20TH INTERNATIONAL DEPENDENCY AND STRUCTURE MODELING CONFERENCE, DSM 2018

TRIESTE, ITALY, OCTOBER 15 – 17, 2018

Conceptual Framework for Collaborative Risk Management during the Design Phase of Green Building Projects using DSM

Lungie Maseko[1], David Root[2], Venkatachalam Senthilkumar[3]

[1]Student, University of Witwatersrand
[2]Professor, University of Witwatersrand
[3]Assistant Professor, University of Sharjah

Abstract: Construction projects are ambitious in terms of the complexity in its components, structures, design requirements, information flows, stakeholder integration and technological integration particularly in green building projects. As a consequence, management of these projects becomes increasingly integrated; however, risk management has taken little account of these interdisciplinary and iterative trends. This leads to poor risk management outcomes, where traditional risk management practices that rely on allocating risks to specific individual entities are not able to accommodate the collaborative facets. Experienced practitioners were interviewed regarding their current practices and techniques towards managing interdependent design tasks that resulted in inseparable collective risks. Prospective utilization of Dependency Structure Matrices (DSM) and its analysis of identifying the existence of these collaborative Design Risks among the clusters of designs are proposed as a solution in this paper. Since the paper is explorative in terms of the application of the DSM method on identifying and managing the collaborative risk management in green building design, conceptual frameworks are only proposed.

Keywords: Collaboration, Design tasks, Green buildings, Risk sharing

1 Introduction

Building design involves complex and comprehensive work that requires the cooperation of various specialties as collaborating stakeholders (Liu et al., 2014). With the multifaceted nature of projects, building design becomes increasingly difficult and complex. Thus the major shift towards collaborative design approaches (El-Diraby et al., 2017). However the traditionally used planning methods such as CPM and PERT cannot model the iterative nature of design processes (Senthilkumar et al., 2010). Dependency Structure Matrix (DSM) is an effective method developed to model iterative process (Senthilkumar and Varghese, 2013). This study intends to discover how project stakeholders in collaborative teams manage inseparable risks within their different design tasks on green buildings and how DSM can be proved to be effective in representing the design process and managing risk within the design domains.

Collaborative design, demands the process of coordination and cooperation of different stakeholders who share their knowledge in both the design process and the design content (Kleinsmann, 2006), as a means of attaining the unified design goals in the most efficient and effective ways (Liu et al., 2014). Traditionally, risk management has given little consideration to the collaboration within the interdisciplinary and iterative design process. Risk management practices continue to rely on allocating risks to specific individual entities, which is increasingly problematic given the non-coherence of the growing collaborative green building sector, where the design philosophy is holistic and treats the building as a complex integrated system (El-Diraby et al., 2017), that is best designed, and efficiently executed through collaborative practices.

Chiu (2002) defines collaboration "as an activity that requires participation of individuals for sharing information and organizing design tasks and resources." This means that the stakeholders would provide each other with new insights that would enable each participant to fulfill his or her own task without compromising/ affecting the design of others whilst meeting the common objectives of green building. These objectives are typically; to lower energy consumption, lower investment costs, and reduced harmful impacts on the environment and on people (EPBD, 2015). In collaborative designs, tasks are interdependent and iterative (Al Hattab and Hamzeh, 2015). Iteration assists in the progressive generation of knowledge, enabling a degree of concurrency and integrating necessary changes, although it can also increase the duration and cost of a project (Wynn and Eckert, 2017). Managing where and how iteration occurs is thus an important issue in practice in order to mitigate these additional costs due to non-value adding iterations or rework. This can be a challenge where it relates to risk. Consequently, the need for stakeholder collaboration and risk management to provide an effective way of managing risks is, present and unavoidable. Risks are inherent in all complex projects (Peckiene et al., 2013) and how risks are shared among stakeholders in the design phase is mostly governed by the dynamic evolution of management. Hence, any dynamic approach needs effective risk management and collaborative efforts among project stakeholders (Lam et al., 2007; Gomes et al., 2016).

Every Collaborative Risk Management (CRM) solution is impacted by people, technology and the nature of multidisciplinary tasks and participants who need to deliver a holistic risk system with a final design product. CRM is about the dynamic management of risk (Rahman and Kumaraswamy, 2005) which plays a major role in achieving value-for-money and cost-efficiency in designing complex projects. Typically, for design only, an activity-based DSM methodology would be used for dependencies and interface identification (Senthilkumar et al., 2010). Yet, inseparable design risks need to be resolved in a holistic manner in all aspects of the green building design process, hence the need to explore alternate methods to formulate the DSM.

