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KEY DETERMINANTS AND BARRIERS IN DIGITAL INNOVATION AMONG SMALL ARCHITECTURAL ORGANIZATIONS

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GUEST EDITORS: Bhzad Sidawi and Neveen Hamza

Runddy Ramilo, PhD (Architecture) candidate
Department of Architecture, Faculty of Built Environment
University of Technology Malaysia
Email: rrunddy2@live.utm.my, http://www.utm.my/

Mohamed Rashid Bin Embi, PhD (Associate Professor)
Department of Architecture, Faculty of Built Environment
University of Technology Malaysia
Email: b-rashid@utm.my

SUMMARY: *The rapid development of digital technology has made architecture a succession of different evolutionary design methodologies. As a result, the rise of computationally driven processes has gain popularity in research and shows a great potential to dramatically improve the design process and productivity that evoke innovations in architectural practices wherein computer-based project plays a vital role. However, as these technologies rapidly develop and are increasingly used in practice, there is a realization that substantial organizational and technological barriers exist that inhibit the effective adoption of these technologies in architectural practices wherein complex projects are being handled. Undeniably it happens in small architectural practices whereby resources are very limited. Relevant literature of the subject shows that research in innovations in manufacturing, product design, technology, construction and engineering practices is substantially conducted but research in digital innovation in design practices is very limited. This paper investigates the factors that impede the effective adoption of emerging digital technologies for the efficient delivery of design projects that are computationally and digitally driven. This involves evaluating digital technologies, technical, financial and organizational barriers when digital innovation is implemented. In order to gain insights of these issues, a pilot study was conducted from several small architectural organizations, and found out relevant attributes and pattern of variables that can be used in establishing a framework for digital innovation.*

KEYWORDS: *Digital Innovation, Architectural Practices, Technologies, Barriers*

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1. INTRODUCTION

As modern world develops and utilizes design technology for architecture, different design methodologies have emerged. Current design research have focused on computationally mediated design process *(Kolarevic, 2003), (Hensel & Menges, 2006), (Littlefield, 2008) and (Datta et al, 2009)* in which 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, design practices are increasingly aided by and dependent on the technology and have resulted to major paradigm shift *(Al Qawasmi & Karim 2004).* It opens new territories of formal exploration in architecture and radically reconfigured 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).* This new design process enables to improved design quality in less time with reduced cost, and can make new levels of complexity and new aesthetics possible *(Luebkeman & Shea, 2005)*. These emerging digital technologies have lead to new design processes which evoke 'digital innovation' in global architectural practices whereby computer-aided architectural design technologies is used not only as a tool for drafting and design, but as an instrument for delivering complex projects that is less in cost, within the time and prescribed quality.

However, while technological advancement of the new technology has the potential for dramatically improving design and productivity, related literature shows that substantial technical and organizational barriers exist that inhibits the effective adoption of these technologies *(Leach & Gou, 2007), (Johnson & Laepple 2004) & (Intrachooto, 2002).* Along with this line of thought, literature of the subject shows that several design practices are not fully utilizing these technologies. Despite of the abundant availability of digital technologies digital innovation does not occur because few knowledge and resources are transferred from one project to another. This occurs when the purpose between projects is dissimilar or projects do not include members of the previous team who has relevant skills or knowledge of the technology. Additionally, Cory & Bozell *(2001)* found out that though architects and designers have acknowledged that the advent of computer aided architectural design in the design process can save an abundance of time and energy, these tools are not being utilized to their full potential. The benefits of intelligent modeling to the design process are to increased productivity, reduced cycle time, better workflow and life cycle applications but these technologies are not fully utilized *(Fallon, 2004)*.

Undeniably it happens in small architectural practices whereby resources are very limited. This is because of the increasing new technology and the current demands of topologically non-linear building design and the issue of sustainability. Small architectural practices are indeed experiencing the challenges triggered by digital innovation. Constant introduction of new digital technology, insufficient design fee, increased global competitions, increasing client's demands and limited costs, limited software knowledge are among the challenges. Undeniably, the digitalization in small architectural practices has not been trouble-free. Business profits as one of the major goals of design practice are at risk when implementing digital innovation. Innovation implies to newness of process, or new way of doing something, and therefore businesses are at risk of failure *(Davila et al, 2006).* While innovation typically adds value, innovation may also have a negative or destructive effect as new developments clear away or change an old organizational forms and practices.

