DECISION SUPPORT SYSTEM FOR BUILDING INFORMATION MODELING (BIM) SOFTWARE SELECTION: A CASE STUDY IN CONSTRUCTION FEASIBILITY STAGE

AHMAD TAUFIK BIN NURSAL

MASTER OF SCIENCE (DECISION SCIENCE)
UNIVERSITI UTARA MALAYSIA
2015

Awang Had Salleh
Graduate School
of Arts And Sciences

Universiti Utara Malaysia

PERAKUAN KERJA TESIS / DISERTASI
(Certification of thesis / dissertation)

Kami, yang bertandatangan, memperakukan bahawa
(We, the undersigned, certify that)

AHMAD TAUFIK NURSAL

calon untuk Ijazah
(candidate for the degree of) MASTER

telah mengemukakan tesis / disertasi yang bertajuk:
(has presented his/her thesis / dissertation of the following title):

"DECISION SUPPORT SYSTEM FOR BUILDING INFORMATION MODELING (BIM) SOFTWARE SELECTION: A CASE STUDY IN CONSTRUCTION FEASIBILITY STAGE"

seperti yang tercatat di muka surat tajuk dan kulit tesis / disertasi.
(as it appears on the title page and front cover of the thesis / dissertation).

Bahawa tesis/disertasi tersebut boleh diterima dari segi bentuk serta kandungan dan meliputi bidang ilmu dengan memuaskan, sebagaimana yang ditunjukkan oleh calon dalam ujian lisan yang diadakan pada : *22 September 2015.*
That the said thesis/dissertation is acceptable in form and content and displays a satisfactory knowledge of the field of study as demonstrated by the candidate through an oral examination held on: *September 22, 2015.*

Pengerusi Viva: *(Chairman for VIVA)*	Assoc. Prof. Dr. Azizan Saaban	Tandatangan *(Signature)*
Pemeriksa Luar: *(External Examiner)*	Dr. Goh Kai Chen	Tandatangan *(Signature)*
Pemeriksa Dalam: *(Internal Examiner)*	Dr. Nor Intan Saniah Sulaiman	Tandatangan *(Signature)*
Nama Penyelia/Penyelia-penyelia: *(Name of Supervisor/Supervisors)*	Dr. Mohd Faizal Omar	Tandatangan *(Signature)*
Nama Penyelia/Penyelia-penyelia: *(Name of Supervisor/Supervisors)*	Sr. Dr. Mohd Nasrun Mohd Nawi	Tandatangan *(Signature)*

Tarikh:
(Date) *September 22, 2015*

Permission to Use

In presenting this thesis in fulfilment of the requirements for a postgraduate degree from Universiti Utara Malaysia, I agree that the Universiti Library may make it freely available for inspection. I further agree that permission for the copying of this thesis in any manner, in whole or in part, for scholarly purpose may be granted by my supervisor(s) or, in their absence, by the Dean of Awang Had Salleh Graduate School of Arts and Sciences. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to Universiti Utara Malaysia for any scholarly use which may be made of any material from my thesis.

Requests for permission to copy or to make other use of materials in this thesis, in whole or in part should be addressed to:

Dean of Awang Had Salleh Graduate School of Arts and Sciences
UUM College of Arts and Sciences
Universiti Utara Malaysia
06010 UUM Sintok

