recovering a natural protection with concurrent relocation of the threatened public of tsunami hazards in central coastal Ecuador. *Science of Tsunami Hazards,* 36: 293-306.

Rosenblueth, E. (1960). The earthquake of 28 July 1957 in Mexico City. In *Proceedings of the 2nd WCEE*, Vol. 1, 359-379.

Saatcioglu, M., Ghobarah, A. and Nistor, I. (2006). Performance of structures in Indonesia during the December 2004 great Sumatra earthquake and Indian Ocean tsunami. *Earthquake Spectra*, 22(S3), 295-319.

Sarmanho, A. and Morales de Castro, R. (2007). Steel Framing. Santiago: Instituto Latinoamericano del Fierro y el Acero.

Sarris, A., Loupasakis, C., Soupios, P., Trigkas, V. and Vallianatos, F. (2010). Earthquake vulnerability and seismic risk assessment of urban areas in high seismic regions: application to Chania City, Crete Island, Greece. *Natural hazards*, 54(2), 395-412.

Schlune, H., Plos, M. and Gylltoft, K. (2011). Safety formats for nonlinear analysis tested on concrete beams subjected to shear forces and bending moments. *Engineering structures*, 33(8), 2350-2356.

Schuster, R. L., Nieto Thomas, A. S., O'Rourke, T. D., Crespo, E. and Plaza-Nieto, G. (1996). Mass wasting triggered by the 5 March 1987 Ecuador earthquakes. *Engineering geology*, 42(1), 1-23.

Serrette, R., Encalada, J., Hall, G., Matchen, B., Nguygen, H. and Williams, A. (2007). Additional shear wall values for light weight steel framing. AISI-Specifications for the Design of Cold-Formed Steel Structural Members. 118, American Iron and Steel Institute, Research Report RP97-2. 102pp

Shing, P. B., Schuller, M., and Hoskere, V. S. (1990). In-plane resistance of reinforced masonry shear walls. *Journal of structural Engineering*, 116(3), 619-640.

Shumway, G. (1954). Carnegie ridge and Cocos ridge in the East Equatorial Pacific. *The Journal of Geology,* 62(6), 573-586.

Steel Mills of the World (2017). http://www.steelmillsoftheworld.com/qualities/steel_grades_american_standards.pdf

Taghdi, M., Bruneau, M. and Saatcioglu, M. (2000). Seismic retrofitting of low-rise masonry and concrete walls using steel strips. *Journal of Structural Engineering*, 126(9), 1017-1025.

Tena-Colunga, A., Juárez-Ángeles, A. And Salinas-Vallejo, V. H. (2009). Cyclic behavior of combined and confined masonry walls. *Engineering Structures*, 31(1), 240-259.

Thomson, P. (2014). A nonlinear finite element model of lightweight walls with cold formed steel members under lateral load. *Revista Facultad de Ingeniería*, (69), 136-151.

Tibaldi, A., Ferrari, L. and Pasquarè, G. (1995). Landslides triggered by earthquakes and their relations with faults and mountain slope geometry: an example from Ecuador. *Geomorphology*, 11(3), 215-226.

Tomazevic, M. (1999). Earthquake-resistant design of masonry buildings (Vol. 1). World Scientific.

Tomaževič, M. and Klemenc, I. (1997). Verification of seismic resistance of confined masonry buildings. *Earthquake Engineering & Structural Dynamics*, 26(10), 1073-1088.

Toulkeridis, T. and Zach, I. (2017): Wind directions of volcanic ash-charged clouds in Ecuador – Implications for the public and flight safety. *Geomatics, Natural Hazards and Risks*, 8(2): 242- 256.

Toulkeridis, T., Chunga, K., Rentería, W., Rodriguez, F., Mato, F., Nikolaou, S., Cruz D´Howitt, M., Besenzon, D., Ruiz, H., Parra, H. and Vera-Grunauer, X. (2017c): The 7.8 M_w Earthquake and Tsunami of the 16th April 2016 in Ecuador - Seismic evaluation, geological field survey and economic implications. *Science of Tsunami Hazards*, 36: 197-242.

Toulkeridis, T., Mato, F., Toulkeridis-Estrella, K., Perez Salinas, J.C., Tapia, S. and Fuertes, W. (2018): Real-Time Radioactive Precursor of the April 16, 2016 Mw 7.8 Earthquake in Ecuador. *Science of Tsunami Hazards*, 37: 34-48.

Toulkeridis (2011): Volcanic Galápagos Volcánico. Ediecuatorial, Quito, Ecuador: 364pp.

Toulkeridis, T. (2013): Volcanes Activos Ecuador. Santa Rita, Quito, Ecuador: 152 pp

Trenkamp, R., Kellogg, J.N., Freymueller, J.T., Hector Mora, P. (2002). Wide plate margin deformation, southern Central America and northwestern South America, CASA GPS observations. *J. South Am. Earth Sci*. 15, 157–171.

USGS/NEIC (United States Geological Survey/National Earthquake Information Center) (2017). Search Earthquake catalogue, http://earthquake.usgs.gov/earthquakes/search/

Vargas, Y. F., Pujades, L. G., Barbat, A. H. and Hurtado, J. E. (2013). Evaluación probabilista de la capacidad, fragilidad y daño sísmico de edificios de hormigón armado. *Revista internacional de métodos numéricos para cálculo y diseño en ingeniería*, 29(2), 63-78.

Veljkovic, M. and Johansson, B. (2006). Light steel framing for residential buildings. *Thin-walled structures*, 44(12), 1272-1279.

Vielma, J. C., Barrios, A. and Alfaro, A. (2016). Numerical Study of the Seismic Response of a Mid-Rise RC Building Damaged by 2009 Tucacas Earthquake. In Earthquakes and Their Impact on Society (pp. 345-361). Springer International Publishing.

Winch, G. (1998). Zephyrs of creative destruction: understanding the management of innovation in construction. *Building research & information*, 26(5), 268-279.

Ye, L., Kanamori, H., Avouac, J. P., Li, L., Cheung, K. F., and Lay, T. (2016). The 16 April 2016, M W 7.8 (M S 7.5) Ecuador earthquake: A quasi-repeat of the 1942 M S 7.5 earthquake and partial re-rupture of the 1906 M S 8.6 Colombia–Ecuador earthquake. *Earth and Planetary Science Letters*, 454, 248-258.

Yoshimichi, K., Nobuyoshi, U., Ryoichi, K., and Yoshifumi, S. (1999). Seismic Resistance and Design of Steel-Framed Houses. *Nippon Steel Technical*, 16.