Literature of the subjects shows that small architectural firms are extremely affected by challenges with consequential negative effect to the organization. The main cause of this interwined challenges is mainly due to the small projects, less design fee and fewer human resources that is not substantial to support digital innovation. While small architectural firms are extremely affected with challenges, this is not the case of big architectural firms. The main reason is they have big projects with considerable design fee that can support digital innovation. Big architectural organization is able to cope with challenges because they have able to provide the logistics and support from the organization. *(Ramilo, 2014).* Big architectural firms is competing globally, the organization is more vested in innovation, able to cope with the advent of digital technology, and have acknowledge the risk

To shed light on this issue, this paper investigates the key determinants that impede the effective adoption of digital innovation focused in small architectural practices whereby projects are computationally and digitally driven. Specifically it will seek to answer the following research questions: What are the digital technologies (ie non-parametric, parametric and building performance simulation) used in architectural practices in digital innovation? What are the challenges and barriers that small architectural practices encountered when introducing digital innovation? To what extent technical, financial and organizational barriers affect small architectural organizations? Does years of practice experience has correlation with digital innovation?

2. WHAT IS DIGITAL INNOVATION IN ARCHITECTURE?

Digital innovation in architecture can be defined as the use new digital tools and other relevant evolutionary design process to improve of architectural design, building form, sustainability, delivery of services and productivity. New design processes refers to computationally mediated methods which differs from the conventional paper based architecture by independently using parametric modelling tools, building performance simulation tools, scripting or algorithms that can be reinforced by the conventional non-parametric tools and other relevant methodologies. Its attributes is to improve but not limited to (1) architectural design through form finding, facade optimization, digital fabrication, material assembly, cost optimization (2) sustainability by using the building performance simulation tools by evaluating energy efficiency, airflows, daylighting, wind analysis and the implication of climate to architectural forms, (3) structural conceptualization by finite element analysis to investigate structural behavior and stability (4) improving productivity to achieve less time and cost.

Despite the rapid changes in digital technology are revolutionizing specific types of digital innovation, digital innovation in architecture is not recognized as digital innovation but a user-end application of computer aided design technology. Since there is the possibility of confusion of the term, for the purpose of this paper, an in-depth literature review was conducted to shed light of clear definition of digital innovation, types of innovation and what kind of innovation is digital innovation in architecture because of the lack of literature of the subject.

Innovation is a new way of doing something that is made useful. It may also refer to incremental, emergent or radical and revolutionary changes in thinking, products, processes, or organizations. It is defined as the introduction of new elements or a new combination of old elements in industrial organizations *(Schumpeter 1934).* Innovations are not representative solely of breakthroughs. Generally, innovation is the process where a good idea or creation of new knowledge concerning a product or process begins to affect its context.

To summarize the meaning innovation, it can be generically defined as the successful implementation of new ideas from which commercial values are generated. It is pervasive and diverse, and is usually associated with, but not limited to, technological advancement. Innovations may be introduced on the market (product innovation) or used within a production process (process innovation). Innovations therefore involve a series of scientific, technological, organizational, financial and commercial activities. All these innovation activities share common goals that are to promote economic growth through improved performance and enhanced competitiveness.

In architecture, engineering and construction research *(Male and Stocks, 1989)* they have highlighted that there are four distinct types of innovation (1) Technological innovation, which utilizes new knowledge or techniques to provide a product or service at lower cost or higher quality, (2) Organization innovation, which does not require technological advances but involves “social technology” that is changing the relationship between behaviors, attitudes and values. (3) Product innovation, which may have a low hardware dependency, provides better utilization of resources and involves advances in technology resulting in superior products or services. (4) Process innovations, which substantially increase efficiency without significant advances in technology.

Digital innovation in architecture is one form of process innovation. Relevant definition of process innovation is an implementation of a new or significantly improved production or delivery method including significant changes in techniques, equipment and or software *(Svensson, 2011).* Likewise, process innovation is defined as the introduction of new elements into a firm’s production or service operation to produce a product or render a service *(Rosenberg, 1982), (Utterback and Abernathy, 1975)* with the aim of improving productivity, capacity, flexibility, quality, reducing costs, rationalizing production processes *(Edquist, 2001), (Simonetti et al., 1995)* and lowering labor costs *(Vivarelli and Toivanen, 1995), (Vivarelli and Pianta, 2000*). Following innovation research of Reichstein and Salter, (2006) process innovation is related to new capital equipment *(Salter, 1960)* and the practices of learning-by-doing and learning-by-using *(Cabral and Leiblein, 2001),* Similarly, *(Hollander, 1965)* defines process development as “the implementation of new or significantly improved production or delivery methods. This includes significant changes in techniques, equipment and/or software”. By reviewing the literature of process innovation *(Svensson, 2012), (Edquist, 2001), (Simonetti et al., 1995), (Vivarelli and*

Toivanen, 1995), (Vivarelli and Pianta, 2000), digital innovation in architecture is one that can be considered as process innovation.

Through the literature review, digital innovation in architecture is considered a digital process innovation in architecture that is inherited in vast development of information science. Information science refers to new combinations of digital and physical components to produce novel products or services or to the embedding of digital computer and communication technology into a traditionally non-digital product or service *(Yoo et al, 2010), (Henfridsson et al, 2009), (Svensson, 2012*). It can be gleaned that without the development of information science there could be no digital innovation in architecture.

