Embedding Cultural Knowledge in Building Information Modeling (BIM) for Fabrication Efficiency to Reduce Industrialized Construction Waste

M. Abdul Ghafar [1], R. Ibrahim [2] and Z. Shari [3]

[1] PHD Candidate; Department of Architecture, Faculty of Design and Architecture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia; (+603) 89464090; FAX (+603) 89480017; email: maszu650@yahoo.co.uk
[2] Professor; Faculty of Design and Architecture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia; (+603) 89464090; FAX (+603) 89480017; email: rahinah@upm.edu.my
[3] Senior Lecturer; Department of Architecture, Faculty of Design and Architecture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia; (+603) 89464040; FAX (+603) 89480017; email: zalina@upm.edu.my

ABSTRACT

Going "green" and global has marshaled Architects, Engineers and Contractors (AEC) to use Building Information Modeling (BIM) to be competitive across the globe. However, little is known on the effect of cultural and human factors on BIM technologies in industrialized building projects, especially in Malaysia. This paper examined the extant literature of BIM technologies to reduce construction waste and improving the efficiency of Industrialized Building Systems (IBS) in fabrication process. The paper supports BIM's implementation as AEC professionals' communication culture, effective cultural knowledge to mitigate knowledge loss, and key enabler for fabrication in a project. The paper concludes that despite having competent technological support, fabrication efficiency is still much affected by cultural knowledge between professionals during design phase which could affect production of waste in IBS construction. The result is expected to improve AEC collaboration knowledge during sustainable development through efficient environmental management during an industrialized project lifecycle.

INTRODUCTION

Globalization and sustainability issues have urged Architects, Engineers and Contractors (AEC) using BIM especially in developing countries like Malaysia to become globally competitive. Malaysia is particularly interested in utilizing BIM and Industrialized Building Systems (IBS) to address the Construction Industry Master Plan 2006-2015 (CIMP 2006-2015) as a means to direct the future of Malaysian construction industry. Prior studies potentially saw application of BIM would support IBS fabrication process (Fischer & Kunz 2004; Knight & Sass 2010); cost, quality and assembly efficacy (Buswell et al. 2007). Other literature highlight IBS downfall with poor technical understanding, poor knowledge transfer from assemblers to workers (Rashidi et al. 2012), and no short-term profits (Lou & Kamar 2012). The authors agree with Rashidi et al. (2012) that lacking knowledge transfer and understanding are potentially the key factors contributing to further waste production. However, little is known on the effect of culture and human factors on BIM technologies in IBS building projects, especially in Malaysia. The authors recommend focusing and investigating the cultural and human effects of BIM technologies in IBS building projects as increasing number of professionals are embracing BIM, particularly in Malaysia.

RESEARCH METHOD

Selected literature survey was conducted to examine how CAD technologies in BIM and professionals' culture could reduce waste in fabrication deliveries. Then it present CAD technologies associated with BIM enabled (POP models (Fischer and Kunz 2004)) IBS fabrication. We tried to identify how cultural knowledge enhances fabrication efficiency under such headings as: waste typology in industrialized production; cultural knowledge in fabrication; and understanding the roles of discontinuous member in fabrication. Towards its conclusion, we present descriptive findings of how BIM communication culture, effective culture in fabrication, and integration of BIM communication–cultural knowledge in a systematic manner will eventually reduce industrialized construction waste. This paper is proposing a discussion leading towards the potential theoretical direction of professionals' cultural knowledge in the construction industry that could accelerate BIM adoption technologies to improve the fabrication efficiency in IBS construction.