Abstrak

Penerimaan perisian Permodelan Maklumat Pembinaan (BIM) telah terbukti bermanfaat kepada industri pembinaan bagi meningkatkan rekabentuk, analisis, pembinaan, operasi dan pengurusan data. Disebabkan pelbagai jenis perisian BIM di pasaran, proses pemilihan perisian BIM yang memenuhi keperluan projek dianggap rumit. Kajian terdahulu telah mendedahkan bahawa kebanyakan pemilihan perisian adalah berdasarkan popularity dan cadangan daripada syarikat lain. Justeru, pemilihan yang tidak tepat boleh mengakibatkan penggunaan perisian BIM yang tidak sepenuhya dan memberi kesan negatif ke atas pelaburan perisian BIM. Berdasarkan tinjauan literatur terdapat kekurangan pendekatan yang sistematik dalam pemilihan perisian BIM bagi memenuhi keperluan projek tertentu. Ini menekankan keperluan untuk alat pembuatan keputusan bagi memilih perisian BIM yang bersesuaian. Penyelidikan ini bertujuan untuk membangunkan Sistem Sokongan Pemutusan (DSS) yang dinamakan topsis4BIM yang mengintegrasikan antaramuka pengguna, pangkalan data bercirikan BIM, Fuzzy TOPSIS dan alatan Web 2.0. Projek pembinaan sebenar telah digunakan sebagai kajian kes untuk demonstrasi dan pengesahan rangka kerja DSS. Hasil kajian menunjukan penggunaan topsis4BIM dapat memperbaiki proses pemilihan perisian BIM berbanding amalan sedia ada. Selain itu, ianya juga telah menghasilkan satu rangka kerja baharu untuk pembinaan DSS masa hadapan dengan mengunakan alatan Web 2.0. Kajian ini memperkenalkan satu pendekatan pembuatan keputusan yang inovatif dan ekonomikal yang boleh menjadi garis panduan untuk meningkatkan penggunaan BIM dalam kalangan pengamal pembinaan

Kata Kunci: Permodelan maklumat pembinaan, Sistem sokongan keputusan, Pembuatan keputusan pelbagai kriteria, alatan Web 2.0

Abstract

The adoption of Building Information Modelling (BIM) software has proven to be beneficial to the construction industry to improve the design, analysis, construction, operation and data management. Due to the variety of BIM software on the market, choosing the right BIM software in construction projects is deemed to be a complicated decision making process. Previous studies revealed that software selection is mainly made based on popularity and recommendation from other companies. Consequently, inaccurate selection would lead to the underutilised features and negative effect the investment on the BIM software. Based on literature, there is a lack of systematic approach to select the right BIM software for specific project requirements. This highlights the needs for decision making tools to select the appropriate BIM software. This research aims to develop a Decision Support System (DSS) named topsis4BIM which integrates graphical user interfaces, BIM features database, Fuzzy TOPSIS and Web 2.0 tools. A real construction project was used as a case study for demonstrating and validating the DSS framework. The findings indicate that the use of topsis4BIM improves the BIM software selection process compared to the current practice. In addition, it also produce a new framework for the next generation DSS using Web 2.0 tools. The study introduces an innovative and economical decision making approach that can guide construction practitioners towards the betterment of BIM adoption.

Keywords: Building information modelling, Decision support system, Multi criteria decision making, Web 2.0 tool

Acknowledgement

I would first like to thank the Almighty God (Allah) for His blessing bestowed upon me throughout the course of my Master study. I wish to take this opportunity to thank my family especially my mother for her encouragement, without her support, this master journey would not have been fulfilled. I would like to thank Dr. Mohd Faizal Omar and Sr. Dr. Mohd Nasrun Mohd Nawi who undertook the crucial role as supervisors and for they constant invaluable guidance, assistance, emotional support and encouragement throughout of my master study.

I would also like to thank both of my senior Adam Shariff Adli Aminuddin and Tisya Farida Abdul Halim for their continuous invaluable advice. I would also wish to express my appreciation to academic and non-academic staff in School of Science Quantitative (SQS) UUM for any assistance whatsoever renderer toward the production of this thesis. I would also like to thank all respondent who involved in this study. Last, many warm thanks to all my friends who have supported me through every step of the way.

Table of Contents

List of Tables

List of Figures

List of Appendices

List of Abbreviations

3D	:	Three dimensional medium
AEC	:	Architecture, Engineering and Construction
AHP	:	Analytic Hierarchy Process
BIM	:	Building Information Modeling
CAD	:	Computer Aid-Design
CGI	:	Common Gate-away interface (CGI)
CIDB	:	Construction Industry Development Board
CM@R	:	Construction Management at Risk
CMAA	:	Construction Management of Association America
CPM	:	Critical Part Method
CREAM	:	Construction Research Institute of Malaysia
DB	:	Design Build
DBB	:	Design Bid Build
DSS	:	Decision Support Systems
EIS	:	Executive Information System
ELECTRE	:	ELimination and Choice Expressing Reality
ES	:	Enterprise System
GDP		Gross Domestic Product
HTML	:	HyperText Markup Language
ICT	:	Information Communication and Technology
IPD	:	Integrate Project Delivery
MADM	:	Multi Attribute Decision Making

