KEY DETERMINANTS AND BARRIERS TO DIGITAL INNOVATION ADAPTATION AMONG ARCHITECTURAL PRACTICES

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This thesis is dedicated to my children who
would also like to be an architect, Runddy John and Runddy Matthew
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ABSTRACT

Digital innovation is recognized as a new architectural design process to improve building design, productivity with less construction cost and time. However, it is also recognized that it creates changes in design processes that can in turn alter business goals. The destructive negative impact to architectural practice varies from the size of the architectural firm. To elucidate the problem, this thesis investigates the key determinants and barriers that impede architectural practices in digital innovation adaptation. Its objectives are to investigate the digital technologies used by architectural practices in digital innovation adaptation; examine the barriers, how crucial it is and which among the barriers is the most significant; and to evaluate whether there is a significant relationship between the size of architectural practices and barriers in digital innovation adaptation. An in-depth literature review of digital innovation tools and processes and digitally innovative projects in architectural practices was conducted. This study has utilized quantitative and qualitative survey method where data from selected forty five (45) architectural practices that have utilized digital innovation were collected through the use of structured survey. The data were analyzed through descriptive statistics, *Scheffe* post hoc and multiple regression analysis and was subsequently validated. The result of this study revealed that technological, financial, organizational, process and psychological barriers were more pressing in smaller architectural practices than bigger architectural practices. Among the six (6) subsequent barriers that were examined, financial barrier was found to be the most crucial in digital innovation adaptation. It was also found out that the size of architectural practice and barriers in digital innovation adaptation are significantly correlated. This finding means that the bigger the architectural practice, the less that it is affected by barriers in digital innovation adaptation, while the smaller architectural practice, the more that it is affected by barriers in digital innovation adaptation. With this findings, a guideline for digital innovation adaptation in architectural practices was recommended.

ABSTRAK

Inovasi digital telah diakui sebagai proses reka bentuk senibina terkini bagi memperbaiki reka bentuk bangunan, meningkatkan produktiviti dengan pengurangan kos dan masa pembinaan. Walau bagaimanapun, inovasi digital turut membawa perubahan kepada proses reka bentuk yang seterusnya mengubah matlamat sesebuah perniagaan. Impak negatif yang boleh merosakkan firma-firma senibina adalah berbeza mengikut saiz sesebuah firma. Bagi menjelaskan permasalahan tersebut, tesis ini mengkaji penentu-penentu utama serta halangan-halangan yang menyekat firma-firma senibina dalam penyesuaian terhadap inovasi digital. Objektif kajian ini adalah untuk mengkaji teknologi-teknologi digital yang diguna pakai oleh firma-firma senibina dalam pengadaptasian inovasi digital; mengenal pasti halangan; serta untuk menilai sama ada terdapat hubung kait yang signifikan di antara saiz firma-firma senibina dengan halangan-halangan dalam pengadaptasian inovasi digital. Kajian literatur yang terperinci telah dijalankan bagi mengenal pasti peralatan-peralatan yang terlibat dengan inovasi digital serta proses-prosesnya, serta projek-projek inovasi digital yang terlibat di syarikat-syarikat senibina. Kaedah kuantitatif dan kualitatif soal selidik berstruktur telah digunakan; di mana data-data telah dikumpul daripada empat puluh lima (45) firma senibina terpilih yang mengamalkan kaedah inovasi digital. Data-data tersebut kemudiannya dianalisa secara statistik diskriptif, *Scheffe post hoc* serta analisa pelbagai regresi. Hasil kajian mendapati, faktor teknologi, kewangan, organisasi, proses dan halangan-halangan psikologi lebih dominan dalam firma-firma senibina yang lebih kecil berbanding dengan firma-firma senibina yang lebih besar. Di antara keenam enam (6) halangan yang telah dianalisa, halangan kewangan didapati sebagai penentu yang paling penting dalam pengadaptasian inovasi digital. Kajian turut mendapati bahawa saiz sesebuah firma senibina serta halangan-halangan dalam pengadaptasian inovasi digital adalah berkait secara signifikan. Penemuan-penemuan ini menyimpulkan bahawa semakin besar sesebuah syarikat senibina maka ia semakin kurang terkesan dengan halangan-halangan pengadaptasian inovasi digital. Manakala, semakin kecil firma senibina maka ia akan semakin terkesan dengan halangan-halangan pengadaptasian inovasi digital. Berdasarkan penemuan ini, sebuah garis panduan untuk pengadaptasian inovasi digital bagi firma senibina telah disyorkan.

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LIST OF ABBREVIATIONS

AEC	-	Architecture, Engineering and Construction
ADT	-	Autodesk's Architectural Desktop
BIM	-	Building Information Modeling
BRE	-	Building Research Establishment
CAAD	-	Computer Aided Architectural Design
CAD	-	Computer Aided Design
CAM	-	Computer Aided Machine
CATIA	-	Computer Aided Three-Dimensional Interactive Application
CDD	-	Component Distribution Diagramming
CNC	-	Computer Numerically Controlled
DWG	-	Drawing
FEM	-	Finite Elements Method
ETFE	-	Ethyltetraflouroethylene
IT	-	Information Technology
GT	-	Gehry Technologies
M & E	-	Mechanical and Electrical
MEP	-	Mechanical, Electrical and Plumbing
NURBS	-	Non-Uniform B-Splines
R & D	-	Research and Design
ROI	-	Return of Investment
VBA	-	Visual Basic Application
2D	-	Two Dimensional
3D	-	Three Dimensional
4D	-	Four Dimensional

LIST OF SYMBOLS

F	-	F ratio
f	-	Frequency
n	-	Number of respondents
p	-	Probability level

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CHAPTER 1

BACKGROUND OF THE STUDY

1.1 Introduction

As modern world develops and utilizes design technology for architecture, different design methodologies have emerged. Current design research focuses on computationally mediated design process (Kolarevic, 2003; Hensel and Menges, 2006; Littlefield, 2008; Datta *et al*., 2009) which is essentially concerned with form finding and building performance simulation i.e. structural, environmental, constructional and cost performance through the integration of physics and algorithms. Since its emergence, architectural practices are increasingly aided by and dependent on the technology and have resulted in major paradigm shift (Qawasmi and Karim, 2004; Pauwels *et al.,* 2011). It opens new territories of formal exploration in architecture and radically reconfigures the relationship between design and production creating a direct digital connection between what can be imagined and designed, and what can be built through 'file-to-factory' processes of computer numerically controlled (CNC) fabrication (Kolarevic, 2003; Janssen *et al.,* 2011; Davis, 2011). These new digital technologies and its processes (Luebkeman and Shea, 2005), helps improved quality of design, reduced cost and time, and new aesthetics as possible. The advent of digital technologies have evoked 'digital innovation' in architectural practices wherein digital technologies are not just used

for the primary purpose of construction documentation and visualization, but also for modeling and documenting projects that is aesthetically and structurally sound, less in construction cost and time (Shi and Tang, 2013).

