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A MEASUREMENT INSTRUMENT FOR THE TECHNOLOGY EXTENT AND PROCESS EFFICIENCY IN BIM ENABLED CONSTRUCTION PROJECTS

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Technology use in all fields can play an important role as the booster in creating lean and efficient processes. Technology use may result in reduced duplications and delays in workflows while helping to speed up task realization. Building Information Modeling (BIM) enhances knowledge share, use and reuse for better collaboration, communication, coordination, and monitoring as a knowledge base platform. BIM enhanced construction projects may positively affect the process efficiency. The aim of this paper is to define a measurement instrument of BIM usage as technology enhancer tool and of process efficiency of construction projects. Research leans on the prominent literature to concrete the measurement instrument. A survey is established to construction project professionals to understand the technology efficiency and process efficiency in BIM enabled construction projects. The research based on the related data collected from 92 professionals experienced both in traditional project delivery methods and BIM enabled construction projects. The respondents are the construction industry experts comprised of construction project managers, BIM managers, and BIM implementation experts (architects, civil engineers, mechanical engineers, electrical engineers etc.). Data is analyzed and tested with structural equation modeling software to verify the proposed measurement instrument. The technology efficiency and process efficiency factors for BIM enabled construction projects are tested and refined. Research findings present the measurement instrument for both technology and process efficiency in BIM enabled construction projects.

Keywords: Building information modeling, Structural equation modeling, Construction firms.

1 RESEARCH BACKGROUND

Significant quantities of resources are wasted each year as a result of inefficient or non-existent quality management procedures (Arditi and Gunaydin 1997). Therefore, project management focuses on efficiency of process during project life cycle in order to minimize cost, to clarify routines and to clear division of resources (Farsi and Fillippini 2004). Efficiency, which is the status of organizations' utilized resources and achieved goals with less percentage of normal used resources, focuses on the resource investment versus output (Jacobs and Chase 2010). Therefore, it is clear that resource (money, time, etc.) saving is possible through efficiency improvement efforts (Reed *et al.* 1996). However, many researchers suggest that because of its easy to mimic techniques, efficiency is important but not enough for organizational performance (Frumkin and Kim 2001). On the other hand, the lack of process efficiency improvement intention may cause impotence of competitiveness among other companies those keep up with new approaches for more efficient processes. Technology can enhance process efficiency by improving the methods for task implementation. Construction companies need technological solutions for more efficiency. BIM, as a relatively new technological platform for improving knowledge share, use and reuse for better collaboration, communication, coordination, and monitoring, establishes a base for efficient processes in construction projects. This paper aims to develop a measurement instrument for both technology and process efficiency in BIM enabled construction projects. The following sections present a short description of methodology used in this research, and the research findings related to the development of measurement instrument.

2 TECHNOLOGY AND PROCESS EFFICIENCY IN BIM ENABLED PROJECTS

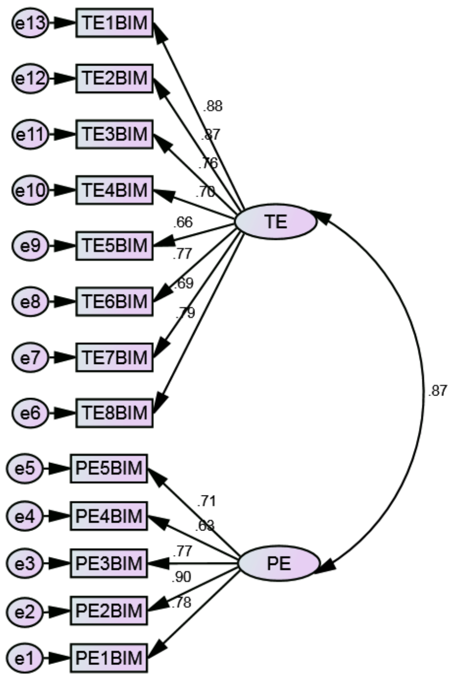
The AEC industry has long been focused on increasing quality, while decreasing time, cost, and change with an aim of fulfilling the scope by using construction management techniques. Integrated project delivery triggers efficiency among process enhancers (Azhar *et al.* 2008). Forging collaboration through extensive information exchange increases process efficiency (Glick and Guggemos 2009). Therefore, compared to traditional processes, BIM improves efficiency by enhancing integration and allowing more accurate and efficient collaboration in construction project processes (Carmona and Irwin 2007). BIM serves as a virtual model, which accurately simulates the real world building with fully encompassed information within and significantly changes the workflow and project delivery processes (Hardin 2009), enhances project collaboration and control among stakeholders, improves productivity (less re-work, conflicts and changes), increases quality and performance, accelerates project delivery, reduces wastages, reduces construction time and cost (Azhar 2011), triggers new revenue and business opportunities (Qian 2012, Barlish and Sullivan 2012, Succar 2009). Hence, the extent of technology efficiency may increase process efficiency in BIM enabled construction projects. In the light of the related literature, the measurement instrument is developed for the extent of technology efficiency in BIM enabled construction projects. The hypothesized factors are represented in Figure 1.