BIM WORK CULTURE

This section discusses how BIM work culture could reduce industrialized construction wastage. Heuristically, Virtual Design and Construction (VDC)–developed by the Centre for Integrated Facility Engineering (CIFE), Stanford University for the design-construction-operation team; and extended by Sacks et al. (2010) as BIM due to similar tenets, components, and procedures. The POP models (Fischer & Kunz 2004) in VDC consists of multidisciplinary performance models of *product* (Kam & Fischer 2004)– e.g. Floors, Walls and Beams (Kunz & Fischer 2012); *organization* (Jin et al., 1995)–e.g. explicit connections of accomplished tasks and milestones, communicating reciprocal interdependence between team members, associating and reworking communication with downstream–upstream tasks for failures and exceptions, and indicating formal organizational hierarchy (Nissen & Levitt 2002); and *process* (Kam et al. 2003)–e.g. 4D CAD visualization of macro and micro schedules, delivery dates and activities (Kam et al. 2003). It uses Industry Foundation Classes (IFC)–an interoperable international standard allowing smooth information exchange between tools for visual interoperability and information efficacy (Kam et al. 2003) where suggestion for solutions (Fischer & Kunz 2004) and accurate decision (Bouchlaghem *et al. 2*005) to conflicts can be analyzed for *n*D's interoperability (Lee et al. 2005).

During fabrication, CAD models are linked to CAD numeric control (CNC) machine to produce speedy, accurate products regardless of mass production or small quantities (Knight & Sass 2010); hence help reduce waste and variation orders. Kam and Fischer (2004) described the POP models as an active visual communicator during the early phase of design for project team members aware of the sequenced planned work, schedules, conflicts, etc. We posit therefore that the POP models could identify early anomalies in assembly and agree with Kam et al. (2003) having a visual communicator could increase non-professional awareness and knowledge flow to appreciate design concepts, design rationale, constructability and field issues. The authors agree with Ibrahim and Nissen (2007) that in a complex dynamic environment such as fabrication-construction deliveries, knowledge flow is crucial to eradicate anomalies and rework between team members. Kam et al. (2003) agree that designers' accurate properties of the product models could provide other team members to reuse data and embedded accurate information in their software application to coordinate fabrication process, thus minimizing rework. Consequently, we agree that IFC in POP models would allow smooth interoperability of data between team members, cut half of the documentation time and convey accurate information hence will minimize rework in the subsequent assembly process.

CULTURAL KNOWLEDGE IN FABRICATION

This section discusses how cultural knowledge could enhance fabrication efficiency to reduce industrialized waste. Hofstede (1997; pg. 10) regards culture as "several layers of mental programming within themselves, corresponding to different levels of culture". Layers of mental programming based on Hofstede's perspectives are personality, culture, and human nature. Another layer of culture in societies are national culture differences, cultural differences according to region, religion, gender, generation and class, and organizational culture. In our case, we posit that much of organizational culture is more likely to be influenced by AEC professionals' characteristics, such as complacency with 2D traditional method (Fischer 2006) to deliver projects. This trait is inherit from their earlier tertiary trainning and previous experiences during projects (Ibrahim & Pour 2010; Rahimian & Ibrahim 2011) hence making them reluctant accepting new ways of delivering projects. For this reason, the authors propose to study how these cultural and mental programming layers could enhance fabrication efficiency in reducing industrialized waste.

Many scholars highlight that construction waste production is getting higher due to lack of professional awareness (Poon, Yu, & Jaillon 2004); less defined professionals' responsibilities in handling waste (Osmani, Glass, & Price 2006); and professionals' attitude and behavior in waste management (Begum et al. 2009). Waste in this context is inefficient use of resources and capital, which add cost but do not add value to product (Koskela 2000). Ohno (1988) categorizes seven types of industrial waste namely: 1) overproduction 2) inventory, 3) extra processing steps, 4) motion, 5) defects, 6) waiting, and 7) transportation; and 8) making-do waste (Koskela 2004). Industrialized waste production is influenced by cultural knowledge. The authors also agree with (Knight & Sass 2010) that cultural and social factor play equal roles to make these technologies accepted and validated in the construction industry. Additionally, a study by Abdul Ghafar et al. (2013) posit that organization would depend on team's work culture, method of knowledge transfer for discontinuous membership in a building project, and further enhancement of professional education programs. Herewith, we can consider that adaptation of CAD technologies together with professionals' culture, in the early stage of design, could promote effective fabrication practices to reduce industrialized waste.