Zhao, B., Taucer, F. and Rossetto, T. (2009). Field investigation on the performance of building structures during the 12 May 2008 Wenchuan earthquake in China. *Engineering Structures*, 31(8), 1707-1723.

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WATER PERMEABILITY AND CARBONATION MODELLING OF DIFFERENT VARIANTS OF CONCRETE USING ANN

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Abstract
Corrosion of reinforcement is a major durability problem in the RCC structures. Carbonation is one of the causes of corrosion of the reinforcement. Carbonation of reinforced concrete structures reduces the pH of concrete which increases the rate of corrosion of steel reinforcement. The accurate assessment of this carbonation depth for different concrete mixes by virtue of lab analysis is not adequate and henceforth was further simulated, predicted and validated using neural network. The artificial neural network used in this study is of multi layered perceptron type comprising of three layers. After simulation training of the neural network, it was further implemented for this study in order to predict concrete carbonation depth. This paper presents a comparative study of the performance curves, regression plots, predicted values and error histograms of the different variants of concrete mixes included in this study. Accordingly, the values of carbonation depth predicted by the aforesaid neural network matches the lab obtained values very accurately, which would further aid in various endeavours such as anticipating durability, life of concrete structures as well as in identifying a particular concrete mix for a specific set of conditions.

Keywords: *Carbonation, Artificial Neural Network, PPC, PSC.*

INTRODUCTION

Carbonation of concrete has been identified as one of the foremost causes of premature degradation, loss of serviceability and safety of Reinforced Concrete Structures (RCC) (Taffese et al., 2015). In Carbonation induced corrosion, atmospheric carbon dioxide penetrates inside the concrete. Penetrated CO_2 dissolves in the pore solution to form carbonic acid, which reacts with calcium hydroxide and un-hydrated silicates in the cement paste, forming mainly calcium carbonate (Talakokulaa et al., 2016; Silva et al., 2015). This reaction reduces the pH of the concrete pore solution lies in between 12 to 13, which will decrease due to carbonation to a value up to 9 or some time up to 8 (Papadakis et al., 1992).

Carbonation rates vary depending on factors such as: type and amount of cement used, concrete porosity, curing time, and type and quantity of minerals added (Baker, 1988; Moreno and Sagues, 1998). This necessitates the prediction of concrete carbonation depth in concrete structures, which further facilitates the assessment of durability and life of these RCC structures. A number of laboratory as well as mathematical models already exist for the prediction of carbonation depth. However, it is very difficult to consider the various parameters influencing as well as inducing carbonation in concretes. In view of this, the new approach of use of Artificial Neural Network (ANN) for the prediction of carbonation depth in different variants of concrete mixes has been undertaken. The different concrete mixes included in the present study were Portland Pozzolana Cement (PPC) with quarry dust and sand as well as Portland Slag Cement (PSC) with quarry dust and sand.

EXPERIMENTAL PROGRAM

Carbonation Tests

Concrete samples were cast and cured for 28 days. The three concrete cubes with different water-cement ratio for each of the different variants (i.e. PPC with quarry dust and sand as well as PSC with quarry dust and sand). These were then conditioned in a laboratory air environment for 14 days. After 14 days, cubes were placed in a storage chamber with active control on carbon dioxide (4±0.5) %, temperature (20±2)^{0}C and relative humidity (55±5) % for a period of 70 days. After the accelerated carbonation exposure, samples were removed from the chamber and split in half perpendicular to the exposed faces and were cleaned properly for further processes. For measurement of carbonation depth these split samples were sprayed with solution (1% phenolphthalein in 70% ethanol). Results thus obtained were used as input parameters in simulation and prediction of carbonation depth as tabulated below (Table 1-8).

Permeability Test

According to the DIN (German institute for standardization) standard the permeability of the concrete was measured by finding the depth of penetration of water inside the concrete. Concrete specimens of size 150 mm X 150 mm X 150 mm were subjected to constant water pressure of 0.5 N/mm^2 acting perpendicular to the mould, for a period of 3 days according to DIN 1048. Just after releasing the pressure, the specimens were removed and broken at the middle. The depth of water penetration was then measured.

THE LEVENBERG-MARQUARDT ALGORITHM

The Levenberg-Marquardt algorithm, which was independently developed by Kenneth Levenberg and Donald Marquardt, provides a numerical solution to the problem of minimizing a nonlinear function (Sapna et al., 2012; Muhammad IbnIbrahimy et al., 2013). In the artificial neural-networks field, this algorithm is suitable for training small and medium-sized problems. This algorithm is fast, and the convergence gradient is stable as compare to several other existing methods of neural network training such as error back propagation (EBP) algorithm, which is comparatively slower.

The Levenberg-Marquardt algorithm is typically derived on the basis of a) steepest descent algorithm b) Newton's method c) Gauss-Newton's algorithm and d) Levenberg-Marquardt algorithm. The update rule of steepest descent algorithm could be expressed as:

$$w_{k+1} = w_k - \alpha g_k \quad (1)$$

The update rule of Newton's method is:

$$w_{k+1} = w_k - H_k^{-1} g_k \quad (2)$$

The update rule of Gauss-Newton's algorithm could be expressed as:

$$w_{k+1} = w_k - (J_k^T J_k)^{-1} J_k e_k \quad (3)$$

From the above-mentioned equations, the update rule of Levenberg-Marquardt algorithm could be expressed as:

$$w_{k+1} = w_k - (J_k^T J_k + \mu I)^{-1} J_k e_k (4)$$

The different indices in the algorithms are as follows:

w = weight vector, k = index of iterations, α = learning constant, g = gradient, H = Hessian matrix, J = Jacobian matrix, μ = Combination co-efficient, I = Identity matrix, e = error vector

ESTABLISHMENT OF PREDICTION MODEL FOR CONCRETE CARBONATION DEPTH

Architectural Design of ANN

The basic architecture of Artificial Neural Network (ANN) based on Levenberg-Marquardt algorithm i.e. feed forward back propagation network used in this study is shown in Figure 1(a) – (d) below. The artificial neural network used in this study is of multi layered perceptron type comprising of three layers. These are input, hidden and output layer. The hidden layer is tan-sigmoid in nature and the output layer is purelin in nature. Each of the aforesaid layers, irrespective of the input layer, in this study is characterized by a weight matrix and an output vector. The optimum results in this ANN were obtained with 6 inputs, 30 tan-sigmoid hidden neurons and 1 linear neuron in output layer.