The ability to achieve efficient processes is vital for modern companies (Smith and Fingar 2003). Construction processes are complex and changes occur throughout the project. Process improvement in construction aims better product for less cost within specified time frame. The American General Contractors claims that “Building Information Model is a data-rich, object-oriented, intelligent and parametric digital representation of the facility. Views and data appropriate to various users’ needs can be extracted and analyzed from the model to generate information that can be used to make decisions and improve the process of delivering the facility” (AGC 2006). BIM as a platform improves collaboration, communication, coordination, monitoring, and control for integrated project delivery may improve process efficiency in construction projects. According to related literature, the measurement instrument is developed for the extent of process efficiency in BIM enabled construction projects. The hypothesized factors are represented in Figure 1 (Lee *et al.* 2011, Jacobs and Chase 2010, PMI 2007).

3 METHODOLOGY

A methodology that contains a structured questionnaire was adopted in this study. A structured questionnaire is applied to 92 construction industry professionals experienced in both traditional method and BIM enabled construction projects to verify the measurement instrument for the extent of technology and process efficiency in BIM enabled construction projects. 92 respondents out of 140 randomly selected professionals, representing a response rate of 67%.

The respondents are the construction industry experts comprised of construction project managers, BIM managers, and BIM experts (architects, civil engineers, mechanical engineers, electrical engineers etc.). The collected data analyzed with structural equation modeling method.



Factor Code	*The Extent of Technology Efficiency Factors*
TE1BIM	Minimized change
TE2BIM	Increased collaboration
TE3BIM	Robust communication
TE4BIM	Fulfilled operational requirements and specifications
TE5BIM	Fulfilled technical specifications
TE6BIM	Well maintained logistics
TE7BIM	High performance target cost projection
TE8BIM	Minimized life cycle cost

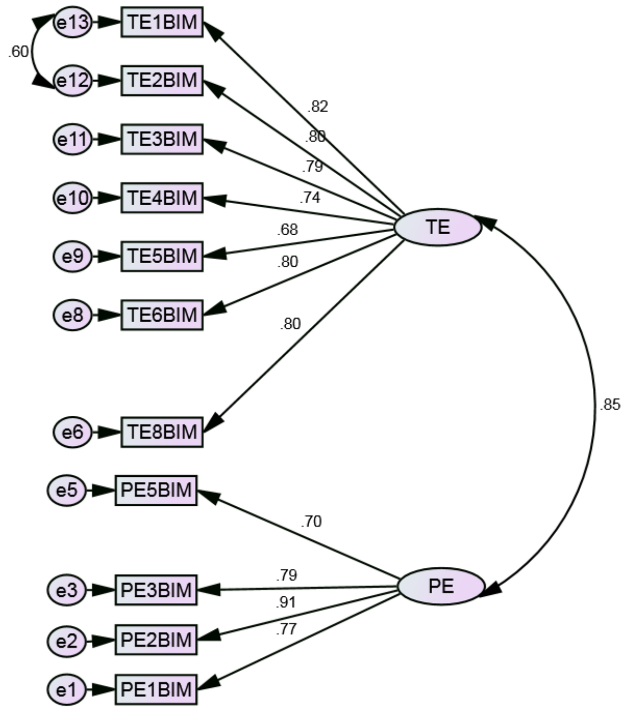
Factor Code	*The Extent of Process Efficiency Factors*
PE1BIM	Meeting short-term targets of deliverables
PE2BIM	Meeting procurement goals
PE3BIM	Meeting performance targets
PE4BIM	Knowledge capture
PE5BIM	Safety index