On the other hand, while the advancement of the new digital technologies has the potential for improving productivity, profit and design dramatically, literature of the subject revealed that substantial organizational and technical barriers exist that inhibit the effective adoption of these new technologies (Johnson and Laepple, 2002; Intrachooto, 2002; Henfridsson *et al.,* 2014; Berente *et al.,* 2014; Leach and Gou, 2007).

Despite the availability of new digital technologies that is abundant, digital innovation is not implemented. This is because only few knowledge and resources are transferred and utilized from one project to another. It usually happened when the primary objective or purpose of projects is not similar and does not include team members of the previous project who has the right skills, proficiency of the new process and knowledge of the technology. Furthermore, Cory and Bozell (2001) elucidated that although architectural practices have acknowledged that the use of new digital innovation process can save a substantial amount of energy and time, these new digital technologies are minimally utilized. The benefits of digital innovation are to reduce cost, better work flow, reduce life cycle applications, and increase productivity, however these technologies are not fully utilized to its full potential (Fallon, 2004).

Looking further into digital innovation research of Johnson and Gunderson (2009) they have enumerated critical issues about technical and staff's abilities that are problematic in today's architecture, engineering and construction industry. It relates to organizational and technical barriers which are important when adopting the new technology (Whyte and Levitt, 2011; Yoo *et al.,* 2012).

Innovation research in different allied fields also revealed that companies implementing digital innovation are impede by several challenges and barriers which shared common and the same attributes. A survey in product design and manufacturing that was conducted by O'Sullivan (2002), elucidated that out of three thousand new innovation ideas for products, minimal number are successful because failure is part of innovation process and cannot be evaded. Most successful innovative organizations needs to importantly consider an appropriate level of risk when implementing innovation because the negative effect of failure of unsuccessful innovation is worse than a simple loss of investment or a bankruptcy. According to O'Sullivan (2002), failure can be also psychological which leads to loss of confidence among staff, and even resistance to change and improvement in the future. O'Sullivan (2002) added that the primary causes of unsuccessful innovation have been thoroughly research and found out that it varies to size of organization. Some problems are external and outside the control and influence of the organization. Several causes of failure in organizations elicited are poor organization, poor empowerment, poor knowledge management, poor leadership and poor communication.

In architecture, engineering and construction (AEC) innovation research evaluated by Johnson and Laepple (2002), it was concluded that practices adopting innovation is negatively affected by barriers and challenges relevant to additions of logistics and changes of organization structure. These include additions of expertise, costly investment of software, changes of new work processes, marketing strategies, and changes in culture and leadership of organization. Research studies made by Cory and Bozell (2001) have shown that while the advent of digital technology have benefited the construction industry, commercial issues that relates to cost, time and new methodology occur. With this issues, architectural practices should importantly consider software costs, software learning curve, design costs in relation to time, software and speed of computer to handle complex geometry, partition of the model among multiple users, level of details necessary that software can model, integration of models from multiple sources, web publishing, extraction of working drawings, maintenance and speed, all of which affect the profit and liquidity of the organization.

A research by Civil Engineering Research Foundation (1996) revealed nine (9) barriers to innovation in the construction industry. These include lack of technology transfer, salary disincentives, limited basic and industrial research and design, poor leadership, high equipment cost, adversarial relationships, inflexible building codes and standards, risk and liability, and construction based initial costs.

In technological innovation research of Inchachoto (2002), he coined that innovation in technology is better fostered by a team with has the work experience prior to innovation than a team of individuals selected through their expertise. According to Inchachoto (2002), collaboration is very useful and serves as multiple functions such as psychological assurance, financial security and technical-risk reduction. In order to attain success in innovation, the organization should consider team dynamics and project logistics. Project logistics are funding from outside the organization, collaboration in research, demonstration, validation and technical evaluation. Furthermore as added by Inchachoto (2002), it is very important to allocate budget for research in technological innovations.

1.2 Statement of the Problem

It is evident that digital innovation is happening in architectural practices but it is also evident that some architectural practices are facing challenges (Whyte, 2010; Whyte and Lobo, 2010). This is due to rapid increase of new digital technology and the current trends of non-orthogonal building design and the issue of sustainability. A number of architectural practices are indeed experiencing challenges evoked by the introduction of digital innovation. Unexpected client's demands, costly equipment, the new processes brought by the new digital technology, increasing global competitions, lack of knowledge of the technology, limited software, limited logistics are among the challenges (Braglia and Frosolini, 2014). Undeniably, implementing digital innovation in architectural practices is

problematic and not trouble-free. Return of investment and practices profit is the bottom line of business are at risk of failure when digital innovation is implemented.

Another challenge in implementing innovation is coping up with the change in organizational management of the organizations because innovation is doing something new and requires new knowledge of the processes (O'Sullivan (2002). To successfully implement innovation, it requires varied understanding of the main stages through which an innovation is to be developed (O'Sullivan (2002).

Furthermore in research studies of Perrow (1999) and Williams *et al, (*2014) it was concluded that firms which are engaged in building design are organizationally complex, and have non-linear and multiple interdependencies between their sub-systems. They are considered as complex organizations because the design processes are segmented and requires high efficiency and productivity. According to Whyte and Lobo (2010), digital technologies enable new design processes and the new method of interaction and infrastructure which increase the interactivity and complexity of practices leads to several issues such as limited time, low productivity, and cost which enable more logistics, managerial skills and leadership.

In management perspective (Kallinikos, 2005; Dossick and Neff, 2008), it was elucidated that leadership skills helps managers in organizations to handle the increasing coupling of technological solutions because of nature of loose coupling of organization set-up of organizations. According to Kallinikos (2005) and Dossick and Neff (2008) it is important to analyze digital technologies, organizational structures and processes to avoid failure.