The efficacy of ANN depends primarily on feature set, network architecture and a suitable algorithm. Therefore, this design of ANN was trained using the Levenberg-Marquardt algorithm, which has a minimum performance with mean square error (MSE), by virtue of the gradient of the performance function. Network generalization improvisation and over fitting in this study was avoided by randomly dividing the input data as 70%, 15% and 15% for training, validation and testing purposes respectively.

The weights of the input and hidden layer from the first training session were reutilized in further training iterations, in order to improve training with less time consumption in the process. These iterations were carried out until optimum regression values were obtained. Finally, performance plots, regression plots, error histograms and training state were generated. Comparison graphs were also generated in order to test the efficiency of the network.

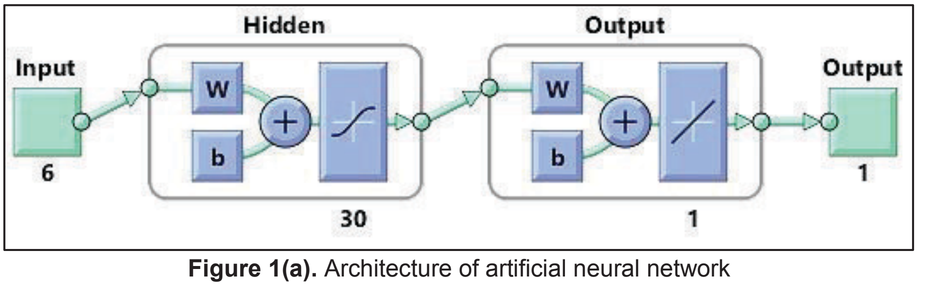

Figure 1(a). Architecture of artificial neural network

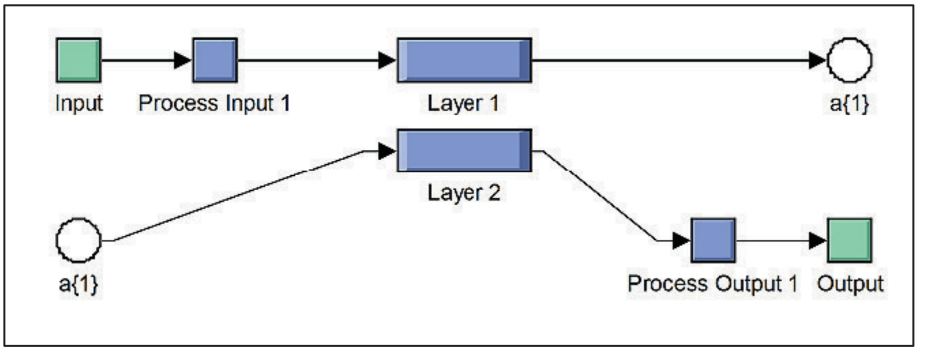

Figure 1(b). Architecture of hidden layer

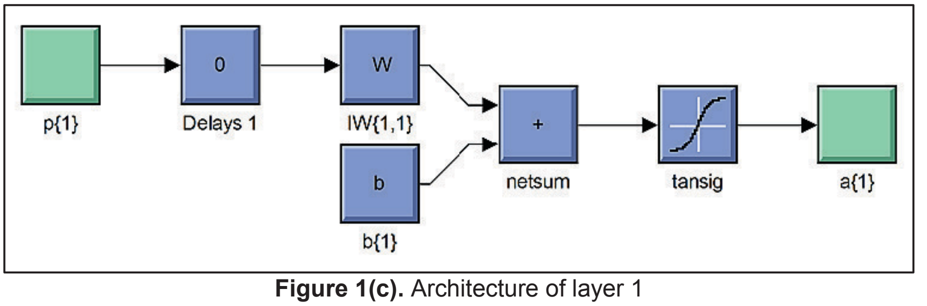

Figure 1(c). Architecture of layer 1

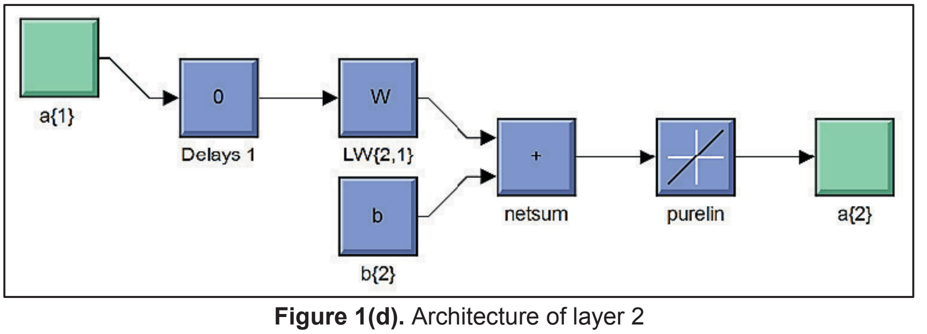

Figure 1(d). Architecture of layer 2

The selection of the network input factors

The actual rate of carbonation depends on the permeability of concrete, its moisture content, the environment's CO_2 content and Relative Humidity (RH). Based on the Fick's law of diffusion, the carbonation depth can be expressed as follows:

$$x = k\sqrt{t}(5)$$

Where, k = the carbonation coefficient (mm/year$^{0.5}$)
(x) = the depth of carbonation (mm)
t = the time of exposure in (years) (NhiuZhiguon and You Ri, 2013)

Carbonation reduces pH value and destroys the passive film around the steel (Chandrasekaraiah et al., 2014). Correspondingly the input factors included in this study are:

- water-cement ratio (W/C)
- cement content (C)
- CO_2 concentration
- relative humidity (RH)
- depth of water penetration
- pH

Training for concrete carbonation depth prediction model

In this study, concrete carbonation depth prediction was undertaken using a three-layer feed forward neural network i.e. input, hidden and output layers. Normalization of input and output values was followed by neural network training, without any addition of random data.

Performance curves

Figure 2(a) – 2(d) shows the performance curves based on Levenberg-Marquardt algorithm of the feed forward neural network used in this study, used for PPC with quarry dust, PPC with sand, PSC with quarry dust and PSC with sand.