Figure 1. The conceptual measurement instrument of the extent of technology and process efficiency (including 8 factors for technology efficiency and 5 factors for process efficiency) (left) and the factor list with codes and names of technology efficiency and process efficiency (right).

4 FINDINGS

The goal is to identify factors that affect the extent of technology and process efficiency in BIM enabled construction projects. An intensive literature review was conducted to accomplish this task. Comprehensive item generation process is needed for construct validity (Nunnally 1978). A conceptual measurement model was developed in accordance with the theoretical background. 8 factors for the extent of technology efficiency and 5 factors for the extent of process efficiency were identified (Figure 1). The factors are formulated into statements to conduct a proper question to respondents. Five-point Likert Scale is used for collecting data from respondents, where 5 represents strongly agree, 4 indicates agree, 3 indicates neutral, 2 indicates disagree, and 1 indicates strongly disagree. The data that is collected from professionals, who are both experienced in traditional and BIM delivery methods, about the extent of technology and process efficiency in BIM enabled construction projects, is tested using AMOS Version 22.0 to validate measurement model. Data and analysis results related to measurement model are represented in observed variables (Figure 1), latent variables (Figure 1) and goodness-of-fit comparisons (Table 1). The data collected via questionnaire survey was tested for content validity, convergent validity, reliability, and multicollinearity. Goodness-of-fit of the models were assessed (Bollen and Long 1993). Content validity is assured with an extensive literature review in the research field for obtaining correlation between theoretical do006Dain and specific measurement variables

(Carmines and Zeller 1991). Convergent validity was tested with α = 0.001 level of significance for all factors loadings (Churchill, 1979).



Factor Code	*Estimate (Conceptual Model)*	*Estimate (Refined Model)*	*P-Value*
TE1BIM	.877	.822	0.001
TE2BIM	.868	.799	0.001
TE3BIM	.755	.795	0.001
TE4BIM	.704	.743	0.001
TE5BIM	.661	.677	0.001
TE6BIM	.770	.795	0.001
TE7BIM	.691	-----	0.001
TE8BIM	.791	.708	0.001

Factor Code	*Estimate (Conceptual Model)*	*Estimate (Refined Model)*	*P-Value*
PE1BIM	*.782*	*.774*	*0.001*
PE2BIM	*.903*	*.907*	*0.001*
PE3BIM	*.772*	*.790*	*0.001*
PE4BIM	*.632*	-----	*0.001*
PE5BIM	*.710*	*.700*	*0.001*

Figure 2. The refined measurement instrument of the extent of technology and process efficiency (left) and factor loadings for conceptual and refined models with respective significance level value (including 7 factors for technology efficiency and 4 factors for process efficiency) (right).