MCDM	:	Multi Criteria Decision Making
MIS	:	Management Information System
MODM	:	Multi Objective Decision Making
MY SQL	:	Structured Query Language
OLAP	:	Online Analytical Processing
PDM	:	Project Delivery Method
PHP	:	Personal Home Page
PKK		Contractor Service Centre
PMBOK	:	Project Management Book of Knowledge
POM	:	Production and Operational Management
PROMETHEE	:	Preference Ranking Organization Method for Enrichment of Evaluations
PWD		Pubic Work Department
ROC	:	Rank Order Centroid
SAW	:	Simple Average Weight
TOPSIS	:	Order Preference by Similarity to an Ideal Solution
TPS		Transaction Processing System
TQM	:	Total Quality Management
UTHM	:	Universiti Tun Hussein Onn Malaysia
UUM	:	Universiti Utara Malaysia
VIKOR	:	VIseKriterijumska Optimizacija I Kompromisno Resenje

CHAPTER ONE
INTRODUCTION

1.1 Research Background

Construction sector is one of the main contributor in Malaysia's Gross Domestic Product (GDP) within the years of 1991 to 2010 with average of 4.09 % GDP, and 3 % to 5.7 % of national economy (Khan, Liew, & Ghazali, 2014). This is due to the role of construction sector who provide initial infrastructure and building for other sector such as manufacturing, industrial and even tourism sectors (Yong & Mustaffa, 2012). Therefore, the construction sector is significant in social-economy development in Malaysia.

Realising the importance of construction sector, several government agencies have been established such as Construction Industry Development Board (CIDB), Ministry of Work, the Contractor Service Centre (PKK), the Board of Engineer, the Board of Architect and the Board of Surveyors (Kamal, Haron, Ulang, & Baharum, 2012). Numerous efforts have been taken by these agencies in order to enhance the development of construction sector. Since 2007, CIDB has been actively promoting the use of a new technology which is Building Information Modelling (BIM) via seminars, workshops, development of roadmap for BIM adoption in Malaysia, and other promotional programmes. Since the introduction of BIM, it has been recognised in the industry as a significant technology that can enhance construction project management.

The contents of the thesis is for internal user only

REFERENCES

Abdullah, M. R., & Egbu, C. (2011). The Application of Analytical Hierarchy Process (AHP) As a Decision Tool in Choosing The Type of Industrialised Building System (IBS) For Housing Projects. In *Procs 27th Annual ARCOM Conference* (pp. 555–562). Bristol, UK.

Afshari, A., Mojahed, M., & Yusuff, R. M. (2010). Simple Additive Weighting approach to Personnel Selection problem. *International Journal of Innovation, Management and Technology*, *1*(5), 511–515.

Aghaei, S., Nematbakhsh, M. A., & Farsani, H. K. (2012). Evolution of the World Wide Web : From Web 1.0 to Web 4.0. *International Journal of Web & Semantic Technology*, *3*(1), 1–10.

Ahmad, I., Azhar, S., & Lukauskis, P. (2004). Development of a decision support system using data warehousing to assist builders/developers in site selection. *Automation in Construction*, *13*(4), 525–542.

Alias, M. A., Zaiton, S., Hashim, M., & Samsudin, S. (2008). Multi Criteria Decision Making And Its Appkications: A Literature Review. *Jurnal Teknologi Maklumat*, *2*, 129–152.

Anderson, P. (2007). What is Web 2 . 0 ? Ideas , technologies and implications for education by. *JISC Technolgy and Standard Wacth*, *60*, 64.

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C., & O'Reilly, K. (2011). BIM adoption and implementation for architectural practices. *Structural Survey*, *29*(1), 7–25.

Ayağ, Z., & ÖzdemİR, R. G. (2007). An intelligent approach to ERP software selection through fuzzy ANP. *International Journal of Production Research*, *45*(10), 2169–2194.