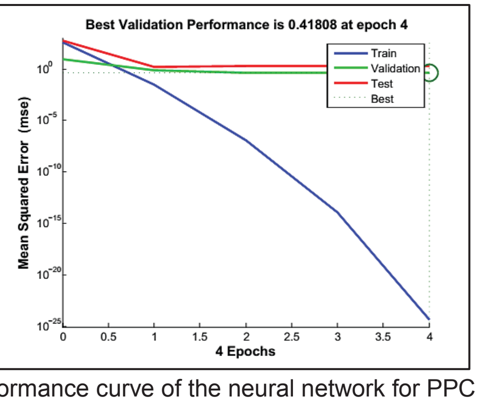

Figure 2(a). Performance curve of the neural network for PPC with quarry dust

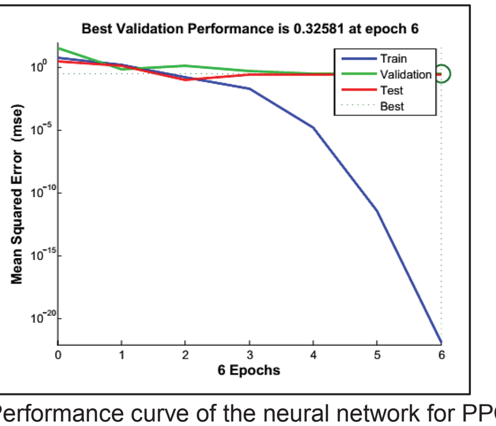

Figure 2(b). Performance curve of the neural network for PPC with sand

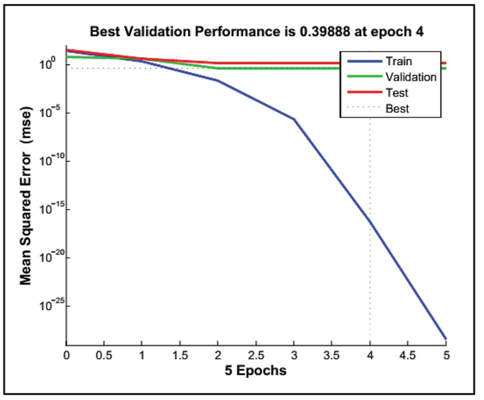

Figure 2(c). Performance curve of the neural network for PSC with quarry dust

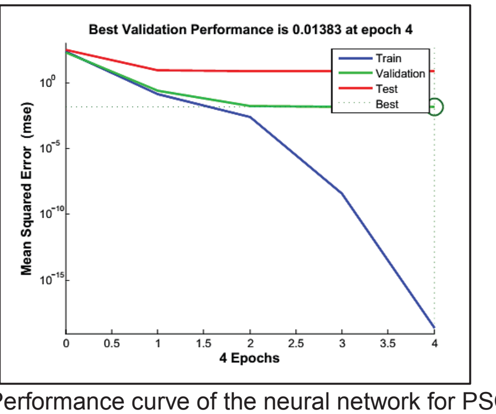

Figure 2(d). Performance curve of the neural network for PSC with sand

In the above figures, blue curve is the training curve, red is the test and green are the validation curve. The dotted line indicates the best performance (with least error) achieved by the neural network. The training of the network stops with the overlapping of the validation curve with that of the best performance curve. It can be comprehended from the above figures, that the mean squared error performance of PSC with sand was the least, followed by PSC with quarry dust, PPC with quarry dust and finally PPC with sand that achieved the least mean squared error in 6 epochs. The other three variants achieved the same in 4 epochs.

Regression Plots

The regression plots for PPC with quarry dust, PPC with sand, PSC with quarry dust and PSC with sand were generated in order to equate the correlation between the targets and obtained outputs. An R value of 1 indicates the closest and best correlation between the output and the target. On the other hand, an R value of 0 is indicative of random correlation. The different regression plots for all the different variants obtained, with training of the neural network using Levenberg-Marquardt algorithm in Matlab R22013a are shown in Figures 3(a) – 3(d) below:

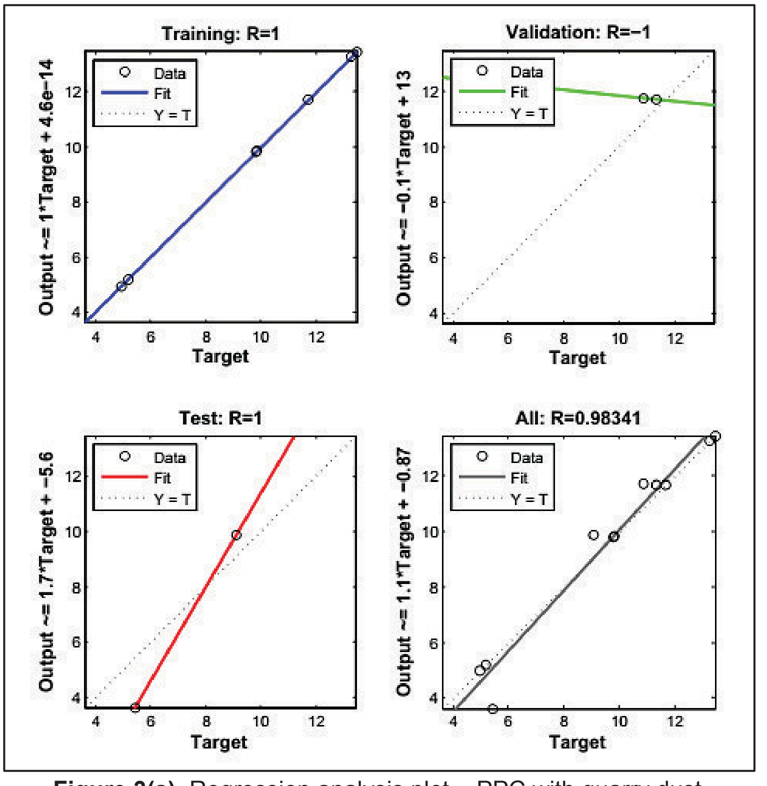

Figure 3(a). Regression analysis plot – PPC with quarry dust

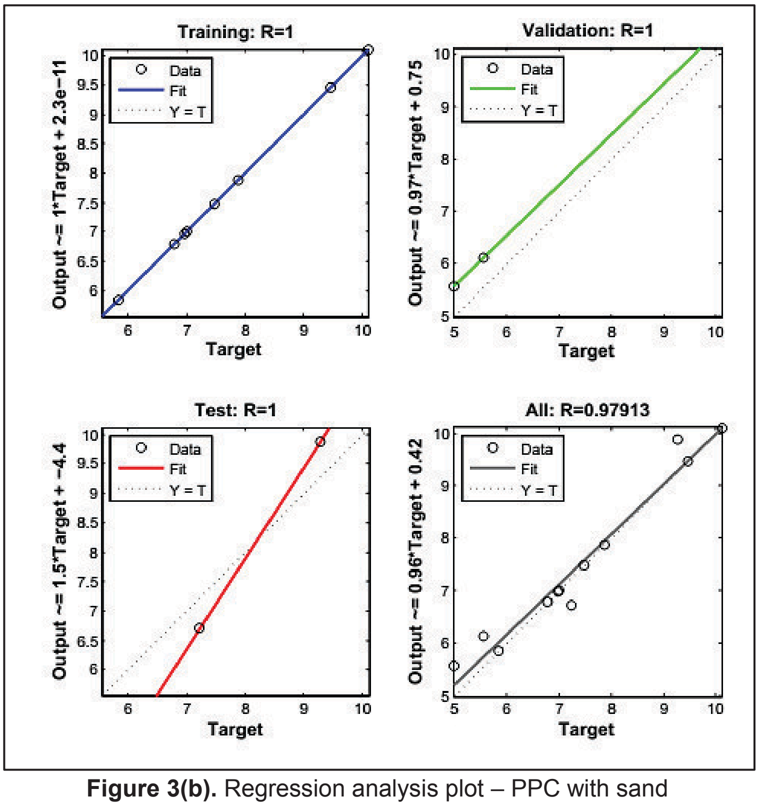

Figure 3(b). Regression analysis plot – PPC with sand

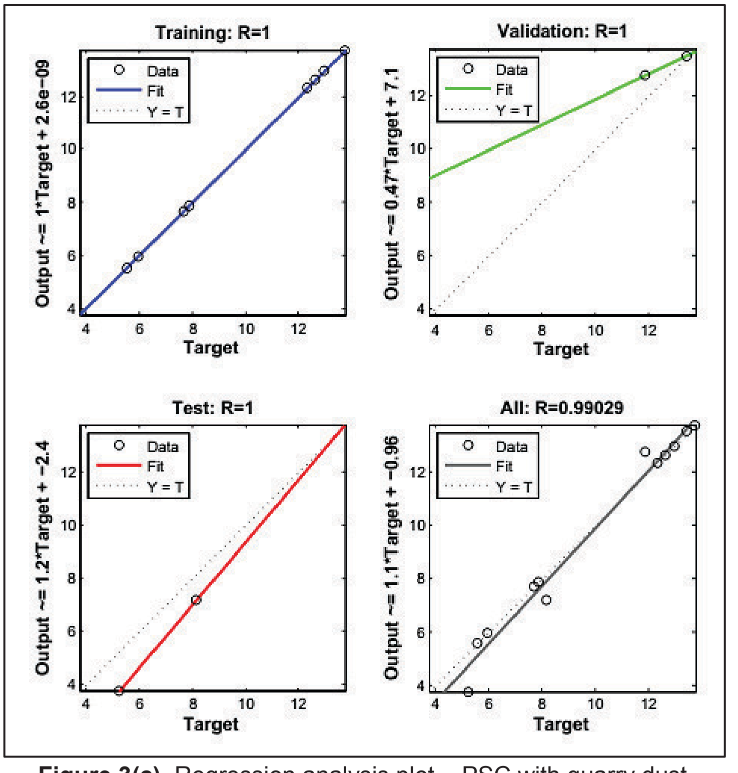

Figure 3(c). Regression analysis plot – PSC with quarry dust

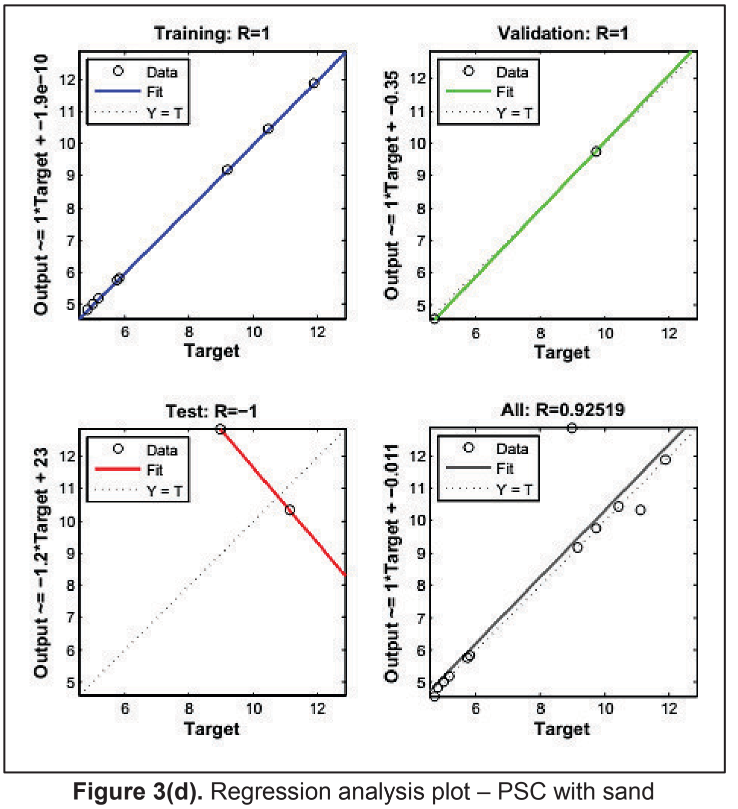

Figure 3(d). Regression analysis plot – PSC with sand

RESULTS AND DISCUSSION

The simulated [Table 1-4] and predicted [Table 1-8] results of concrete carbonation depth of PPC with quarry dust and sand as well as PSC with quarry dust and sand have been tabulated below:

Table 1. Simulation results of network training for PPC with quarry dust data

Input factors							Predicted value by Levenberg-Marquardt algorithm	
Cement content	w/c ratio	RH (%)	Water (kg)	CO_2 Concentration (%)	Depth of water penetration (mm)	Expectations	Carbonation depth (mm)	Remarks
330	0.45	55	148.50	(4±0.5)	20.70	5.43	3.61	Simulation
330	0.45	55	148.50	(4±0.5)	21.89	4.96	4.96	Simulation
330	0.50	55	165.00	(4±0.5)	28.50	9.85	9.85	Simulation
330	0.50	55	165.00	(4±0.5)	27.80	9.10	9.87	Simulation
330	0.55	55	181.50	(4±0.5)	29.80	11.36	11.69	Simulation
330	0.55	55	181.50	(4±0.5)	30.00	10.89	11.74	Simulation
330	0.60	55	198.00	(4±0.5)	32.30	13.28	13.28	Simulation
330	0.60	55	198.00	(4±0.5)	31.85	13.46	13.46	Simulation