2 Green Buildings Management with Collaborative Risk Management Principles

Green buildings (GB) are structures designed to promote efficient use of resources (e.g., energy, water, and materials) and that promotes sustainability (WCED, 1987). The US Environmental Protection Agency (2016) defines green building as: "the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction."

Green Building designs are complex undertakings that have given rise to reciprocal interdependencies between multiple and diverse stakeholders, hence the high dependence on information, followed by the connectedness of tasks (Austin et al., 2002; Ahn et al., 2016). Further, Bakhshi et al. (2016) defines GBs complexity as an intricate arrangement of varied interrelated parts in which the elements can change and evolve constantly with an effect on project objectives. Yet, they are the most effective solutions to increase the efficiency of buildings through resource utilization and recycling, mitigating the negative impact of the construction industry on the environment (Zuo and Zhao 2014). This has been made possible through *inter alia,* mutual collaboration, adjustments towards working collectively and responding to emergent, unforeseen problems in real-time. However project realities are such that current risk practices promote competitive attitudes between the project stakeholders involved because they tend to work for their self-interests and thus safe-guard their existence in the project (Alsalman 2012). So, it is vital to change, not only risk management (RM) practices; but, mindsets to shift towards mutual adjustments and rapid adaptation where stakeholders will be in a give-and-take interdependence (Morris 2013). The change from traditional RM to CRM is loaded with uncertainties on risk sharing among all project stakeholders and their response to this cultural shift.

Risk sharing requires all stakeholders within complex projects to take a closer look at their own risk universes. It is a useful method for handling complex designs (Melese et al., 2016), and a collaborative way of managing risks by taking advantage of the different views from different stakeholders (Olander, 2007). CRM appears to be a relevant problem as it emphasizes equitable and balanced risk sharing among contracting stakeholders who want to eliminate improper or unfavorable risk sharing outcomes which result in cost and time overrun and, undoubtedly, in legal disputes (Loosemore and McCarthy, 2008).

In this vein, the traditional tools (PERT, Gantt and CPM) based on workflows have failed to address interdependency (feedback and iteration) and would not be suitable for modeling information flows that determine the design phase (Yassine et al., 1999). Hence, DSM is identified as a useful tool for coping with design issues (Steward, 1981). The DSM matrix can be used to identify appropriate stakeholders, teams, and the ideal sequence of the tasks (Lindemann, 2009). A DSM involves a square matrix with an equal number of rows and columns that shows relationships between tasks in a system (Eppinger and Browning, 2012). Collectively, these complexities and interdependencies of tasks result in inseparable design risks. These kind of risks cannot be transferred or allocated to an individual, but would have to be shared collaboratively. How then do project stakeholders in collaborative teams deal with inseparable risks within their different design tasks?

3 Identifying Inseparable Risks within the Design Phase

The emphasis of effective RM in dealing with the broad spectrum of risks is to move beyond the traditional RM mechanics to examine the sources of unknown risks (Jarkas and Haupt 2015). Though the construction industry has long managed to identify and analyse known risks, it has recognized that dealing with the hidden, less obvious aspects of uncertainty is complicated and results in inseparable risks, and this requires practitioners to be more proactive in their approach (Smith and Merritt 2002). Inseparable risks arise from uncertainties, ambiguities and arrays of risk factors that are intricately connected (Thamhain, 2013).

In practice, a typical approach to risks is trying to identify them as early as possible and respond to them as quickly as possible once identified (Kim, 2017). However, green projects anticipate unidentified risks, also known as ‘unknown unknowns’ that have traditionally been underemphasized by risk management (Thamhain, 2013). It is difficult to trace the causes and culprits of these unknown unknowns as they require inventive risk handling decisions on risk allocation (Jin et al., 2017). Predicting and controlling such unknown risks has also developed impractical risk preferences for some project stakeholders because they sometimes actively ignore those (Alles 2009). These risk attitudes have made the risk sharing process challenging (Walker, 2015).