In digital innovation research of Johnson and Laepple (2002), it is concluded that there is an interrelationship between business goals, work processes, and the

adoption of new digital technology. That is, changes in business goals generally require revising work processes which can be enhanced further by the introduction of digital technology. It is also recognized that innovations using digital technology creates possibilities for new work processes that can, in turn, alter business goals, understand how digital technology influences architectural organization, and therefore it is important to understand all three of these interrelated elements (Figure 1.1).

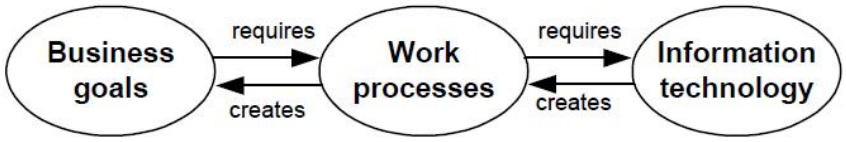

Figure 1.1 Model to understand the role of technology in innovation (Johnson and Laepple, 2002).

Innovation is a new way of doing something or new set of process and businesses are at risk of failure (Davila *et al*., 2006). While innovation increase value typically, it may have negative destructive effect to organizations, and possibility of changes in organizational structures and practices. The negative impact varies from the size of organization (Davila *et al*., 2006). Through the literature of the subject, innovation is accepted to increase productivity and profit in business, and therefore the mentioned barriers should be effectively managed by organizations to attend success in digital innovation (Johnson and Laepple, 2002).

In this study, it is argued that the success or failure of digital innovation in architecture does not only depend on the knowledge of the new digital technology and processes but it is also influenced by organizational factors which may vary from the size of architectural organization.

1.3 Objectives of the Study

To evaluate knowledge relevant to the mentioned problems, the main exploration of this study is focused in evaluating key determinant factors and barriers that impede architectural practices in digital innovation adaptation. Addressing these factors that impede architectural practices in digital innovation adaptation will poster a deeper understanding of the digital processes and how architectural organizations adapt with the advent of new technology. Specifically the objectives of this research are:

1. To investigate the digital technologies used by architectural practices in digital innovation adaptation.

2. To examine the barriers, how crucial it is and which among the barriers is the most significant in digital innovation adaptation.

3. To investigate whether there is a significant relationship between the size of architectural practices and barriers in digital innovation adaptation.

1.4 Research Questions

This research assessed key determinant factors and barriers that impede architectural practices when implementing digital innovation. Specifically, it sought to answer the following research questions:

1. What are the digital technologies used by architectural practices in digital innovation adaptation?

2. What are the barriers, how crucial it is and which among the barriers is the most significant in digital innovation adaptation?

3. Is there a significant relationship between the size of architectural practices and barriers in digital innovation adaptation?

1.5 Significance of the Study

The main exploration of this study is focused on evaluating the key determinant factors and barriers that impede architectural practices in digital innovation adaptation. Addressing the factors that impede architectural practices in digital innovation adaptation will foster a deeper understanding of the digital processes and how architectural practices adapt with the advent of new technology. The significance of this research lies on the deeper understanding of technological, financial, organizational, government, process and psychological barriers as key aspects in architectural practices management particularly in digital innovation management.

Digital innovation research in the context of architecture is still very limited, therefore the findings and conclusion drawn from this research will be helpful in increasing literature on the subject. Though the variables identified herein are already informally known before this study is conceptualized, there is no formal publication or journal in the context of architecture that can be used as a guide or reference to identify barriers and challenges in digital innovation in an architectural

practices. This study therefore will unleash the gap of traditional paper-based architects to move forward using the new digital technologies through digital innovation. Developing knowledge in these aspects is significant from the following perspectives:

1. Defining digital innovation in context of architecture. Studies in digital innovation in information science have established the definition of digital innovation but there is no well established definition of digital innovation in architecture. Defining digital innovation in context of architecture is very significant.

2. Identifying the digital technologies used in digital innovation. Although digital technologies for digital innovation has been identified and used in architectural practices, there has been a limited literature that elucidate the used of variety of digital tools that is being utilized in a life cycle of the project.

3. Increasing the understanding about technological, financial, organizational, government, process and psychological barriers as key aspects in architectural practice management.

4. Identification of the benefits and constraints of new digital technologies in architecture and increase understanding of the relationship between size of architectural practice and barriers in digital innovation adaptation.

1.6 Scope and Limitation

The scope of this study is focused on evaluating digital technologies and barriers that impede digital innovation adaptation in different size of architectural practices specifically from schematic design phase up to construction documentation phase of architectural projects that employ digital innovation.

The following variables were the focus in this study: digital technologies which are non-parametric, parametric, building information modeling, building performance simulation and scripting; and the six (6) subsequent barriers that impede architectural practices in digital innovation such as technological barriers, organizational barriers, financial barriers, governmental barriers, psychological barriers and process barriers are the limitation of the study.

Singapore was chosen as the model for this study because the country has the availability of resources such as digital tools, complexity of projects, skills, knowledge transfer and presence of variety of sizes of architectural organizations that have implemented digital innovation. Through experience and observations, digital innovations exist in several architectural organizations in Singapore.

The number of respondents is forty five (45) architectural practices selected on the basis of digital innovation experience and size of architectural practice. The list of respondents is categorized in three groups (small, medium, big) is presented in Appendix B. There are many architectural practices in Singapore but those architectural practices that have employed digital innovations for the purpose of form finding, building information modeling (BIM), optimization or other computationally driven processes using new digital tools were only selected. With this, fifteen (15) of each group (small, medium and big architectural practices) comprised the number of respondents because there are only fifteen (15) big architectural practices in the country that are digitally innovative.

1.7 Originality and Contribution of this Study

There are lots computational design researches that are focused on digital modeling techniques and sustainability. Those studies are tailored on modeling techniques, parametric modeling and generative design and simulation of air flows, heat and other issues that relates to minimizing energy and improving thermal comfort. These studies of digital processes and modeling techniques in architecture have mostly been carried out in research institutes and universities but research on how this computationally driven process negatively affects architectural practices has not been explored yet. There are limited literature that elucidates how architectural practices adopt in digital innovation and how it affects the practice focused in the context of architecture.