Azhar, S., Hein, M., & Sketo, B. (2011). Building Information Modeling (BIM): Benefits , Risks and Challenges. *Leadership and Management in Engineering*.

Banias, G., Achillas, C., Vlachokostas, C., Moussiopoulos, N., & Papaioannou, I. (2011). A web-based Decision Support System for the optimal management of construction and demolition waste. *Waste Management (New York, N.Y.)*, *31*(12), 2497–502.

Barassi, V., & Trere, E. (2012). Does Web 3.0 come after Web 2.0? Deconstructing theoretical assumptions through practice. *New Media & Society*, *14*(8), 1269–1285.

Baxter, P. & Jack, S. (2008). Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers. *The Qualitative Report*, *13*(4), 544–559.

Bessedik, I., Taghezout, N., & Saidi, A. (2012). Web 2.0 integration in a Web-Based Decision Support System: Effect study of social networking on decision-making.

Second International Conference on the Innovative Computing Technology (INTECH 2012), 365–370.

Beynon, M. J., & Wells, P. (2008). The lean improvement of the chemical emissions of motor vehicles based on preference ranking: A PROMETHEE uncertainty analysis. *Omega*, *36*(3), 384–394.

Bharati, P., & Chaudhury, A. (2004). An empirical investigation of decision-making satisfaction in web-based decision support systems. *Decision Support Systems*, *37*(2), 187–197.

Bhargava, H. K., Power, D. J., & Sun, D. (2007). Progress in Web-based decision support technologies. *Decision Support Systems*, *43*(4), 1083–1095.

Borenstein, D. (1998). Towards a practical method to validate decision support systems. *Decision Support Systems*, *23*(3), 227–239.

Bourne, L., & Walker, D. H. T. (2008). Project relationship management and the Stakeholder Circle™. *International Journal of Managing Projects in Business*, *1*(1), 125–130.

Bryde, D., Broquetas, M., & Volm, J. M. (2013). The project benefits of Building Information Modelling (BIM). *International Journal of Project Management*, *31*(7), 971–980.

Büyüközkan, G., & Çifçi, G. (2011). A novel fuzzy multi-criteria decision framework for sustainable supplier selection with incomplete information. *Computers in Industry*, *62*(2), 164–174.

Büyüközkan, G., & Ruan, D. (2008). Evaluation of software development projects using a fuzzy multi-criteria decision approach. *Mathematics and Computers in Simulation*, *77*(6), 464–475.

Bytes, A. (2007). Top Criteria of BIM Solution. Retrieved January 1, 2014, from http://aecbytes.com/

Caterino, N., Iunio, I., Manfredi, G., & Consenza, E. (2009). Applicability and effectiveness of different decision making methods for seismic upgrading building structures. In *XIII Convegno Nazionale L'Ingegneria Sismica in Italia, Bologna*.

Cebeci, U. (2009). Fuzzy AHP-based decision support system for selecting ERP systems in textile industry by using balanced scorecard. *Expert Systems with Applications*, *36*(5), 8900–8909.

Chang, Y.-H., Wey, W.-M., & Tseng, H.-Y. (2009). Using ANP priorities with goal programming for revitalization strategies in historic transport: A case study of the Alishan Forest Railway. *Expert Systems with Applications*, *36*(4), 8682–8690.

Chau, K. W., Cao, Y., Anson, M., & Zhang, J. (2002). Application of data warehouse and Decision Support System in construction management. *Automation in Construction*, *12*, 213–224.

Chelson, D. E. (2010). *The effect of building information modelling on construction site productivity*. University of Maryand.

Chen, C. T. (2000). Extensions of the TOPSIS for group decision-making under fuzzy environment. *Fuzzy Sets and Systems*, *114*(1), 1–9.

Chen, Y. Q., Liu, J. Y., Li, B., & Lin, B. (2011). Project delivery system selection of construction projects in China. *Expert Systems with Applications*, *38*(5), 5456–5462.

Chou, S.-Y., Chang, Y.-H., & Shen, C.-Y. (2008). A fuzzy simple additive weighting system under group decision-making for facility location selection with objective/subjective attributes. *European Journal of Operational Research*, *189*(1), 132–145.