3. REVIEW OF DIGITAL TOOLS AND DIGITAL INNOVATION PROCESSES IN ARCHITECTURAL PRACTICES

3.1 Non-parametric geometric modelling

Non-parametric modelling can be considered as conventional digital tools. It is proven useful for construction detailing and visualization. Currently, it is dominated by four high-end packages SketchUp from Last Software, AutoCAD from Autodesk, 3D Studio Max from Kinetix and Maya from Alias that is owned by Autodesk. Some of the modeling tools with wider spread use are listed in Table 1.

TABLE 1 Popular non-parametric modeling tools edited by the researcher

Non-Parametric Modeling Tools	Website
AutoCAD	www.autodesk.com
SketchUp	http://sketchup.google.com
Maya	www.alias.com
3D Studio Max	www.discreet.com
Houdini	www.sidefx.com
Rhinoceros	www.rhino3d.com
Cinema4D	www.maxon-computer.com
Lightwave	www.newtek.com
Caligari Truespace	www.caligari.com
SoftImage	www.softimage.com

3.2 Parametric modelling

Another CAAD tools that is popular today is parametric-based geometric tools. The use of parametric tools efficiently helps architects to generate parametric model of structure and also for concept design that guides variation. The most positive outcome of parameterization in architecture is that architects can create a model of building not only for the primary purpose of form transformations but also for performative architecture. Parameterization enhances the search for better design that is more adapted to any underlying context of architecture to facilitate the discovery of new forms. The current trends of form-making had reduced the time and effort required for change and re-use of models that resulted to better collaboration and understanding between the architect as the main designer, and other allied engineering disciplines. The table 2 is a list of parametric-based software that is available in the market and is widely used in practice.

Gehry and Partners is the pioneer of using parametric modelling in architecture. The firm uses powerful 3-dimensional representation tool, CATIA, to model the complex geometry of their buildings *(Yoo et al, 2010).*

According to Yoo et al (*2010)* the firm uses of a centralized 3D model and database *(figure 1)* that can be used by all consultant and contractor in carrying their work. This process evokes collaboration of team of a project from a series exchange of information interactively.

TABLE 2 High-end parametric modeling tools that are commonly used in design practice

Parametric Modeling Tools	Website
Autodesk Revit	www.autodesk.com
GenerativeComponents	www.bently.com
Rhino-Grashopper	www.grasshopper.com
ParaCloud Modeler	www.paraclouding.com
CATIA	www.3ds.com

In many instances, subcontractors and fabricators collaborated with architects and general contractors during the design stage with the result that key players are involved in the design process much earlier than they normally might be. Such tightly coupled collaboration patterns not only enhanced the quality of communications, thus reducing errors and redundant communication, but also enabled the design team to tap into the expertise of various trades and specialists in a much more meaningful way. Such collaboration at the early stage of design process enabled Gehry and his associates to experiment with new materials and constructions methods for their projects, and at the same time push contractors, subcontractors and fabricators to innovate in their own domains, which in turn inspired others, including Gehry himself, to pursue further innovations.

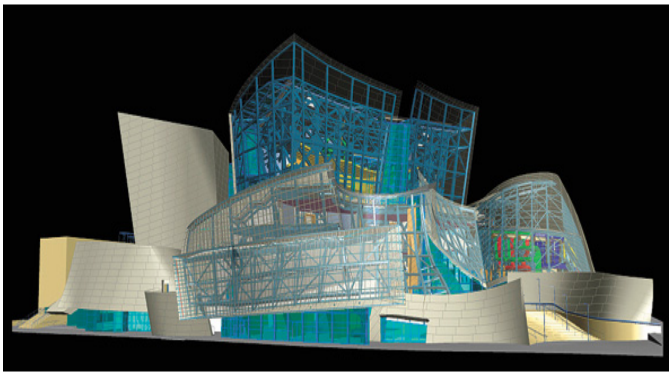

FIG 1. Full 3d model of Gehry's project using CATIA

3.3 Building information modelling (BIM)

Building Information Modeling (BIM) is another form of parametric modelling that represents the process of development and use of a computer generated model to simulate the planning, design, construction and operation of a facility *(Azhar et al, 2006)*. The resulting model, a Building Information Model, is a data-rich, object-oriented, intelligent and parametric digital representation of the facility. The noted main difference of BIM and 2D CAD is that, the last describes a building by independent 2D views like plans, sections and elevations. Furthermore, editing one of these views requires that all other views must be checked or updated. This process is known to be error-prone and is considered as one of the major causes of poor documentation. In addition, data in 2D drawings are graphical entities only unlike the intelligent contextual semantic of BIM models wherein object are defined in terms of building elements and systems *(CRC Construction Innovation, 2007).*

One project that have employed BIM was the Royal London Hospital, (figure 2) the largest new hospital in the UK which has a 905-bed facility. The building is being configured as a three tower containing 6,225 rooms across 110,00 square meters of floor space.