Evaluating the challenges and barriers to digital innovation specifically in context of architecture is very significant. Therefore the findings and conclusion from this research will be helpful in increasing the literature on the subject.

1.8 Structure of the Thesis

The structure of this thesis is organized in six (6) subsequent chapters. Chapter 1 provides an introduction and background of the research. In this chapter, special emphasis is given on statement of the problems and scope of the research which elucidate the reason why this thesis is valuable.

Chapter 2 is an in-depth literature review of digital innovations in architecture. It discusses innovation theories, tools and methodologies of digital innovation in architecture and several innovation studies to unearth the definition of

digital innovation in context of architecture including the impact of digital innovations in architecture. Barriers and challenges that affects architectural practices in digital innovation adaptation, and previous innovation studies in allied fields such as information science, business and organizational management, manufacturing, product design, engineering and construction were also discussed in this chapter.

Chapter 3 is a review of related digital innovation projects from architectural practices. It covers discussions of the digital processes and digital tools from Frank O. Gehry, Fosters and Partners and eight (8) selected architectural practices elucidating computationally innovative projects which are selected on the basis of the type of digital innovation used, digital tools, projects and its significance to this research.

Chapter 4 focuses on the research methodology and how this study was carried out. It outlines the research design that was employed in this research, the literature review, respondents, variables, and how the data were gathered and statistically treated and validated.

Chapter 5 is basically the results of the interviews conducted in local architectural practices. It discusses the findings through descriptive statistics and the researcher's interpretation from the selected respondents. Through the objectives of the study, two primary groups of data (digital technologies and barriers) in digital innovation adaptation were presented and analyzed. The first group was digital technologies used by architectural practices in digital innovation adaptation. These include the non-parametric tools, parametric tools, building information modeling tools, building performance simulation tools and programming languages that were used for scripting. The second group is the barriers in digital innovation which are technological barriers, financial barriers, organizational barriers, governmental barriers, psychological barriers and process barriers. The validation of the findings from the analysis were also discussed in this chapter. It was conducted through re-

interviewing the respondents in more details to provide a concrete conclusion and recommendations of this study.

Chapter 6 finally provides the conclusions based on the research questions and objectives of this study. A digital innovation guidelines for architectural practices was recommended in this chapter, and the potential for future research in context of digital innovation in architecture was also recommended.

to fixed asset purchases. The more complicated the investment, the more complicated the formula becomes significant.

Digital innovation is proven to be worthy investment but it is very beneficial that cost and time vs ROI should be an in-depth research in terms of qualitative benefits of reduced time overruns and lower drawing revision costs not just on the cost of the project but on the part of the architectural practice.

Digital innovation specifically in architecture is already proven to improve productivity, with less construction time and cost, therefore further examining ROI relevant to financial viability of architectural practice will be very helpful.

REFERENCES

Associated General Contractors of America (2005). *The Contractor's Guide to BIM,* 1st ed. AGC Research Foundation, Las Vegas, NV.

Allen, M., and Prusinkiewicz, P., DeJong, T. (2004). *Using L−Systems for Modeling the Architecture and Physiology of Growing Trees*: The L−PEACH Model, Department of Pomology, University of California, Davis.

Altintas, I. (2011). *Collaborative Provenance for Workflow-driven Science and Engineering,* PhD Thesis, University of Amsterdam.

Al Qawasmi, K., and Karim H. (2004). *Architecture in the Digital Age: The Effect of Digital Media on the Design*, *Production and Evaluation of the Built Environment*, Editorial, www.openhouse-int.com

Andraseck, B. (2007). *Biothing and Continuum, in Leach, Neil and Guo, Xu Wei. Emerging Talents, Emerging Technologies*, Archiworld, Jeong, kwang young, Korea.

Atkin, B., Borgbrant, J., and Josephson, P. (2003). *Construction Process Improvement,* Blackwell Science Ltd, UK.

Azhar, S., Hein, M., and Sketo, B. (2006). *Building Information Modelling BIM: Benefits, Risks and Challenges,* McWhorter School of Building Science, Aurburn University, Alabama, USA

Azhar, S., Nadeem, A., Mok, J., and Leung, B. (2008). *Building Information Modeling (BIM): A New Paradigm for Visual Interactive Modeling and Simulation for Construction Projects,* First International Conference on Construction in Developing Countries (ICCIDC–I), Advancing and Integrating Construction Education, Research & Practice, Karachi, Pakistan.

Bahar, Y. N., Pere, C., Landrieu, J., and Nicolle, C. (2013). *A Thermal Simulation Tool for Building and Its Interoperability through the Building Information Modeling (BIM) Platform,* Buildings 380–398.

Bailey, D., Leonardi, P., and Chong, J. (2011). *Minding the Gaps: Technology Interdependence and Coordination in Knowledge Work*, Organization Science, 21(3), 713-730.

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

Becerik-Gerber, B., Jazizadeh, F., Li, N., and Calis, G. (2012) *Application Areas and Data Requirements for BIM-Enabled Facilities Management,* Journal of Construction Engineering and Management 138, 3, 431–442.

Berente N., Lyytinen, K., Yoo, Y (2014). *Introduction to the Digital Technologies & Organizational Innovation Minitrack,* 47th Hawaii International Conference on System Science.

Bernstein, P., and Pittman, J. (2004). *Barriers to the Adoption of Building* Information Modeling in the Building Industry, Autodesk Building Solutions, White Paper.

Bernstein, P., and Pittman, J. (2007). *BIM's Return on Investment,* Autodesk Building Solutions, White Paper.

Bharadwaj, A., El Sawy, O., Pavlou, P., and Venkatraman, N. (2013). *Digital Business Strategy: Toward a Next Generation of Insights,* MIS Quarterly, 37(2), 471—482.

Bjork, B., and Laakso, M. (2011). CAD *Standardization in the Construction Industry: A* Process View, Automation in Construction 19(4): 398-406.

Boland, R.J., Lyytinen, K., and Yoo, Y. (2007). *Wakes of Innovation in Project Networks: The Case of Digital 3D Representations in Architecture,* Engineering, and Construction, Organization Science. 18(4): 631-647.