The goal of identifying inseparable risks is to make the process of risk sharing more efficient through planning and coordination by mutual adjustment, so as to get a better information flow in design (Fundli and Drevland 2014). Design risks have been classified in a number of ways. Arguing that risks arise as a result of interactions between stakeholders, technological interoperability and organizational factors, Smith et al. (2009) suggested that they may be grouped as either involuntary or voluntary, depending on whether the incidents that create the risk are uncertain or beyond the control of the people in charge.

The increasing complexity of projects and knowledge processes, makes it imperative for stakeholders to be keenly aware of the intricate connections of risk variables among complex systems and processes (Thamain 2013), this limits the effectiveness of traditional RM methods. Stakeholders argue that no single person has all the smarts and insight for assessing multi-variable risks and their cascading effects (Hartono et al., 2014). Project stakeholders realize that, while there may be good RM methods which provide a critically important toolset for risk management, it takes the collective thinking and collaboration of all the stakeholders to identify and deal with the complexity of inseparable risks in green building projects.

4 Research method and Data analysis

A case study strategy was adopted in this research, as case studies typically use a variety of data collection methods such as interviews, questionnaires, and observations (Eisenhardt, 1989). CRM is a relatively innovative concept in South Africa and, therefore, it is important to obtain a detailed and comprehensive view of it by investigating it in past and ongoing projects. In particular, how CRM is managed in design processes and how various stakeholders manage inseparable risks, were areas of interest.

The case study data to this investigation was collected through semi-structured interviews; with a mixture of open and close-ended questions (Brink, 2014), where participants were asked - stakeholder techniques on carrying out inseparable tasks, as well as their options and suggestions on CRM processes of green projects.

The case studies comprise of a ‘completed project’ and a ‘project in its design phase’. The completed project is of residential apartments in the V&A Waterfront in Cape Town, South Africa and the project team of this case study reflects on the problems they faced.

The other case study is an academic Forensic Pathology Facility in Johannesburg, South Africa; this project is in its design phase and the project team is still engaging with their risks. In both projects, numbers of stakeholders with varying backgrounds were involved and it thus was interesting to see how CRM could be applied. The objective for the interviews was to explore the possible challenges that had not been identified in the literature review of managing green construction projects; and identifying areas where inseparable risks were and could be managed.

The analysis and interpretation of research data form the major part of the research (Amaratunga et al., 2002). The methodical process used was the DSM, which is a square matrix that focuses on dependencies between elements of one domain like people-people, component –component and task-task sequence relationships. Then, the Domain Mapping Matrix (DMM) was used as it examines the interactions across domains to represent enriched analysis results that provide an expanded view of the complex system (Bartolomei et al., 2007). When applied, a DMM was constructed to map out the interdependencies, interactions, and exchange of information from design tasks and risks, identifying the optimal sequence of tasks, risk interactions and iterations across domains (Yang et al., 2014). The combination of square DSM and rectangular DMM is called Multiple Domain Matrix (MDM) where useful information is provided using intra- and inter-domain networks (Lindemann and Maurer, 2007).

Also, the DSM process was utilized to identify clusters (Browning, 2015) in a matrix analysis approach that minimizes iterations and enhances efficiency in risk management (Jaber et al., 2015). The high interaction of clusters encouraged stakeholders to collaborate, communicate and coordinate better, so to identify and examine interfaces between the clusters and keep iterations at a minimum; minimizing the number of task dependencies (Austin et al., 2001).

5 Findings

This research is still on going and, more interviews are still to be conducted. For now, 15 semi-structured interviews with different experts were conducted to understand the current risk allocation practices and the way inseparable risks can be managed in collaborative circumstances.

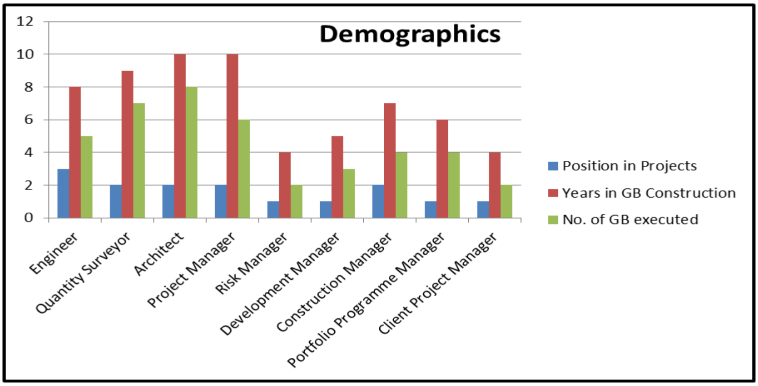

Figure 1.Profile of Respondents

Based on the interviews **Figure 1** represents the research demographics and 65% of the projects done by the respondents were in Gauteng, 15% in the Western Cape and the other 15% was in different South African provinces, with only 5% on international projects.