The accuracy of the measurement instrument is assured with internal consistency of the constructs, which is a measure for reliability based on Cronbach's alpha value (Lin *et al.* 2005). According to Churchill (1979) the threshold value for reliability is 0.6 for exploratory studies, whereas it is .70 and higher for Nunnally (1978) and Flynn *et al.* (1990). The numbers on the arrows stands for the strength of relationship between observed variables (rectangular boxes, Figure 1,2) and latent variables (oval boxes, Figure 1, 2) (Joreskog and Sorbom 1993). Factors related to the extent of technology efficiency and process efficiency for BIM enabled construction projects (Figure 1) were refined over several iterations by removing the variable with low factor loading to improve model (Figure 2). The refined measurement model includes a total of 11 observed variables as opposed to 13 variables for a better model fit of measurement instrument. High performance target cost projection (TE7BIM) factor was eliminated from the measurement instrument because there is another cost related factor called minimized life cycle cost (TE8BIM) which is a better measure with a higher factor loading. Knowledge capture (PE4BIM) factor was eliminated because of it has the lowest factor loading. All factor loadings in the refined measurement model were statistically significant at .001 level. The refined measurement model indicates that the observed variables establish a valid measure for their respective latent variables. Model is also refined with using the modification indices to reduce $\chi 2$ levels for each possible path (Hair *et al.* 1998, Arbuckle 2007, Hoyle and Panter 1995). The refined measurement model is statistically significant at .022 levels which confirms the < .05 level of significance rule (Table

1). The conceptual and refined measurement models were compared using goodness-of-fit indices (Table 1). Multicollinearity is tested with Pearson correlation analysis conducted on the observed variables, which were found to be below 0.90 (Hair *et al.* 1998). The results show that there is no multicollinearity.

Table 1. Goodness-of-fit Indices of conceptual and refined measurement models.

Model **Goodness-of-fit Threshold (acceptable)**	**P-Value** **< *0.05***	**X^2 / df** **< 3.00**	**p-value** **< 0.05**	**GFI** **> 0.76**	**TLI** **> 0.70**	**CFI** **> 0.73**	**RMSEA** **> 0.80**
Conceptual Model	.000	1.974	.000	.833	.905	.922	.103
Refined Model	.022	1.485	.022	.896	.962	.971	.073

The fit of measurement instrument to data was tested via goodness-of-fit indices. One of the determinants of goodness-of fit is relative chi-square ($\chi 2$=df), which should be smaller than 3 (Jaspara 2003). The other determinants those used for model comparisons are the goodness-of-fit index (GFI> .76, Arrindell *et al*. 1998), the comparative fit index (CFI > .73), the Tucker-Levis fit index (TLI > .70), and the root-mean square error of approximation (RMSEA < .080-acceptable) (Klein 1998). Table 1 presents the results of the goodness-of-fit tests for measurement models. The refined measurement model is statistically significant and model fit is good. The statistical results show that the refined measurement instrument is approved. There is a high correlation with a value of .85 between the extent of technology and process efficiency in BIM enabled construction projects, which indicates a strong positive relationship between those variables. The relationship must be assessed in future researches.

5 CONCLUSION

An attempt was made in this study to assess the validity of measurement instrument for the extent of technology and process efficiency in BIM enabled construction projects. The results are satisfactory and the refined measurement instrument is accepted with a good. In conclusion, this research fulfilled its aim to validate a reliable measurement instrument for technology and process efficiency in BIM enabled construction projects, and evidenced a high correlation between two latent variables. In future studies, the relationship between the technology efficiency, process efficiency, and other variables in BIM enabled construction projects will be tested.

References

AGC, *The Contractors' Guide to BIM,* Associated General Contractors (AGC) of America, 2006. Retrieved from www.agc.org in April, 2008.

Arbuckle, J. L., *AMOS 16.0 User's Guide,* AMOS Development Corporation, Chicago, 2007.

Arditi, D., and Gunaydin, H. M., Total Quality Management in the Construction Process, *International Journal of Project Management*, 15(4), 235–43, 1997.

Arrindell, W. A., Sanavio, E., Aguilar, G., Sica, C., Hatzichristou, C., and Eisemann, M., The Development of a Short Form of the EMBU: Its Appraisals with Students in Greece, Guatemala, Hungary and Italy, *Personality Individual Differences*, 27(4), 613–628, 1999.

Azhar, S., Building Information Modeling: Trends, Benefits, Risks, and Challenges for the AEC Industry, *Leadership Manage. Eng.*, 11(3), 241-252, 2011.

Azhar, S., Hein, M., and Sketo, B., *Building Information Modeling: Benefits, Risks and Challenges*, Proc., 44th Associated Schools of Construction National Conference, Auburn, AL, 2008.