Bogacheva (2009). *Psychological Barriers at Innovations Penetration and a Way of their Overcoming by the Personnel Organizations,* Russian State University of Tourism and Service , Myasnikova O. U. , People's Friendship University of Russia.

Bougrain, F. (2003). *Determinants of Innovations in the Building and Construction Innovative Systems,* Innovative Developments in Architecture, Engineering and Construction, Anumba C.J. (ed), Centre for Innovative Construction Engineering (CICE), Millpress, UK.

Braglia, M., and Frosolini, M. (2014). *An Integrated Approach to Implement Project Management Information Systems within the Extended Enterprise,* International Journal of Project Management, 32, 18–29.

Burry, M. (1999). *Paramorph,* AD Profile 139: Hypersurface Architecture II.

Cabral, R., and Leiblein, M.J. (2001) *Adoption of a Process Innovation with Learning-by Doing: Evidence from the Semiconductor Industry,* J. Ind. Econ. 49 (3), 269–280.

Cerovsek, T. (2011). *A Review and Outlook for a Building Information Model (BIM): A Multi-Standpoint Framework for Technological Development,* Advanced Engineering Informatics, 25, 224-244.

Chavada, R., Dawood, N. and Kassem, M. (2012). *Construction Workspace Management: The Development and Application of a Novel 3D Planning Approach and Tool*, ITcon, 17, 213-236.

Cheng, J. C. P., Deng, Y. and Du, Q. (2013). *Mapping Between BIM Models and 3D GIS City Models of Different Levels of Detail,* 13th International Conference on Construction Applications of Virtual Reality. London, United Kingdom.

Chesbrough, H., and Bogers, M. (2014). *Explicating Open Innovation: Clarifying an Emerging Paradigm for Understanding Innovation,* New Frontiers in Open Innovation. Oxford University Press, Oxford.

Christensen, C. M. (1997). *The Innovator's Dilemma,* New York: Harper Business, Coase, Ronald. 1937, The nature of the firm. Economica (November 1937):386-405.

Christenson, M. (2009). *Testing the Relevance of Parameterization to Architectural Epistemology*, Architectural Science Review, 52, 135-141.

Chu, K. (2004). *Genetic Space: Perspecta on 'Code',* Graduate School of Architecture and Planning, Columbia University, USA.

Civil Engineering Research Foundation (1996) *Needed: Lower Risks, More R&D, Architectural Record.*

Coakley, D., Raftery, P., and Molloy, P. (2012) *Calibration of Whole Building Energy Simulation Models: Detailed Case Study of a Naturally Ventilated Building Using Hourly Measured Data,* First Building Simulation and Optimization Conference.

Cory, C., and Bozell, D. (2001). *3D Modeling for the Architectural Engineering and Construction Industry*, International Conference Graphicon, Nizhny Novgorod, Russia, ⟨http://www.graphicon.ru/⟩.

CRC Construction Innovation (2007). *Adopting BIM for Facilities Management: Solutions for Managing the Sydney Opera House,* Cooperative Research Center for Construction Innovation, Brisbane, Australia.

Daziel, B. (2008). *Interoperability and Collaboration,* Littlefield, D., Space Craft: Developments in Architectural Computing, RIBA Publishing, London ISBN 978-185-946-2928.

Datta, S., Hanafin, S and Pitts, G. (2009). *Experiments with Stochastic Processes: Façade Subdivision based on Wind Motion,* The International Journal of Architectual Computing (IJAC) Vol 7, No 3, 390-402 Multi-Science Publishing Co. Ltd., United Kingdom.

Davila et al. (2006). *Making Innovation Work: How to Manage It, Measure It, and Profit from It,* Upper Saddle River: Wharton School Publishing. ISBN 0 13-149786 3.

Davis, D., Burry, J. and Burry, M., (2011) *Untangling Parametric Schemata: Enhancing Collaboration Through Modular Programming,* CAAD Futures 2011.

Dela Cruz, R. (2015). *Interviewed for Validation of Data,* GS Architecture and Engineering, Singapore.

Dew, N. (2010). *Barriers to Innovation Implementation in the U.S. Navy,* Monterey, CA: Naval Postgraduate School, Manuscript in Preparation for Publication.

Dokko, G., Aigam, A., Rosenkopf, L. (2012). *Keeping Steady as She Soes: A Negotiated Order Perspective on Technological Evolution,* Organization Studies 33, 681–703.

Dong, B., Zheng, O., and Li, Z. (2014). *A BIM-enabled Information Infrastructure for Building Energy Fault Detection and Diagnostics,* Automation in Construction.

Dossick, C.S. and Neff, G. (2008). *How Leadership Overcomes Organizational Divisions in BIM,* Enabled Commercial Construction. LEAD, Stanford Sierra

Eastman, C. (1999). *Building Models: Computer Environments Supporting Design and Construction,* CRC Press LLC, USA, ISBN: 0-8493-0259-5.

Eastman, C., Teicholz, P., Sacks, K., and Liston, K. (2011) *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*, John Wiley & Sons.

Edquist C. (2001) *Innovation policy–a systemic approach. The Globalizing Learning Economy,* Oxford University Press, Oxford , 219-238.

Edwards, T., Delbridge, R., and Munday, M. (2007). *Understanding Innovation in Small and Medium-sized Enterprises: A Process Manifest.* Technovation, 25, 1119-1127.

El-Ali, J., and Happold, B. (2008). *The Efficiently Formed Building,* Littlefield, D., Space Craft: Developments in Architectural Computing, RIBA Publishing, London ISBN 978-185-946-2928.

Ettlie, J. (2000). *Managing Technology Innovation,* John Wiley & Sons, Inc., USA.

Edquist C. (2001). *Innovation Policy a Systemic Approach*, The Globalizing Learning Economy, Oxford University Press, Oxford , 219-238.

Fallon, K. K., (2004). *The Shift to Intelligent Modeling,* Symposium conducted at the Computers for Construction ’99 Conference. Chicago, IL.

Frazer, J. (2002). *Creative Design and the Generative Evolutionary Paradigm,* in Bently and Come, pp 253-274.

Gerber, B., Gerber, D., Ku, K. (2011) *The Pace of Technological Innovation in Architecture,* Engineering and Construction Education: Integrating Recent Trends into Curricula, Journal of Information Technology in Construction, ISSN 1874-4753.

Goh, L. (2015). *Interviewed for Validation of Data,* International Design Associates, Singapore.