Chu, M.-T., Shyu, J., Tzeng, G.-H., & Khosla, R. (2007). Comparison among three analytical methods for knowledge communities group-decision analysis. *Expert Systems with Applications*, *33*(4), 1011–1024.

Chu, T.-C., & Lin, Y.-C. (2009). An interval arithmetic based fuzzy TOPSIS model. *Expert Systems with Applications*, *36*(8), 10870–10876.

Chua, A. Y. K., Goh, D. H., & Ang, R. P. (2012). Web 2.0 applications in government web sites: Prevalence, use and correlations with perceived web site quality. *Online Information Review*, *36*(2), 175–195.

CREAM. (2012). BIM Industrial Transformation in Australia. Retrieved January 1, 2014, from http://www.cream.com.my

Department, M. P. W. (2011). Unit Building Information Modeling (BIM). Retrieved December 1, 2014, from https://www.jkr.gov.my

Devi, K., & Yadav, S. P. (2012). A multicriteria intuitionistic fuzzy group decision making for plant location selection with ELECTRE method. *The International Journal of Advanced Manufacturing Technology*, *66*(9-12), 1219–1229.

Durán, O. (2011). Computer-aided maintenance management systems selection based on a fuzzy AHP approach. *Advances in Engineering Software*, *42*(10), 821–829.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). *BIM Handbook: A guide to building information modeling for owners, managers,designers, enggineers and contractors*. Hoboken, NJ, USA: John Wiley & Sons, Inc.

Ertu, İ., & Karaka, N. (2008). Comparison of fuzzy AHP and fuzzy TOPSIS methods for facility location selection. *Journal Advance Manufacturing Technology*, *39*, 783–795.

Gencer, C., & Gürpinar, D. (2007). Analytic network process in supplier selection: A case study in an electronic firm. *Applied Mathematical Modelling*, *31*(11), 2475–2486.

Goh, K. C. (2011). *Developing Financial Decision Support for Highway Infrastructure Sustainability*. Queensland Univeristy of Technology.

Gu, N., & London, K. (2010). Understanding and facilitating BIM adoption in the AEC industry. *Automation in Construction*, *19*(8), 988–999.

Hannele, K., Reijo, M., Tarja, M., Sami, P., Jenni, K., & Teija, R. (2012). Expanding uses of building information modeling in life-cycle construction projects. *Work (Reading, Mass.)*, *41 Suppl 1*, 114–119.

Haron, A. T. (2013). *Organisational Readiness To Implement Building Information Modelling : A Framework For Design Consultants In Malaysia*. University of Salford Manchester.

Hendi, A. (2007). *Decision Support System for Equipment Selection in Construction Projects*.

Hergunsel, M. F. (2011). *Benefit of Building Information Modelling for construction managers and BIM based scheduling*. Worcester Polytechnic Institute.

Hoegg, R., Martignoni, R., Meckel, M., & Stanoevska, K. (2006). Overview of business models for Web 2.0 communities. In *GeNeMe2006* (Vol. 2006, pp. 1–17).

Hove, S. E., & Anda, B. (2005). Experiences from Conducting Semi-structured Interviews in Empirical Software Engineering Research. In *11th IEEE International Software Metrics Symposium (METRICS'05)* (pp. 23–23). Ieee.

Hsu, C. -l. (2010). Sociology of Hyperlink Networks of Web 1.0, Web 2.0, and Twitter: A Case Study of South Korea. *Social Science Computer Review*, *29*(3), 354–368.

Huang, J.-J., Tzeng, G.-H., & Ong, C.-S. (2005). Multidimensional data in multidimensional scaling using the analytic network process. *Pattern Recognition Letters*, *26*(6), 755–767.

Hung, S.-Y., Ku, Y.-C., Liang, T.-P., & Lee, C.-J. (2007). Regret avoidance as a measure of DSS success: An exploratory study. *Decision Support Systems*, *42*(4), 2093–2106.