Barlish, K., and Sullivan, K., How to Measure the Benefits of BIM — A Case Study Approach, *Automation in Construction*, 24 149–159, 2012.

Bollen, K. A., and Long, J. S., *Testing Structural Equation Models*, Sage, Newbury Park, CA., 1993.
Carmines, E. G., and Zeller, R. A., *Reliability and Validity Assessment*, Sage, Newbury Park, CA, 1991.
Churchill, G. A., A Paradigm for Developing Better Measures for Marketing Constructs, *J. Marketing Res.*, 16(1), 64–73, 1979.
Farsi, M., and Filippini, M., An Empirical Analysis of Cost Efficiency in Nonprofit and Public Nursing Homes, *Annals of Public and Cooperative Economics*, 75(3), 339–365, 2004.
Frumkin, P., and Kim, M.T., Strategic Positioning and the Financing of Nonprofit Organizations: Is Efficiency Rewarded in the Contributions Marketplace?, *Public Administration Review*, 61(3), 2001.
Glick, S., and Guggemos, A., *IPD and BIM: Benefits and Opportunities for Regulatory Agencies*, Proc., 45th Associated Schools of Construction National Conference, Gainesville, FL, 2009.
Hair, J. F, Anderson, R. E., Tatham, R. L., and Black, W. C., *Multivariate Data Analysis*, 5th Ed., Prentice-Hall, Upper Saddle River, NJ, 88–92, 1998.
Hardin, B., *BIM and Construction Management*, Wiley, Indianapolis, IN, 2009.
Hoyle, R. H., and Panter, A. T., *Writing about Structural Equation Models, Structural Equation Modeling: Concepts, Issues, and Applications*, R. H. Hoyle, ed., Sage, Thousand Oaks, CA, 158–176, 1995.
Jacobs, F., Chase, R., *Operations and Supply Chain Management*, 13th. McGraw-Hill/Irwin, New York, NY, 2010.
Jaspara, A., Cognition, Culture and Competition: An Empirical Test of the Learning Organization, *Learn. Organization Int. J.*, 10(1), 31–50, 2003.
Joreskog, K. G., and Sorbom, D., *LISREL 8: Structural Equation Modeling with the SIMPLIS Command Language*, Scientific Software International, Chicago, 1993.
Klein, R. B., *Principles and Practice of Structural Equation Modeling*, Guilford Press, New York, 1998.
Lee, S., Lee, D., Schniederjans, M., Supply Chain Innovation and Organizational Performance in The Health Care Industry, *Int. J. Oper. Prod. Manag.*, 31(11), 1193–1214, 2011.
Lin, C., Chow, W., Madu, C., Kuei, C., Yu, P., A Structural Equation Model of Supply Chain Quality Management and Organizational Performance, *Int. J. Prod. Econ.*, 96(3), 355–365, 2005.
Nunnally, J. C., *Psychometric Theory*, 2nd Ed., McGraw-Hill, New York, 1978.
Reed, R., Lemak, D. J., and Montgomery, J. C., Beyond Process: TQM Content and Firm Performance, *The Academy of Management Review*, 21(1), 173-202, 1996.
PMI, *Construction Extension to the PMBOK® Guide, 3rd edition. Project Management Institute*, Newton Square, Pennsylvania, USA, 2007.
Qian, A., Benefits and ROI of BIM for Multi-Disciplinary Project Management. National University of Singapore, 2012. Retrieved from http://www.icoste.org/wp-content/uploads/2011/08/Benefits-and-ROI-of-BIM-for-Multi-Disciplinary-Project-Management.pdf on August 19, 2013
Smith, H., and Fingar, P., *Business Process Management—The Third Wave*, Florida: Meghan-Kiffer, 2003.
Succar, B., The Five Components of BIM Performance Measurement, *Part of Proceedings: W096 — Special Track 18th CIB World Building Congress (combined with W104)*, May 2010, Salford, UK, University of Newcastle, NSW Australia, 2010.