Grilo, A. and Goncalves, R. (2011). *Value Proposition on Interoperability of BIM and Collaborative Working Environments*, Automation in Construction, 19, 522-530.

Gunay, B., O’Brien, W., and Beausoleil-Morrison, I. (2013). *A Critical Review of Observation Studies, Modeling, and Simulation of Adaptive Occupant Behaviors in Offices,* Building and Environment 70 (Dec. 2013), 31–47.

Hall, B. (2011). *“Innovation and Productivity”,* UNU-MERIT Working Papers 028.

Hansmeyer, M. (2003). *L-System in Architecture: Nature’s and Processes as Generators of Architectural Design*, (http://www.michaelhansmeyer.com/projects)

Havenmann, S. (2005). *Generative Mesh Modeling,* Doctoral Thesis, Technischen Universität Braunschweig.

Hedayati, A., Mohandes, S., Preece, C. (2015). *Studying the Obstacles to Implementing BIM in Educational System and Making Some Recommendations,* Journal of Basic and Applied Scientific Research, ISSN 2090-4304.

Henfridsson, O., Mathiassen, L., and Svahn, F. (2014). *Managing Technological Change in the Digital Age: The Role of Architectural Firms,* Journal of Information Technology, 29(1), 27—43.

Henfridsson, O., Yoo, Y., and Svahn, F. (2009) *Path Creation in Digital Innovation: A Multi-Layered Dialectics Perspective, Viktoria Institute,* Sweden. Sprouts: Working Papers on Information Systems 9 (20).

Hensel, M., Menges, A., and Weinstock, M. (2004). *Emergence: Morphogenetic Design Strategies,* Architectural Design Journal: Wiley Academy, London

Hesselgreen, L., Charitou, R., and Dritsas, S. (2008). *Architectural Structure, Computational Strategies,* Littlefield, D., Space Craft: Developments in Architectural Computing, RIBA Publishing, London ISBN 978-185-946-2928.

Hjalmarsson, A., Johannesson, P., Juell-Skielse, G., and Rudmark, D. (2014). *Beyond Innovation Contests: A Framework of Barriers to Open Innovation of Digital Services*, 22nd European Conference on Information Systems, Tel Aviv.

Hollander S. (1965). *The Sources of Increased Efficiency: A Study of DuPont Rayon Plants,* MIT Press Books.

Hoffman, L. (2005). *Constraint-Based Computer Aided- Design,* Journal of Computing and Information Science in Engineering in J. Shah, USA.

Hylving, L., Henfridsson, O., and Selander, L. (2012) *The Role of Dominant Design in a Product Developing Firm's Digital Innovation,* Journal of Information Technology Theory and Application 13, 2 (2012), 5–21.

Intrachooto, S. (2002). *Techological Innovation in Architecture: Effective Practices for Energy Efficient Implementation,* PhD Thesis, Massachusetts Institute of Technology, USA.

Isikdag, U. (2012). *Design Patterns of BIM-based Service-oriented Architectures,* Automation in Construction, 25, 59-71.

Janssen, P., Chen, K., Basol, C. (2011*). Iterative Virtual Prototyping: Performance-based Design Exploration,* Proceedings of 29th eCAADe Conference, Ljubljana, Slovenia.

Janssen, P., and Chen, K. (2011). *Visual Dataflow Modelling: A Comparison of Three Systems*, in Proceedings of the CAAD Futures '11.

Johnson, B. and Gunderson, D. (2009). *Educating Students Concerning Recent Trends in AEC: A Survey of ASC Member Programs*, Annual Associated Schools of Construction International Conference Gainesville, Florida

Johnson R., and Laepple, E. (2002). *Digital Innovation and Organizational Change in Design Practice,* ACADIA22: Connecting Crossroads of Digital Discourse.

Jones M., and Saad M. (2003). *Managing Innovation in Construction*, Thomas Telford, London, UK.

Jung, Y. and Joo, M. (2011). *Building Information Modelling (BIM) Framework for Practical Implementation,* Automation in Construction, 20, 126-133.

Kallinikos, J. (2005). *The Order of Technology: Complexity and Control in a Connected World Information and Organization*, 185-202, ISSN 1471-7727.

Kanter, R., Stein, B., and Jick, T. (1983). *The Challenge of Organizational Change: How Company Experience It and Leaders Guide It*, Free Press, A Division of Schuster, Rockefeller Center, USA.

Khon, M. (2008). *Drawing Out the Model,* Littlefield, D., Space Craft: Developments in Architectural Computing, RIBA Publishing, London ISBN 978-185-946-2928.

Khosrowshahi, F. and Arayici, Y. (2012). *Roadmap for Implementation of BIM in the UK Construction Industry*, Engineering, Construction and Architectural Management, 19, 610-635.

Kolarevic, B. (2005). *Architecture in the Digital Age: Design and Manufacturing*, Taylor & Francis ISBN 0415278201, 2005

Kolarevic, B., and Malkawi, K. (2003). Performative Architecture: Beyond Instrumentality Spon Press UK, ISBN 0-415-700-83-3.

Lam, K., Zhao, J., Ydstie, E., Wirick, J., Qi, M., and Park, J. (2014) *An EnergyPlus Whole Building Energy Model Calibration Method For Office Buildings Using Occupant Behavior Data Mining And Empirical Data,* In Building Simulation Conference 160–167.

Lawrence, M., Pottinger, R., Staub-French, S. and Nepal, M. P. (2014). *Creating Flexible Mappings between Building Information Models and Cost Information,* Automation in Construction, 45, 107-118.

Leach N, Guo, X. (2007). *Emerging Talents, Emerging Technologies,* Archiworld-Korea.

Lee, J., and Berente, N. (2012). *Digital Innovation and the Division of Innovative Labor: Digital Controls in the Automotive Industry*, Organization Science, 23(5), 1428—1447.

Lee, J., Veloso, F.M., Hounshell, D. (2011). *Linking Induced Technological Change, and Environmental Regulation: Evidence from Patenting in the U.S. Auto Industry*, Research Policy 40, 1240–1252.

Lim, M. (2015). *Interviewed for Validation of Data,* Park and Associates, Singapore.

Lindenmayer, A. (1968). *Mathematical Models for Cellular Interaction in Development,* Parts I and II, Journal of Theoretical Biology, 18:280–315.