Ibbs, W., & Chih, Y.-Y. (2011). Alternative methods for choosing an appropriate project delivery system (PDS). *Facilities*, *29*(13/14), 527–541.

Isfandyari-Moghaddam, A., & Hosseini-Shoar, M. (2014). Factors affecting Web 2.0 adoption: a case study. *Program: Electronic Library and Information Systems*, *48*(1), 2–15.

Kabli, M. R. (2009). *A multi-attribute decision making methodology for selecting new R&D project portfolio with a case study of Saudi oil refining industry*. University of Nottingham.

Kahkonen, K. E. E. (1995). Interactive decision support system for building construction scheduling. *Journal of Computing in Civil Engineering*, *8*(4), 519–535.

Kamal, E. M., Haron, S. H., Ulang, N., & Baharum, F. (2012). The Critical Review on the Malaysian Construction Industry, *3*(13).

Kent, D. C., & Becerik-gerber, B. (2010). Understanding construction industry experience and Attitudes toward Integrated Project Delivery. *Journal of Construction Engineering and Management*, 815–825.

Khan, R. A., Liew, M. S., & Ghazali, Z. Bin. (2014). Malaysian Construction Sector and Malaysia Vision 2020: Developed Nation Status. *Procedia - Social and Behavioral Sciences*, *109*, 507–513. doi:10.1016/j.sbspro.2013.12.498

Khazanchi, D. (1991). Evaluating Decision Support System : A Dialectical Perspective. *Journal Information System*, 90–97.

Kinzli, K., Asce, M., Gensler, D., Dejonge, K., Oad, R., & Shafike, N. (2010). Validation of a Decision Support System for Improving Irrigation System Performance, 1–10.

Konchar, B. M., & Sanvido, V. (1998). Comparison of U.S project delivery system. *Journal of Construction Engineering and Management*, 435–444.

Kontio, J. (1996). A case study in applying a systematic method for COTS selection. *Proceedings of IEEE 18th International Conference on Software Engineering*, 201–209.

Kou, G., Shi, Y., & Wang, S. (2011). Multiple criteria decision making and decision support systems - Guest editor's introduction. *Decision Support Systems*, *51*(2), 247–249.

Kumar, J. V., & Mukherjee, M. (2009). Scope of Building Information Modeling (BIM) in India. *Journal of Engineering Science and Technology Review*, *2*(1), 165–169.

Lai, V. S., Trueblood, R. P., & Wong, B. K. (1999). Software selection: a case study of the application of the analytical hierarchical process to the selection of a multimedia authoring system. *Information & Management*, *36*(4), 221–232.

Lai, V. S., Wong, B. K., & Cheung, W. (2002). Group decision making in a multiple criteria environment: A case using the AHP in software selection. *European Journal of Operational Research*, *137*(1), 134–144.

Latiffi, A. A., Mohd, S., & Brahim, J. (2014). Building Information Modeling (BIM) Roles in The Malaysia Contrcution Industry. *Sustainable Solutions Structural Engineering and Constrcution*, 749–754.

Latiffi, A. A., Mohd, S., Kasim, N., & Fathi, M. S. (2013). Building Information Modeling (BIM) Application in Malaysian Construction Industry. *International Journal of Construction Engineering and Management*, *2*, 1–6.

Lee, M. R., & Lan, Y. (2007). From Web 2 . 0 to Conversational Knowledge Management : Towards Collaborative Intelligence. *Journal of Enterpreneuership Research*, *2*(2), 47–62.

Liu, Z. (2010). *Feasibility Analysis of BIM Based Information System for Facility Management at WPI*. Worcester Polytechnic Institute.

Lu, H., Yu, H., & Lu, S. S. K. (2001). The effects of cognitive style and model type on DSS acceptance : An empirical study. *European Journal of Operational Research*, *131*.

Marwan, A. (1986). *An Investigation into the factors Influencing the succes of DSS in the construction industry*. Clemson University.

McCaffrey, J. D. (2009). Using the Multi-Attribute Global Inference of Quality (MAGIQ) technique for software testing. In *ITNG 2009 - 6th International Conference on Information Technology: New Generations* (pp. 738–742).