Data analysis focused on how each project managed its CRM practices. An analysis on sources of design risk, project risk management process, collaborative activities and the design process results was achieved. Second, cross-case analysis was performed in order to examine similarities and differences in the projects. Based on the categories presented by Burns and Stalker (1961) and Geraldi (2008), comparisons on how different risk management systems were used in the two projects affected CRM.

Figure 2 shows how the use of DSM/DMM aims to handle Collaborative Risks (CR) during the design phase by identifying interdependencies. On DMM people-activities and people-components, communication plans on how identified CR will be managed should be discussed by stakeholders. And, these matrices will potentially identify clusters of risks; improve coordination and management, for CR to be shared equitably.

	Stakeholders	**Design Tasks**	**Design Components**
Stakeholders	People DSM	People Activity Domain Mapping Matrix	People Building Components Domain Mapping Matrix
Design Tasks		Activity DSM	Activity Building Component Domain Mapping Matrix
Design Components			Component DSM

Figure 2.MDM Mapping System for capturing the Design Process Interfaces in various domains

For collaborative activities as shown in **Figure 3**, interviews were analyzed using the DMM matrix to plot the information and map-out interdependencies between the stakeholder and the RM activities, it is a Domain Mapping Matrix which captures the interrelationships among various stakeholders on specific RM tasks. The purpose of this matrix is to illustrate the interactions capturing procedure which can be adopted using DMM and their useful contribution in this process of uncertainty reduction and management.

Interdependencies of varying strengths are identified across activities and by clustering; this DMM identifies areas between tasks and stakeholders that require a high level of coordination and integration. Interfaces between these activities indicate the people who must communicate to transfer information. But, inseparable risks still need to be allocated on design processes. A fair and equitable risk sharing is essential to ensuring a successful delivery of a project design. Stakeholders must work collaboratively to seek an equitable sharing of risk based on an appropriate methodology that seeks to allocate design risks in an efficient manner and with specific considerations. In doing so, the intention will be to reduce project disputes and benefit of all parties.

Collaborative Activities	Owner	Architect	Quantity Surveyor	Structural designer	Electrical designer	Mechanical and plumbing designer	Fire protection designer	Main contractor	Sub-contractors (Mechanical, Plumbing, Electrical, Fire)	Process and technology manager
Determine reciprocal responsibility of stakeholders	x	x	x	x	x	x	x	x	x	x
Determine how to allocate benefits and risks	x	x	x	x	x	x	x	x	x	x
Establish mechanism of conflict coordination	x	x	x	x	x	x	x	x	x	x
Analyze functional requirements of the design		x	x	x	x	x	x	x	x	
Determine design criteria for each specialty		x	x	x	x	x	x	x		
Determine standards for exchanging BIM data	x	x	x	x	x	x	x	x		x
Determine time control points for design tasks	x	x	x	x	x	x	x	x	x	x
Examine the schedule jointly	x	x	x	x	x	x	x	x	x	x
Examine the site design jointly	x	x	x	x	x	x	x	x	x	
Considerations of environmentally safe methods of construction		x	x	x			x	x		x

Figure 3.Collaborative Activities

Figure 4 is a conceptual framework of the application of DSM methods. Participative use of DSM/DMM/MDM methods will create situations for stakeholders to discuss their tasks, information needed, risks anticipated and the interdependencies. This will enable them to outline the design of the information exchange process, engaging all involved. These methods are enabling tools to create crucial communication lines, to reduce assumptions and uncertainty between stakeholders. The combinations of these matrices provide improved decision support for stakeholders on the purposes in the conceptual framework; clustering analysis being the decisive factor to create understanding on the collaborative risk context; accountability and transparency will then be achieved and risk sharing will be done fairly.

Discussion

Due to the dynamic, complex nature of green designs and the interplay of multi-stakeholders, RM processes used require collaboration between the stakeholders. The collaboration needed has been amplified by the interdependencies of stakeholders and their dependable tasks which resulted to inseparable risks. The use of DSM/DMM/MDM methods to improve RM practices is a solution towards equitable and balanced risk sharing.