Littlefield, D. (2008). *Space Craft: Developments in Architectural Computing,* RIBA Publishing, London ISBN 978-185-946-2928.

Love, J., Roper, S., Bryson, J.R., (2011). *Openness, Knowledge, Innovation and Growth in UK Business Services, Research Policy,* 40 (10), 1438–1452.

Luebkeman, C., and Shea, K. (2005). *CDO: Computational Design + Optimization in Building Practice,* The Arup Journal 2005.

Lyytinen, K., and Damsgaard, J. (2011). *Inter-organizational Information Systems Adoption: A Configuration Analysis Approach,* European Journal of Information Systems, 20(5), 496-509.

Macintosh, A., Priest, R., and Clegg, F. (2008). *The Daylight Optimized Facade,* D., Space Craft: Developments in Architectural Computing, RIBA Publishing, London ISBN 978-185-946-2928.

Male, S., and Stocks, R. (1989). *Competitive Advantage in Construction* Butterworth-Heinemann Ltd., USA.

Magetsari, A. (2015). *Interviewed for Validation of Data,* Aedas, Singapore.

Mangune, A. (2015). *Interviewed for Validation of Data,* Daewoo Architecture and Engineering, Singapore.

Marzouk, M. and Aty, A. (2012). *Maintaining Subways Infrastructures using BIM,* Construction Research Congress 2012: Construction Challenges in a Flat World Proceedings of the Congress, West Lafayette, Indiana, 2320-2328.

Mason, C., and Perreault, W. (1991). *Collinearity, Power, and Interpretation of Multiple Regression Analysis*, Journal of Marketing Research , Vol. 28, No. 3.

Merschbrock, C. (2012). *Unorchestrated Symphony: The Sase of Inter-organizational Collaboration in Digital Construction Design,* Journal of Information Technology in Construction, 17(22), 333-350.

Merschbrock, C., and Munkvold, B. (2012). *A Research Review on Building Information Modelling in Construction: An Area Ripe for IS Research,* Communications of the Association for Information Systems, 31(1), 207-228.

Mina, C. (2015). *Interviewed for Validation of Data,* Liu & Woo Architects, Singapore.

Mohandes, S., Preece, C., and Hedayati, A. (2014). *Exploiting the Effectiveness of Building Information Modeling during the Stage of Post Construction*, Journal of Basic and Applied Scientific Research. 4(10): 5-16.

Morales, F. (2015). *Interviewed for Validation of Data,* Aedas, Singapore.

Nawari, N. O. (2012). *BIM Standard in Off-site Construction,* Journal of Architectural Engineering, 18, 107-113.

Nejat, A., Darwish, M. M., and Ghebrab, T. (2012). *BIM Reaching Strategy for Construction Engineering Students*, AC 2012-5582.

Nir, E. (2006) *From No-Dimensions to N-Dimensions with Parametric Point Clouds*, Department of Interior, Building and Environment, Ramat-Gan 52526, Israel.

Ortega, N. (2015). *Interviewed for Validation of Data,* DP Consultants, Singapore.

O' Sullivan, D. (2002). *Framework for Managing Development in the Networked Organizations,* Journal of Computers in Industry (Elsevier Science Publishers B. V.) 47 (1): 77–88. doi:10.1016/S0166-3615(01)00135-X. ISSN 0166–3615.

Oxman, R. (2007). *Digital Architecture as a Challenge for Design Pedagogy: Theory, Knowledge, Models and Medium,* Elsevier, Volume 29, Issue 2.

Pagalilauan, J. (2015). *Interviewed for Validation of Data,* Moser and Associates, Singapore.

Paronda, A. (2015). *Interviewed for Validation of Data,* Jurong Consultants, Singapore.

Patayan, D. (2015). *Interviewed for Validation of Data,* MKPL Architects, Singapore.

Pauwels, P., Van Deursen, D., Verstraeten, R., De Roo, J., De Meyer, R., Van De Walle, R.and Van Campenhout, J. (2011). *A Semantic Rule Checking Environment for Building Performance Checking,* Automation in Construction, 20, 506-518.

Pazlar, T. and Turk, Z. (2011) *Interoperability in Practice: Geometric Data Exchange Using the IFC ,* Standard, ITcon, 362-380.

Pearson, G. (1908). *A Brief History of Linear Regression for Statistics, Journal of Statistics Education* Volume 9, Number 3.

Perrow, C. (1999). *Normal Accidents: Living with High-Risk Technologies,* Princeton, New Jersey, Princeton University Press.

Ramilo, R., and Rashid M. (2014). *Critical Analysis of the Key Determinants and Barriers in Digital Innovation Adoption Among Architectural Firms,* Frontiers of Architectural Research, ELSEVIER.

Ramilo, R., and Rashid M. (2014). *Key Determinants and Barriers in Digital Innovation among Small Architectural Organizations,* Journal of Information Technology in Construction, ISSN 1874-4753, (ITcon), Vol. 19, pg. 188-209.

Redmond, A., Hore, A., Alshawi, M. and West, R. (2012). *Exploring How Information Exchanges Can Be Enhanced Through Cloud BIM,* Automation in Construction.

Reid, R. L. (2011). *Judging BIM,* Civil Engineering Magazine, (ASCE), 66-83.

Robert, M., and Weiss, A. (1988). *The Innovation Formula: How Organizations Turn Change into Opportunity,* Business Strategist Series, Ballinger Publishing Company, ISBN 0-88730-352-8, USA**.**

Rosenberg, N. (1982). *Inside the black box: Technology and Economics*. Cambridge University Press, USA.

Salter, W. (1960). *Productivity and Technical Change,* Cambridge: Cambridge University Press.

Sahal, D. (1981). *Patterns of Technological Innovation,* Addison-Wesley Publishing Company, Advanced Book Program, World Science Division, UK.

Schnabel, M. (2007). *Disparallel Spaces: Parametric Design Experience,* CAADRIA Proceedings, Thailand Simonetti R., Archibugi D., Evangelista R., (1995) Product and process innovations: How are they defined? how are they quantified? Scientometrics 32(1), 77-89.

Schumpeter, J. (1934). *The Theory of Economic Development,* Harvard University Press, Boston, USA.