Montazer, G. A., Saremi, H. Q., & Ramezani, M. (2009). Design a new mixed expert decision aiding system using fuzzy ELECTRE III method for vendor selection. *Expert Systems with Applications*, *36*(8), 10837–10847.

Moravveju, M. Y. (2013). *Selection of the Industrialized Building material supplier by Analytical Hierachy Process method*. Universiti Teknologi Malaysia.

Mulebeke, J. a. W., & Zheng, L. (2006). Analytical network process for software selection in product development: A case study. *Journal of Engineering and Technology Management*, *23*(4), 337–352.

Murugesan, S. (2007). Second Generation Web Technology. *IEEE Computer Society*, (August), 34–41.

Nielson, J. (2000). Why you only need to test with 5 users. Retrieved January 1, 2015, from http://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/

O'Leary, T. J., Goul, M., Moffitt, K. E., & Radwan, A. E. (1990). Validating Expert System. *IEEE Expert*, 51–58.

Olatunji, O. A. (2011). Modelling the costs of corporate implementation of building information modelling. *Journal of Financial Management of Property and Construction*, *16*(3), 211–231.

Omar, M. F. (2012). *The Structured and Practical Approach in Development of Decision Support System for Consultan Selection in Public Sector Infrastructre Project*. Queensland University of Technology.

Otamendi, J., Pastor, J. M., & Garcı´a, A. (2008). Selection of the simulation software for the management of the operations at an international airport. *Simulation Modelling Practice and Theory*, *16*(8), 1103–1112.

Ozturk, B. A., & Ozcelik, F. (2014). Sustainable Supplier Selection with A Fuzzy Multi-Criteria Decision Making Method Based on Triple Bottom Line, *5*(3), 129–147.

Pekin, A., Ozkan, G., Eski, O., & Karaarslan, U. (2006). Application of the Analytic Hierarchy Process (AHP). In *5th International Symposium on Intelligent Manufacturing System* (pp. 1–16). Sakarya, Turkey.

Pena, G. (2011). *The evaluation of trainning needs for Building Information Modelling*. University of Texas.

Peters, M., & Zelewski, S. (2008). Pitfalls in the application of analytic hierarchy process to performance measurement. *Management Decision*, *46*(7), 1039–1051.

Power, D. J., & Sharda, R. (2007). Model-driven decision support systems: Concepts and research directions. *Decision Support Systems*, *43*(3), 1044–1061.

Public Work Department, M. P. W. D. (2013). Projek Perintis BIM. Retrieved February 5, 2014, from https://www.jkr.gov.my

Reilly, T. O., & Media, O. R. (2007). What Is Web 2.0: Design Patterns and Business Models for the Next Generation of Software. *Comunication and Strategies*, (65), 17–37.

Ribeiro, R. a., Moreira, A. M., van den Broek, P., & Pimentel, A. (2011). Hybrid assessment method for software engineering decisions. *Decision Support Systems*, *51*(1), 208–219.

Rob, P., & Coronel, C. (2009). *Database System: Design, Implementation and Management* (Eighth.). United State: THOMSON.

Roh, S. (2012). *The Pre-Positioning of Humanitarian Aid: The Warehouse Location Problem*. Cardiff University.

Rohena, R. (2011). *Building Information Modelling (BIM) Implementation in Naval Construction*. Lousiana State University.

Ruiz, J. M. (2009). *BIM Software evaluation model for general contractors*. University of Florida.

Ruiz, M. C., & Fernández, I. (2009). Environmental assessment in construction using a Spatial Decision Support System. *Automation in Construction*, *18*(8), 1135–1143.

Safa, M., Shahi, A., Haas, C. T., & Hipel, K. W. (2014). Supplier selection process in an integrated construction materials management model. *Automation in Construction*, *48*, 64–73.

Samuel, O. W., Omisore, M. O., & Ojokoh, B. a. (2013). A web based decision support system driven by fuzzy logic for the diagnosis of typhoid fever. *Expert Systems with Applications*, *40*(10), 4164–4171.

Saremi, M., Mousavi, S. F., & Sanayei, A. (2009). TQM consultant selection in SMEs with TOPSIS under fuzzy environment. *Expert Systems with Applications*, *36*(2), 2742–2749.