Studies have found that epistemological characteristics–combination of complex, uncertain and equivocal environment–are conveying poor tacit information to team members especially during formal documentation and negotiation for approval process (Ibrahim & Paulson 2008); and deficient understanding of interdependencies in multiple workflows (Ibrahim & Nissen 2007) are hampering knowledge flow and effective assembly of discontinuous members. For instance, the specialist contractor in the fabrication process is denoted as a discontinuous member—coming into the team when needed and leaving when task is completed. This implies that fabrication waste production is likely due to a combination of cultural knowledge differences between professionals and weak interdependent monitoring over the complex multiple workflows. This is making discontinuous member suffer from "knowledge loss" phenomenon, hindering the fabrication efficiency thus causing unnecessary wastages. The authors are expecting amalgamation of BIM with professionals' culture and firm monitoring over complex discontinuous membership workflow in the early stage of design could prevent knowledge loss thus reduce industrialized waste. In turn, it would facilitate fabrication efficiency. In view of the above, we posit that cultural knowledge and technologically support could allow smooth interoperability, ensure accurate information and minimize rework in subsequent fabrication process towards inhibiting unnecessary wastage.

DISCUSSION ON UTILIZATION OF BIM FOR FABRICATION EFFICIENCY

So far, we have presented a background on organizational culture and identify its influence on the successful implementation of BIM in IBS fabrication process. The exploration of BIM technologies and cultural knowledge shows that both of these elements are not only very important and interrelated with one another, but they could enhance the fabrication efficiency required in IBS assemblies. We further discuss these factors below.

BIM as professional's communication culture. The implementation of BIM technologies has shown many potential benefits in the IBS construction. However, professionals are still reluctant to implement BIM because of some cultural factors. According to Paulson and Fondahl (1980), this is due to: individuals' attitudes towards risks involved; struggle in executing; and other participants' acceptance in implementing new technologies. Delavari et al. (2011) posit that engaging human side of building professionals is equaly important especially when IT–supported procedure is involved during design stage. The authors concur with Vafa et al. (2009) that effective visual communication could enable professionals to anticipate and mitigate unnecessary action and information flow from material procurement to construction project.

Discontinuous membership during fabrication delivery. Cultural differences between professionals in AEC could significantly effects several dimensions of their beliefs and values which could lead to misunderstandings, conflict and poor organizational performance (Hofstede, 1997). For instance, a study by Ramsey and Levitt (2005) discovered that team members cultivate "a set of beliefs" and are fused with individuals skills and experiences, to form oneself knowledge in the operating environment. For example "sticky" tacit knowledge phenomenon (Nissen 2006) is hampering discontinuous membership learning necessary project's information; hence leading to misunderstanding, variants and rework. They do not know what sort of information is required and need to be sent out, especially in relation to projects' tacit information (Flanagan, Eckert & Clarkson 2007). For instance, discontinuous specialists such as MEP specialists are only present in the later stage of construction, making them prone to knowledge loss (Shumate, Ibrahim, & Levitt 2010) and difficulty tracking information seamlessly from inexperienced professionals. The authors agree with Burton and Obel (2004) to centralize decision making in a functional hierarchy as opposed to organizational hierarchy for complex, highly interdependent tasks to produce better quality outcomes. Therefore, the authors posit that the integration of BIM with cultural knowledge could accelerate a project's comprehension for discontinuous membership in fabrication efficiency processes of a project.

Fabrication efficiency and cultural knowledge. Globalization is changing how AEC professionals communicate and work. The foreseen differences of cross-culture knowledge are forcing AEC professionals to learn new design tools, and do design differently from conventional norm. In a study by Horii, Jin and Levitt (2005), they discover that cultural knowledge difference between east professionals–steep hierarchies and centralized decision making–and west professionals–flatter hierarchies and decentralized decision making– is resulting in low performance in high interdependence tasks during project's collaboration. The authors agree with Shumate et al. (2010) that the occurrence aggravates knowledge loss. It is hindering team members to effectively produce efficient fabrication delivery. With this mind, this study agrees with Abdul Ghafar et al. (2013) that when a design decision knowledge skips the fabrication task, the mistake only manifest when builder realizes a building component has arrived at site with wrong specification. Therefore, we posit that despite having competent technological support, fabrication efficiency is still much affected by cultural knowledge between professionals during design phase which could affect production of waste in IBS construction.