Table 2. Simulation results of network training for PPC with sand data

Input factors							Predicted value by Levenberg-Marquardt algorithm	
Cement content	w/c ratio	RH (%)	Water (kg)	CO_2 Concentration (%)	Depth of water penetration (mm)	Expectations	Carbonation depth (mm)	Remarks
330	0.45	55	148.50	(4±0.5)	12.30	5.56	5.56	Simulation
330	0.45	55	148.50	(4±0.5)	12.65	4.98	4.98	Simulation
330	0.50	55	165.00	(4±0.5)	13.20	6.79	6.79	Simulation
330	0.50	55	165.00	(4±0.5)	12.98	7.01	6.93	Simulation
330	0.55	55	181.50	(4±0.5)	19.83	7.47	7.71	Simulation
330	0.55	55	181.50	(4±0.5)	20.00	7.23	7.37	Simulation
330	0.60	55	198.00	(4±0.5)	23.70	9.46	9.46	Simulation
330	0.60	55	198.00	(4±0.5)	23.89	9.28	9.32	Simulation

Table 3. Simulation results of network training for PSC with quarry dust data

Input factors							Predicted value by Levenberg-Marquardt algorithm	
Cement content	w/c ratio	RH (%)	Water (kg)	CO_2 Concentration (%)	Depth of water penetration (mm)	Expectations	Carbonation depth (mm)	Remarks
330	0.45	55	148.50	(4±0.5)	22.50	5.96	5.65	Simulation
330	0.45	55	148.50	(4±0.5)	21.75	5.23	5.23	Simulation
330	0.50	55	165.00	(4±0.5)	28.15	7.67	7.67	Simulation
330	0.50	55	165.00	(4±0.5)	28.40	8.15	7.26	Simulation
330	0.55	55	181.50	(4±0.5)	30.32	11.88	12.76	Simulation
330	0.55	55	181.50	(4±0.5)	29.80	12.34	12.34	Simulation
330	0.60	55	198.00	(4±0.5)	32.00	13.76	13.76	Simulation
330	0.60	55	198.00	(4±0.5)	32.10	13.43	13.99	Simulation

Table 4. Simulation results of network training for PSC with sand data

Input factors							Predicted value by Levenberg-Marquardt algorithm	
Cement content	w/c ratio	RH (%)	Water (kg)	CO_2 Concentration (%)	Depth of water penetration (mm)	Expectations	Carbonation depth (mm)	Remarks
330	0.45	55	148.50	(4±0.5)	20.12	4.84	4.83	Simulation
330	0.45	55	148.50	(4±0.5)	19.83	5.00	4.91	Simulation
330	0.50	55	165.00	(4±0.5)	22.50	5.82	5.81	Simulation
330	0.50	55	165.00	(4±0.5)	22.76	5.76	5.49	Simulation
330	0.55	55	181.50	(4±0.5)	25.70	9.72	8.07	Simulation
330	0.55	55	181.50	(4±0.5)	25.86	9.18	7.88	Simulation
330	0.60	55	198.00	(4±0.5)	28.65	10.45	10.54	Simulation
330	0.60	55	198.00	(4±0.5)	28.70	11.12	10.70	Simulation

It could be inferred from the obtained results that the neural network design using the Levenberg-Marquardt algorithm is highly accurate in predicting the concrete carbonation depth for different variants of PPC and PSC. In this study the neural network was trained using the aforesaid algorithm by virtue of distribution of weights for all the inputs, generation of output and finally comparison with the targets. This process was repeated with redistribution of weights, until optimum output was obtained with minimum error. The then finalized network design was further used for the prediction of concrete carbonation depth as presented in Table 4–8.

Table 5. Prediction results of concrete carbonation depth for PPC with quarry dust

Input factors						Predicted value by Levenberg-Marquardt algorithm	
Cement content	w/c ratio	RH (%)	Water (kg)	CO_2 Concentration (%)	Depth of water penetration (mm)	Carbonation depth (mm)	Remarks
330	0.45	55	148.50	(4±0.5)	22.20	5.20	Prediction
330	0.50	55	165.00	(4±0.5)	28.00	9.81	Prediction
330	0.55	55	181.50	(4±0.5)	29.50	11.70	Prediction

Table 6. Prediction results of concrete carbonation depth for PPC with sand

Input factors						Predicted value by Levenberg-Marquardt algorithm	
Cement content	w/c ratio	RH (%)	Water (kg)	CO_2 Concentration (%)	Depth of water penetration (mm)	Carbonation depth (mm)	Remarks
330	0.45	55	148.50	(4±0.5)	12.45	5.85	Prediction
330	0.50	55	165.00	(4±0.5)	13.62	6.97	Prediction
330	0.55	55	181.50	(4±0.5)	19.74	7.88	Prediction

Table 7. Prediction results of concrete carbonation depth for PSC with quarry dust

Input factors						Predicted value by Levenberg-Marquardt algorithm	
Cement content	**w/c ratio**	**RH (%)**	**Water (kg)**	**CO_2 Concentration (%)**	**Depth of water penetration (mm)**	**Carbonation depth (mm)**	**Remarks**
330	0.45	55	148.50	(4±0.5)	22.32	5.54	Prediction
330	0.50	55	165.00	(4±0.5)	28.05	7.87	Prediction
330	0.55	55	181.50	(4±0.5)	30.16	12.62	Prediction

Table 8. Prediction results of concrete carbonation depth for PSC with sand

Input factors						Predicted value by Levenberg-Marquardt algorithm	
Cement content	**w/c ratio**	**RH (%)**	**Water (kg)**	**CO_2 Concentration (%)**	**Depth of water penetration (mm)**	**Carbonation depth (mm)**	**Remarks**
330	0.45	55	148.50	(4±0.5)	20.50	4.73	Prediction
330	0.50	55	165.00	(4±0.5)	23.00	5.20	Prediction
330	0.55	55	181.50	(4±0.5)	25.10	8.98	Prediction

Error histograms [Figure 4(a) - 4(d)] were plotted for the design of the neural network used in this study, in order to comprehend the relative error for different input values (a. PPC with quarry dust, b. PPC with sand, c. PSC with quarry dust and d. PSC with sand). This neural network design with six input features, indicated maximum instances of errors disseminated around the zero line with the minimum being -0.8 and the maximum being 1.7 for PPC with quarry dust, PPC with sand and PSC with quarry dust. In the case of PSC with sand the minimum and the maximum instances of errors ranged in between -3.7 and 0.6 respectively.

These histograms thus are suggestive of fairly accurate results in case of PPC with quarry dust and sand as well as PSC with quarry dust as the values are closer to zero. However, PSC with sand shows a slight deviation from the zero-error line wards the left-hand side [Figure 4(d)].