Sebastian, R. (2011). *Changing Roles of the Clients, Architects and Contractors Through BIM,* Engineering, Construction and Architectural Management, 18, 176-187.

Sexton, M., and Barrett, P. (2003). *A Literature Synthesis of Innovation in Small Construction Firms: Insights, Ambiguities, and Questions,* Construction Management and Economics, Volume 21, Issue 6.

Shabanesfahani, A., and Tabrizi, F. (2012). *Barriers of Systemic Innovation to Increase Productivity of Engineering and Construction Industries of the World*, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) ISSN: 2278-1684 Volumes 4, Issue 1.

Shah, J. (1998). *Designing with Parametric CAD: Classification and Comparison of Construction Techniques,* Sixth International Workshop on Geometric Modelling Proceedings, Tokyo, Japan.

Shelden, D. (2002). *Digital Surface Representation and the Constructability of Gehry's Architecture,* PhD Thesis MIT, USA.

Shi, X., and Tang, W. (2013) *Performance-driven Architectural Design and Optimization Technique from a Perspective of Architects,* Automation in Construction 32:125-135.

Siaw, M. (2015). *Interviewed for Validation of Data,* CPG Consultants, Singapore.

Simonetti, R., Archibugi, D., and Evangelista, R. (1995). *Product and Process Innovations: How are they defined? How are they Quantified?,* Scientometrics 32 (1), 77–89.

Singh, V., Gu, N. and Wang, X. (2011). *A Theoretical Framework of a BIM-based Multi-Disciplinary Collaboration Platform*, Automation in Construction, 134-144.

Snoonian, D. (2005). *The Case for a Digital Master Builder,* www.architecturalrecord.construction.com/features/archives

Spithoven, A., Clarysse, B., and Knockaert, M. (2011). *Building Absorptive Capacity to Organize Inbound Open Innovation in Traditional Industries,* Technovation 31 (1), 10–21.

Spithoven, A., Vanhaverbeke, W., and Roijakkers, N. (2013). *Open Innovation Practices in SMEs and Large Enterprises,* Small Business Economics 41 (3), 537–562.

Svahn, F. (2012). *Digital Product Innovation: Building Generative Capability through Architectural Frames*, Automation in Construction.

Svensson, J. (2012). *Living Lab Principles - Supporting Digital Innovation,* Halmstad University, P.O. Box 823, 301 18 Halmstad, Sweden

Terzidis, K. (2006). *Algorithmic Architecture,* Architectural Press, ISBN 0750667257.

Terzidis K. (2003). *Expressive Form: A Conceptual Approach to Computational Design*, Spon Press 29, New York 10001, ISBN 0-415-31743-6, USA.

Thomas, G., and Bone, R. (2000) *Innovation at the Cutting Edge: The Experience of Three Infrastructure Projects,* CIRIA Funders Report FR/CP/79, CIRIA, London, UK.

Tiwari, R., Buse, S. (2007). *Barriers to Innovation in SMEs: Can the Internationalization of R & D, Mitigate Their Effects?,* Proceedings of the First European Conference on Knowledge for Growth: Role and Dynamics of Corporate R & D, Seville, Spain.

Underwood, J. and Isikdag, U. (2011). *Emerging Technologies for BIM 2.0,* Construction Innovation Information, Process Management, 11, 252-258.

Utterback J. M. and Abernathy W. (1975). *A Dynamic Model of Process and Product Innovation,* Omega 3(6), 639-656.

Vanhaverbeke, and W., Cloodt, M. (2014). *Theories of the Firm and Open Innovation, New Frontiers in Open Innovation,* Oxford University Press, Oxford.

Vivarelli M. and Pianta M. (2000). *The employment impact of innovation: Evidence and Policy,* Psychology Press.

Vivarelli M. and Toivanen O. (1995). *The Economics of Technology and Employment: Theory and Empirical Evidence*, Edward Elgar London.

Walker, M. (2008). *Collaboration Through Building Information Modeling in Space Craft: Developments in Architectural Computing* in David Littlefield, RIBA Publishing.

Walcoff, C., Ouellette, R., and Cheremisinoff, P. (1983). *Techniques for Managing Technological Innovation,* Ann Arbor Science Publishers 1983, ISBN-9780250406036.

Westergren, U., and Holmstro J. (2012). *Exploring Preconditions for Open Innovation: Value Networks in Industrial Firms,* Information and Organization, 22(4), 209—226.

Whyte, J. (2010). *Information Management and its Impact on Project Management,* Oxford Handbook on the Management of Projects. P. Morris, J. Pinto and J. Soderlund, Oxford, Oxford University Press.

Whyte, J. and Levitt, R. (2011). *Information Management and the Management of Projects,* Oxford Handbook of Project Management. P. Morris, J. Pinto and J. Söderlund. Oxford, Oxford University Press: 365-387.

Whyte, J. and Lobo, S. (2011). *Coordination and Control in Project-based Work: Digital Objects and Infrastructures for Delivery*, Construction Management and Economics 28(6): 557-567.

Williams, N., Ferdinand, N., and Croft, R. (2014). *Project Management Maturity in the Age of Big Data,* International Journal of Project Management Business. 7, 311–317.

Wu, W., and Raja, I. (2013). *BIM Education and Recruiting: Survey-Base Comparative Analysis of Issues, Perceptions, and Collaboration Opportunities,* Journal of Professional Issues in Engineering Education & Practice 140(2).

Yan Han, P., and Damian, P. (2011). *Benefits and Barriers of Building Information Modelling,* 12th International Conference on Computing in Civil and Building Engineering.

Yoo, J., Boland Jr., R.J., Lyytinen, K., Majchrzak, A., (2012). *Organizing for Innovation in the Digitized World*, Organization Science 23, 1398–1408.

Yoo, Y., Lyytinen, K., Boland, R., Berente, N., Gaskin. J., Schutz, D., and Srinivasa (2010). *Next Wave of Digital Innovation: Opportunities and Challenges,* Report on the Research Workshop: Digital Challenges in Innovation Research, Institute of Business and Information Technology, Fox School of Business and Administration, Temple University.

Zhang, J. P. and Hu, Z. Z. (2011). *BIM and 4D-based Integrated Solution of Analysis and Management for Conflicts and Structural Safety Problems During Construction: Principles and Methodologies,* Automation in Construction, 20, 155-166.