We can conclude that the implemention of BIM technologies and cultural knowledge in IBS practices can certainly give a better fabrication output and enhance information flow between discontinuous membership's interdependencies in complex workflow. By helping reducing fabrication wastage, we agree that BIM supports AEC's practices to undergo a new paradigm shift. Hereby we hypothesize that when waste production is high, fabrication efficiency would reduce where technology and culture are controlled.

CONCLUSION

We discuss BIM as professional's communication culture; discontinuous membership during fabrication delivery; and fabrication efficiency and cultural knowledge. We argue that utilizing BIM would suggest green practice by helping reduce fabrication waste. We hypothesize that when waste production is high, fabrication efficiency would reduce when technology and culture are controlled. We are proposing BIM to be integrated with cultural knowledge to accelerate a project's comprehension for discontinuous membership in fabrication efficiency processes of a project. We posit that the fabrication output could improve if cultural knowledge between discontinuous memberships is seamless, diminishing anomalies before assembly starts. Further study is recommended in facilitating cultural knowledge integration in BIM practices among AEC professionals. The study benefits the training and tool development at off-site fabrication process.

REFERENCES

Abdul Ghafar, M., Ibrahim, R., Shari, Z., & Rahimian, F. P. (2013). "Embedding Work Culture in Building Information Modeling (BIM) for Enhancing Collaboration in Global Projects." *International Journal of 3D Information Modeling (IJ3DIM)* 2(2), 16–29.

Begum, R. A., Siwar, C., Pereira, J. J., & Jaafar, A. H. (2009). "Attitude and behavioral factors in waste management in the construction industry of Malaysia." *Resources, Conservation and Recycling*, *53*(6), 321–328.

Bouchlaghem, D., Shang, H., Whyte, J., & Ganah, A. (2005). "Visualisation in architecture, engineering and construction (AEC)." *Automation in Construction*, *14*(3) 287–295.

Burton, R. M., & Obel, B. (2004). *Strategic Organizational Diagnosis and Design, 3rd Edition*. New York, Kluwer.

Buswell, R. a., Soar, R. C., Gibb, a. G. F., & Thorpe, a. (2007). "Freeform Construction: Mega-scale Rapid Manufacturing for construction." *Automation in Construction*, *16*(2) 224–231.

Delavari, N., Said, N. S., Ibrahim, R., & Abdullah, M. . (2011). "HCI to Engage Design Team Members in IT-integrated Design Collaboration Process." *WSEAS Transaction Information Science and Applications*, *8*(9), 341–355.

Fischer, M. (2006). Formalizing Construction Knowledge for Concurrent Performance-Based Design. In *Intelligent Computing in Engineering and Architecture* (pp. 186–205). Springer, Berlin Heidelberg.

Fischer, M., & Kunz, J. (2004). The Scope and Role of Information Technology in Construction. In *Proceeding-Japan Society of Civil Engineers* (pp. 1–32). DOTOKU GAKKAI.

Flanagan, T., Eckert, C., & Clarkson, P. J. (2007). "Externalizing tacit overview knowledge: A model based approach to supporting design teams." *AIEDAM:*