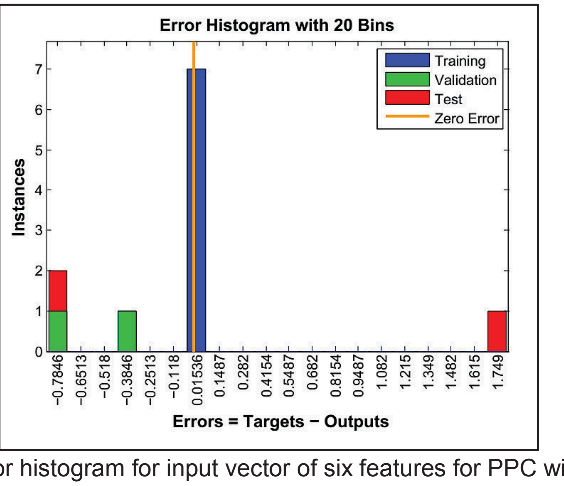

Figure 4(a). Error histogram for input vector of six features for PPC with quarry dust

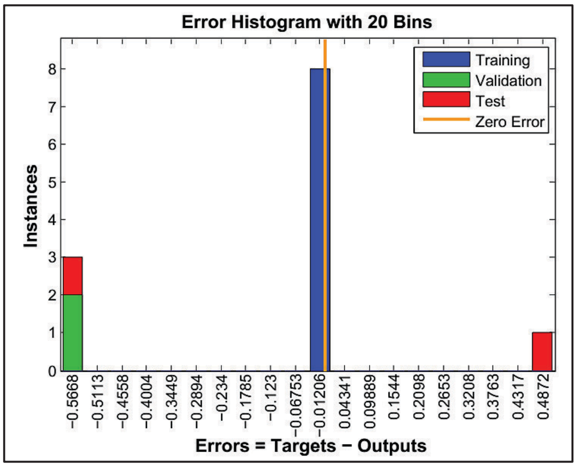

Figure 4(b). Error histogram for input vector of six features for PPC with sand

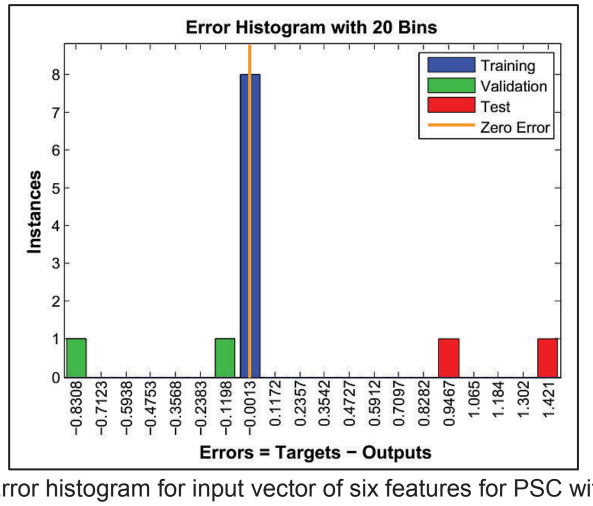

Figure 4(c). Error histogram for input vector of six features for PSC with quarry dust

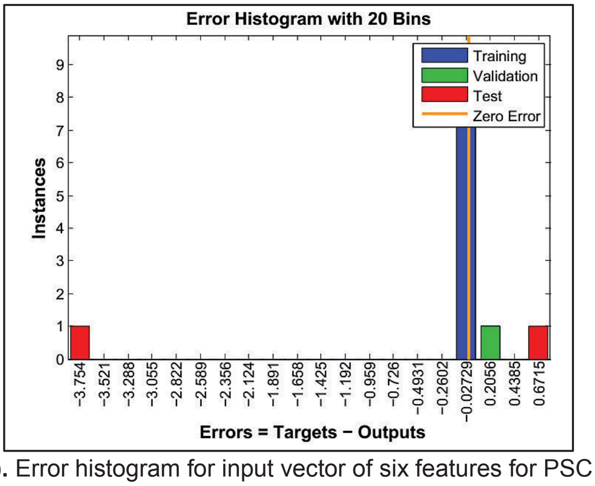

Figure 4(d). Error histogram for input vector of six features for PSC with sand

CONCLUSION

Use of the Levenberg-Marquardt algorithm in the neural network for this study quite accurately simulates as well as predicts the carbonation depth for different variants of concrete mixes used in this study. This aforesaid algorithm was used to train the neural network using six different input parameters obtained from lab analysis i.e. for different concrete mixes each, in order to enable the network to predict the carbonation depth in the concrete mixes. A comparative study of the performance curves, regression plots, predicted values and error histograms indicates that the optimum results in this ANN were obtained with the aforesaid 6 inputs, 30 tan-sigmoid hidden neurons and 1 linear neuron in the output layer. It was observed from theses analysis, that the optimum results pertaining to carbonation depth were obtained for PSC with quarry dust followed by other variants of PPC and PSC.

This neural network along with the algorithm could thus efficiently predict the carbonation depth with different inputs for different concrete mixes. However, some other inputs regarding the sample data such as strength, thickness etc. was not considered in this study and henceforth requires a further comprehensive study.

Compliance with Ethical Standards

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Author A is a Research Scholar in the Department of Civil and Environmental Engineering, Birla Institute of Technology, Mesra, India. The above funding recipient is Author B and guide.

We, all hereby declare that we don't have any conflict of interest.

List of Abbreviations

PPC - Portland Pozzolana Cement
PSC - Portland Slag Cement
ANN - Artificial Neural Network

REFERENCES

Baker, R., (1988), Initiation period, in: Corrosion of steel in concrete, P. Schiessl (Ed.), Chapman & Hall, London, UK, pp. 22-25.

Chandrasekaraiah T, Anantharam H, Krishnamurthy M, Manjunath K. V, Hegde M. N, (2014), Accelerated Testing of Deteriorated Concrete Structures Due To Carbonation, *International Journal of Research in Engineering and Technology*, e ISSN: 2319-1163, p ISSN: 2321-7308, Volume: 03, Special Issue: 06, pp. 19.

Moreno, E, & Sagues A, (1998), Carbonation-induced corrosion on blended cement concrete mix designs for highway structures. *CORROSION/98*, pp.636, NACE International, Houston, TX.

Muhammad IbnIbrahimy, Md. RezwanulAhsan, Othman OmranKhalifa, (2013), Design and Optimization of Levenberg-Marquardt based Neural Network Classifier for EMG Signals to Identify Hand Motions, *Measurement Science Review*, Volume 13, No. 3.