	DSM/DMM/MDM	Purpose	Analysis	Decision Rule/ Application
1.	MDM among People, Activity, Component	To capture the big picture on the overall Project CRM	Clustering	To identify and strategies the project procurement method
2.	DSM People	To Allocate CR to appropriate people who shares the dependent activities/ components	Clustering	Clustering to shape the project communication management protocol
3	DSM Activities	To identify and sequence the design process activities which are collaborative and iterative in nature	Partitioning	Partitioning and Sequencing to avoid schedule delay risk
4	DSM Components	To come up with the work packages, the components which are highly interactive should be procured as a single work package	Clustering	Clustering to come up with work packages and sequencing of work to avoid risk due to lack of collaboration
5	DMM People Activity	To identify collaborative risks within interdependent activities and share the risks to appropriate people	Clustering	To identify and allocate the responsibility of CR, allocate and manage resources
6	DMM People Components	Assign single work packages to suitable people who will share CR equitably	Clustering	To identify and allocate the responsibility of CR, and check performance related risks
7	DMM Activity Component	Sequence design process activities with fitting work package components and comprehend interrelationships	Clustering	To identify and allocate Risk management provisions on design processes against the components.

Figure 4.Conceptual framework on application of DSM methods on managing the CR in Green Building Design Process

The application of the DSM/DMM/MDM methodologies is still limited in CRM practices of designing GB. Future work is required to determine the procedure to manage equitable risk sharing using these methodologies efficiently as means to improve the stakeholders' behavior in their interactions across multi-domains through work package allocation, communication and collaboration clauses on the contracts, partnership and alliancing arrangement, penalty clauses, contingency allocation, etc. Though the study can also be expecting some limitations, the proposed conceptual method shows potential for improvement on the collaborative risk management during the design of green building projects. Further validation is needed to claim the rigor of this finding, which will be provided in the forthcoming publications.

References

Ahn, Y. H., Jung, C. W., Suh, M. and Jeon, M. H., 2016. Integrated Construction Process for Green Building, Procedia Engineering 145: 670-676.

Al Hattab, M. and Hamzeh, F., 2015. Using social network theory and simulation to compare traditional versus BIM–lean practice for design error management, Automation in Construction 52: 59-69 .

Alsalman, A. A. 2012. Construction risks allocation: Optimal risk allocation decision support model (Doctoral dissertation), Oregon State University.

Austin, S., Baldwin, A., Hammond, J., Murray, M., Root, D., Thomson, D. and Thorpe, A., 2001. Design Chains, A Handbook for Integrated Collaborative Design, Thomas Telford Publishing, London.

Austin, S., Newton, A., Steele, J. and Waskett, P., 2002. Modelling and managing project complexity, International Journal of Project Management 20(3): 191-198.

Bakhshi, J., Ireland, V. and Gorod, A., 2016. Clarifying the project complexity construct: Past, present and future, International Journal of Project Management, 34(7): 1199-1213

Bartolomei, J., Hastings, D., de Neufville, R. and Rhodes, H., 2007. Engineering Systems Multiple Domain Matrix: An Organizing Framework for Modeling Largescale Complex Systems, Systems Engineering 15(1): 41–61.

Brink, S. 2014. Interview, New York: Springer.

Browning, T. R., 2015. Design Structure Matrix Extensions and Innovations: a survey and new opportunities, IEEE Transactions on Engineering Management.

Chiu, C. H., 2002. The effects of collaborative teamwork on secondary science, Journal of Computer Assisted Learning 18 (3): 262-271.

Eisenhardt, E. M., 1989. Building theories from case study research, Academy of Management Review 14(4): 532-550.

El-Diraby, T., Krijnen,T. and Papagelis, M., 2017. BIM-based collaborative design and socio-technical analytics of green buildings, Automation in Construction 82: 59-74.

El-Sayegh, S. M., 2008 Risk assessment and allocation in the UAE construction industry, International Journal of Project Management 26(4): 431-438.

Eppinger, S. D. and Browning, T. R., 2012. Design structure matrix methods and applications, MIT press.