Sebastian, R. (2011). Changing roles of the clients, architects and contractors through BIM. *Engineering, Construction and Architectural Management*, *18*(2), 176–187.

Sheng, Q., Lei-shan, Z., & Yi-xiang, Y. (2010). A Web-based Distributed Group Decision Support System for Railway Construction Organization.

Shim, J. P., Warkentin, M., Courtney, J. F., Power, D. J., Sharda, R., & Carlsson, C. (2002). Past, present, and future of decision support technology. *Decision Support Systems*, *33*(2), 111–126.

Soni, V. V. K. (2008). *Evaluation of Point-Cloud Software using Multi-attribute*.

Tan, P. S., Lee, S. S. G., & Goh, a. E. S. (2012). Multi-criteria decision techniques for context-aware B2B collaboration in supply chains. *Decision Support Systems*, *52*(4), 779–789.

Tang, L. C. M., Leung, A. Y. T., & Wong, C. W. Y. (2010). Entropic Risk Analysis by a High Level Decision Support System for Construction SMEs. *Journal of Computing in Civil Engineering*, *24*, 81–94.

Taroun, A. (2012). *Decision Support System (DSS) for Construction Project Risk Analysis and Evaluation via Evidential Reasoning (ER)*. University of Manchester.

Taylan, O., Bafail, A. O., Abdulaal, R. M. S., & Kabli, M. R. (2014). Construction projects selection and risk assessment by fuzzy AHP and fuzzy TOPSIS methodologies. *Applied Soft Computing*, *17*, 105–116.

Turban, E., Aronson, J. E., & Liang, T.-P. (2005). *Decision Support Systems and Intelligent Systems* (Seventh Ed.). Practice-Hall of India Private Limited.

Tzeng, G.-H., & Huang, J.-J. (2011). *Multi Attribute Decision Making:Method and Applications*. Taylor & Francis Group.

Vijayvagy, L. (2012). Decision Framework for Supplier Selection through Multi Criteria Evaluation Models in Supply Chain. *International Journal of Management & Innovation*, *4*(2), 16–28.

Wang, J.-W., Cheng, C.-H., & Huang, K.-C. (2009). Fuzzy hierarchical TOPSIS for supplier selection. *Applied Soft Computing*, *9*(1), 377–386.

Wang, X., & Triantaphyllou, E. (2008). Ranking irregularities when evaluating alternatives by using some ELECTRE methods. *Omega*, *36*(1), 45–63.

Wong, K., & Fan, Q. (2013). Building information modelling (BIM) for sustainable building design. *Facilities*, *31*(3), 138–157.

Wright, A., Bates, D. W., Middleton, B., Hongsermeier, T., Kashyap, V., Thomas, S. M., & Sittig, D. F. (2009). Creating and sharing clinical decision support content with Web 2.0: Issues and examples. *Journal of Biomedical Informatics*, *42*(2), 334–46.

Yang, J. L., & Tzeng, G.-H. (2011). An integrated MCDM technique combined with DEMATEL for a novel cluster-weighted with ANP method. *Expert Systems with Applications*, *38*(3), 1417–1424.

Yates, J. K. (1993). Interactive decision support system for building construction scheduling. *Journal of Constrcution Engineering Management*, *119*(2), 226–244.

Yin, R. K. (2003). *Case Study Research Design and Methods*. *SAGE Publication*.

Yong, Y. C., & Mustaffa, N. E. (2012). Analysis of factors critical to construction project success in Malaysia. *Engineering, Construction and Architectural Management*, *19*(5), 543–556.

Zainal, Z. (2007). Case study as a research method. *Jurnal Kemanusiaan*, *9*, 1–6.

Zanakis, S. H., Solomon, A., Wishart, N., & Dublish, S. (1998). Multi-attribute decision making: A simulation comparison of select methods. *European Journal of Operational Research*, *107*(3), 507–529.

Ziaee, M., Fathian, M., & Sadjadi, S. J. (2006). A modular approach to ERP system selection: A case study. *Information Management & Computer Security*, *14*(5), 485–495.