NhiuZhiguon, You Ri, (2013), Experimental Investigation of Concrete Carbonation under Different Conditions, *Study of Civil Engineering and Architecture (SCEA)*-Volume 2 Issue 4, pp 114-117.

Papadakis V G, Fardis M N, Vayenas C G, (1992), Effect of composition, environmental factors and cement lime mortar coating on concrete carbonation, *Materials and Structures*, volume 25, pp. 293-304.

Sapna S, Tamilarasi A, and Kumar M P, (2012), Backpropagation Learning Algorithm Based On Levenberg Marquardt Algorithm, *Computer Science & Information Technology* (CS & IT).

Silva R V, Neves R, Brito J De, Dhir R K, (2015), Carbonation Behaviour Of Recycled Aggregate Concrete, *Cement & Concrete Composites*, volume 62, pp. 22–32.

Taffese Woubishet Zewdu, Sistonen Esko, Puttonen Jari, (2015), CaPrM: Carbonation Prediction Model for Reinforced Concrete Using Machine Learning Methods, pp 70-82.

Talakokulaa V, Bhallab S,Ballc R.J, Bowend C.R, Pescec G.L, Kurchaniae R, Bhattacharjee B, Gupta A, Paine K, (2016), Diagnosis of carbonation induced corrosion initiation and progression in reinforced concrete structures using piezo-impedance transducers, *Sensors and Actuators A*, volume 242, pp 79-81.

GUIDE TO AUTHORS

Aims and Scope:

The Malaysian Construction Research Journal (MCRJ) is the journal dedicated to the documentation of R&D achievements and technological development relevant to the construction industry within Malaysia and elsewhere in the world. It is a collation of research papers and other academic publications produced by researchers, practitioners, industrialists, academicians, and all those involved in the construction industry. The papers cover a wide spectrum encompassing building technology, materials science, information technology, environment, quality, economics and many relevant disciplines that can contribute to the enhancement of knowledge in the construction field. The MCRJ aspire to become the premier communication media amongst knowledge professionals in the construction industry and shall hopefully, breach the knowledge gap currently prevalent between and amongst the knowledge producers and the construction practitioners.

Articles submitted will be reviewed and accepted on the understanding that they have not been published elsewhere. The authors have to fill the Declaration of the Authors form and return the form via fax to the secretariat. The length of articles should be between 3,500 and 8,000 words or approximately 8 – 15 printed pages (final version). The manuscripts should be written in English. The original manuscript should be typed one sided, single-spacing, single column with font of 11 point (Times New Roman). Paper size should be of Executive (18.42 cm x 26.67 cm) with 2 cm margins on the left, right and bottom and 3 cm for the top. Authors can submit the manuscript:

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CODIFICATION AND APPLICATION OF SEMI-LOOF ELEMENTS FOR COMPLEX STRUCTURES

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Abstract (Arial Bold, 9pt. Left and right indent 0.64 cm.)
Damage assessment …… ……(it should be single paragraph of about 100 – 250 words.)

Keywords: *Finite element analysis; Modal analysis; Mode shape; Natural frequency; Plate structure*

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Heading 2 (Arial Bold + Lower Case, 11pt)

Heading 3 (Arial Italic + Lower Case, 11pt)

Body Text: Times New Roman, 11 pt. All paragraph must be differentiated by 0.64 cm tab.

Units: All units and abbreviations of dimensions should conform to SI standards.

Figures: Figures should be in box with line width 0.5pt. All illustrations and photographs must be numbered consecutively as it appears in the text and accompanied with appropriate captions below them.

Figures caption: Arial Bold + Arial, 9pt. should be written below the figures.

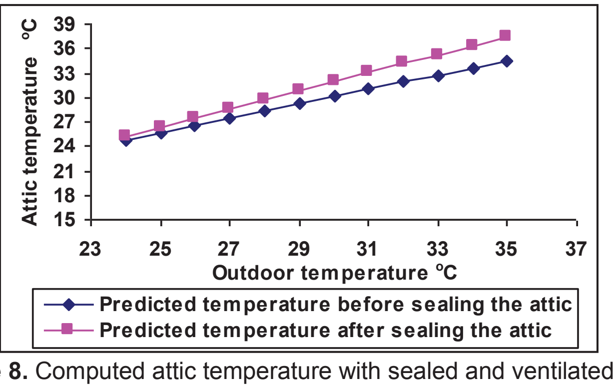

Figure 8. Computed attic temperature with sealed and ventilated attic

Tables: Arial, 8pt. Table should be incorporated in the text.

Table caption: Arial Bold + Arial, 9pt. Caption should be written above the table.

Table Line: 0.5pt.

Table 1. Recommended/Acceptable Physical water quality criteria

Parameter	Raw Water Quality	Drinking Water Quality
Total coliform (MPN/100ml)	500	0
Turbidity (NTU)	1000	5
Color (Hazen)	300	15
pH	5.5-9.0	6.5-9.0

(Source: Twort et al., 1985; MWA,1994)

Reference: Times New Roman, 11pt. Left indent 0.64 cm, first line left indent – 0.64 cm. **Reference should be cited in the text as follows:** "Berdahl and Bretz (1997) found…" or "(Bower et al., 1998)". References should be listed in alphabetical order, on separate sheets from the text. In the list of References, the titles of periodicals should be given in full, while for books should state the title, place of publication, name of publisher, and indication of edition.

Journal

Sze, K. Y. (1994) Simple Semi-Loof Element for Analysing Folded-Plate Structures. *Journal of Engineering Mechanics*, 120(1):120-134.

Books

Skumatz, L. A. (1993) Variable Rate for Municipal Solid Waste: Implementation, Experience, Economics and Legislation. Los Angeles: Reason Foundation, 157 pp.

Thesis

Wong, A. H. H. (1993) *Susceptibility to Soft Rot Decay in Copper-Chrome-Arsenic Treated and Untreated Malaysian Hardwoods*. Ph.D. Thesis, University of Oxford. 341 pp.

Chapter in book

Johan, R. (1999) Fire Management Plan for The Peat Swamp Forest Reserve of North Selangor and Pahang. In Chin T.Y. and Havmoller, P. (eds) *Sustainable Management of Peat Swamp Forests in Peninsular Malaysia* Vol II: Impacts. Kuala Lumpur: Forestry Department Malaysia, 81-147.

Proceedings

Siti Hawa, H., Yong, C. B. and Wan Hamidon W. B. (2004) Butt Joint in Dry Board as Crack Arrester. *Proceeding of 22nd Conference of ASEAN Federation of Engineering Organisation* (CAFEO 22). Myanmar, 55-64.

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