Artificial Intelligence for Engineering Design, Analysis and Manufacturing. 21 227–242.
Hofstede, G. (1997). *Cultures and Organizations: Software of the mind*. Mc Graw Hill International.
Horii, T., Jin, Y., & Levitt, R. E. (2005). "Modeling and Analyzing Cultural Influences on Project Team Performance." *Computational and Mathematical Organization Theory*, *10*(4).
Ibrahim, R., & Nissen, M. E. (2007). "Discontinuity in organizations: Developing a knowledge-based organizational performance model for discontinuous membership." *International Journal of Knowledge Management (IJKM)*, *3*(1), 10–28.
Ibrahim, R., & Paulson, B. C. (2008). "Discontinuity in organizations: Identifying business environment affecting of knowledge flow in PLM." *International Journal of Product Lifecycle Management*, *3*(1) 21–36.
Ibrahim, R., & Pour, F. (2010). "Comparison of CAD and manual sketching tools for teaching architectural design." *Automation in Construction*, *19*(8), 978–987.
Jin, Y., Levitt, R., Kunz, J., & Christiansen, T. R. (1995). "The Virtual Design Team : A Computer Simulation Framework for Studying Organizational Aspects of Concurrent design." *Simulation*, *64*(3), 42–57.
Kam, C., & Fischer, M. (2004). "Capitalizing on early project decision-making opportunities to improve facility design , construction , and life-cycle performance — POP , PM4D , and decision dashboard approaches." *Automation in Construction*, *13*, 53–65.
Kam, C., Fischer, M., Manager, G., Oy, O. G., Karjalainen, A., Manager, C., … Solutions, C. (2003). "The product model and fourth dimension project." *ITcon*, *8*, 137–166.
Knight, T., & Sass, L. (2010). "Looks count: Computing and constructing visually expressive mass." *Artificial Intelligence in Engineering Design, Analysis and Manufactuting* 24, 425–445.
Koskela, L. (2000). *An exploration towards a production theory and its application to construction An exploration towards a production theory and*. VTT Technical Research Centre of Finland.
Koskela, L. J. (2004). Making do-the eighth category of waste. In *Proceedings of the 12th annual conference of the International Group for Lean Construction.*
Kunz, J., & Fischer, M. (2012). Virtual Design and Construction: Themes, Case Studies and Implementation Suggestions. *CIFE Working Paper#097*, *14*.
Lee, A., Marshall Pointing, A., Aouad, G., Tah, J., Cooper, R., & Fu, C. F. (2005). nD modeling- a driver or enabler for construction improvement? In *RICS Research paper Series, University of Salford*.
Lou, E. C. W., & Kamar, K. a. M. (2012). "Industrialized Building Systems: Strategic Outlook for Manufactured Construction in Malaysia." *Journal of Architectural Engineering*, *18*(2), 69–74.
Nissen, M. E. (2006). *Harnessing Knowledge Dynamics Principled Organizational Knowing and Learning* (Vol. 2). IRM Press.
Nissen, M., & Levitt, R. (2002). Dynamic models of knowledge-flow dynamics. *CIFE Working Paper #76*.

Ohno, T. (1988). Toyota production system: Beyond large scale production (pp. 17–20). New York: Productivity Press.

Osmani, M., Glass, J., & Price, A. D. F. (2006). Architect and contractor attitudes to waste minimisation. In *Proceedings of the ICE-Waste and Resource Management* (pp. 65–72.).

Paulson, B. C., & Fondahl, J. . (1980). Towards Improved Transportation Construction Through Research. The Construction Institute, Stanford University, Stanford California.

Poon, C. S., Yu, A. T. W., & Jaillon, L. (2004). "Reducing building waste at construction sites in Hong Kong." *Construction Management and Economics* 2*2*(5), 461–470.

Rahimian, F. P., & Ibrahim, R. (2011). "Impacts of VR 3D sketching on novice designers' spatial cognition in collaborative conceptual architectural design." *Design Studies*, *32*(3) 255–291.

Ramsey, M. S., & Levitt, R. E. (2005). A computational framework for experimentation with edge organizations. Stanford University

Rashidi, A., Ibrahim, R., Said, S. N., & Othman, S. (2012). Computer-aided theoretical model for low tech laborers capability training in industrialized construction industry. In *14th International Conference on Computing and in Civil and Building Engineering (ISCCBE)* (pp. 27–29). Moscow, Russia.

Sacks, R., Koskela, L., Dave, B. A., & Owen, R. (2010). "Interaction of Lean and Building Information Modeling in Construction." *Journal of Construction Engineering and Management*, *136*(9), 968–980.

Shumate, M., Ibrahim, R., & Levitt, R. (2010). "Dynamic Information Retrieval and Allocation Flows in Project Teams With Discontinuous Membership." *European Journal of International Management*, *4*(6), 556–575.

Vafa, M., Ibrahim, R., Hong, T., & Yusuff, R. (2009). "Visualization of Supply Chain network using social network analysis tool for a timber construction project." *Alam Cipta Journal*, *4*(1), 41–50.