EPA – 2016. US Environmental Protection Agency Definition of Green Building https://archive.epa.gov/greenbuilding/web/html/about.html

EPBD – 2015. Energy Performance of Building Directive, compliance study, Written by ICF International, December. https://ec.europa.eu/energy/sites/ener/files/documents

Geraldi, J. G. (2008) The balance between order and chaos in multi-project firms: A conceptual model, International Journal of Project Management, 26 (4): 348-356.

Hartono, B., Sulistyo, S. and Hasmoro, D., 2014. Project risk: Theoretical concepts and stakeholders' perspectives, International Journal of Project Management, 32(3): 400-411.

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): 165 – 194.

Kim, S. D., 2017. Characterization of unknown unknowns using separation principles in case study on Deepwater Horizon oil spill, Journal of Risk Research, 20 (1): 151–168.

Kleinmann, M. S., 2006. Understanding Collaborative Design (Thesis PhD), Technische Universiteit Delft, Nederlands.

Lam, K. C., Wang, D., Lee, P. T., and Tsang, Y. T., 2007. Modelling risk allocation decision in construction contracts, International Journal of Project Management 25(5): 485-493.

Lindemann, U. and Maurer, M., 2007. Facing Multi-Domain Complexity in Product Development, The Future of Product Development.

Lindemann, U., 2009. The design structure matrix (DSM), Retrieved from http://www.dsmweb.org/en/dsm.html

Liu, W., Guo, H. and Skitmore, M., 2014. A BIM-Based Collaborative Design Platform for Variegated Specialty Design, ICCREM 2014: Smart Construction and Management in the Context of New Technology, American Society of Civil Engineers (ASCE), Kunming, China, 320-329.

Morris, P. W. G., 2013. Reconstructing Project Management, Wiley-Blackwell, Chichester.

Olander, S., 2007 Stakeholder impact analysis in construction project management. Construction Management and Economics 25(3): 277–287.

Peckiene, A., Komarovska, A. and Ustinovicius, L., 2013. Overview of risk allocation between construction parties. Procedia Engineering 57: 889-894.

Rahman, M. M. and Kumaraswamy, M. M., 2005. Assembling integrated project teams for joint risk management, Construction Management and Economics 23(4): 365-375.

Runeson, P., Host, M., Rainer, A. and Regnell, B., 2012. Case study research in software engineering: Guidelines and examples, John Wiley and Sons, Inc. Hoboken: New Jersey.

Saunders, M., Lewis, P. and Thornhill, A., 2016. Research methods for Business students, 7th Ed, Italy: Pearson Education Limited.

Schöttle, A., Haghsheno, S., and Gehbauer, F., 2014. Defining Cooperation and Collaboration in the Context of Lean Construction, Proceedings of the 22th Conference of the International Group for Lean Construction, Oslo, Norway.

Senthilkumar, V., Varghese, K. and Chandran, A., 2010. A web-based system for design interface management of construction projects, Automation in Construction, 19(2):197-21

Senthilkumar, V. and Varghese, K., 2013. Case Study–Based Testing of Design Interface Management System, Journal of Management in Engineering, 29(3): 279-288

Smith, N. J., Mernam T. and Jobling, P., 2009. Managing risk: In construction projects, 2nd Edn, Malden, MA: Blackwell Science Inc.

Steward, D. V., 1981. Design structure system: A method for managing the design of complex systems, IEEE transactions on Engineering Management, 28(3): 71-74.

Thamhain, H., 2013. Managing risks in complex projects, Project Management Journal 44(2): 20

WCED – 1987. World Commission on Environment and Development. Our Common Future (Chapter 2): Towards Sustainable Development. http://www.un-documents.net/ocf-02.html

Yang, R. J. and Zou, P. X., 2014. Stakeholder-associated risks and their interactions in complex green building projects: A social network model, Building and Environment, 73: 208-222

Yassine, A. A., Chelst, K. R. and Falkenburg, D. R., 1999. A decision analytic framework for evaluating concurrent engineering, IEEE Transactions on Engineering Management, 46(2): 144-157.

Zuo, J. and Zhao, Z. Y., 2014. Green building research–current status and future agenda: A review, Renewable and Sustainable Energy Reviews, vol.30: 271-281.

Contact: L. Maseko, University of Witwatersrand, Construction Economics and Management, 1 Jan Smuts Avenue, PO Box 20, Wits, South Africa, +27716290992, lungie.maseko@wits.ac.za