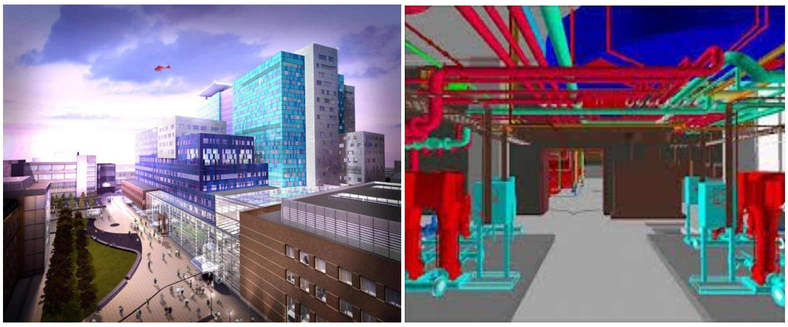

FIG 2. 3D models through BIM by HOK and Skanska

HOK and Skanska made a working strategy based on sharing a BIM dataset via a virtual 'portal'. The business case for BIM built around costs versus perceived value, which shows that this working method should considerably reduce the typical 10 per cent overspend attributed to poor spatial coordination rework and waste for an investment of around 0.5 per cent of the total tender sum. Skanska benefited an increased construction margin. A fewer requests for information (RFIs) and of course an increased fee margin were the benefits for HOK. And the benefit to the client is a better quality, more robust building. Early investment in BIM is therefore important. Cost benefits are already starting to come through even though construction has barely begun. Moreover, the simplicity of BIM data reuse will save £230,000 on the cost of producing an operations and maintenance manual alone, as announced by business model.

HOK and Skanska have both agreed in advance to standardize around Autodesk's Architectural Desktop (ADT) modeling tool thus allowing ADT compatible programs to be used by the key team members, as well as subcontractors. Project participants including architects, engineers, contractors, facilities management team and client, have agreed to feed into, and off, a single portal set up and managed by Skanska's central 3-D CAD and Data Management Group.The central model contains all the data from which, for example, lighting and acoustic studies can be sourced, and verified views generated, structures and cladding systems analyzed, and services mapped out. All computer packages used in the development, analysis, visualization and management of the central 3-D model have been factored into the Data Management Group's 'roadmap'.

3.4 Building performance modelling

Building Performance Modelling is another kind of architecture that is emerging is using building performance as guiding design principle and adopting new performance-based priorities for the design. This new kind of architecture, interrogates a broadly defined performative design above form making. It utilizes the digital technologies of quantitative and qualitative techniques and simulation to offer a comprehensive new approach to the design of the built environment *(Kolarevic, 2003).* Performance-based design is primary used to simulate environmental, thermal, climatic, acoustical etc. as the emphasis of the design like the City Hall, London that was designed by Foster and Partners and ARUP *(figure 3).* This involves finding sustainable strategies using building performance tools or 4d modelling tools that is available in the market. 4d digital technologies are those softwares that can simulate and analyze the unseen such as air flows, energy efficiency, indoor humidity etc. This provides design teams with the high quality information needed to quantify and inform iterative decisions, so the project team can effectively develop creative sustainable solutions at the early stage of the project.

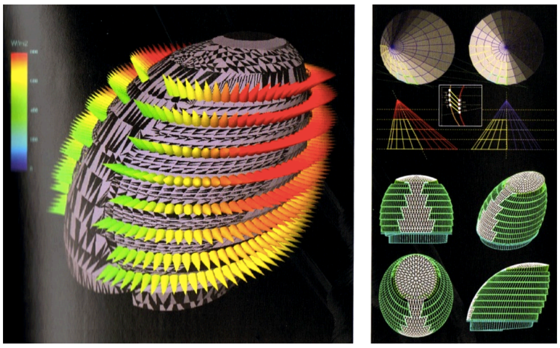

FIG 3. 3D models City Hall, London by Foster and Partners and ARUP

Building performance simulation is already available from major CADD companies Autodesk and Bentley as listed in table 3. They provide plug-inn that is linked to their products. Some of these products can be downloaded from their website and can be used for 30-days trial period.

TABLE 3. Building performance modelling tools for environmental analysis

Building Performance Simulation Tools	Website
IES	www.iesve.com
Radiance	http://wapedia.mobi/en/Radiance
Ecotect	http://ecotect.com
Green Building Studio	www.autodesk.com/greenbuildingstudio.com
Hevacomp	www.bentley.com
Energy Plus	http://apps1.eere.energy.gov

3.5 Scripting

"Script" is derived from written dialogue in the performing arts, where actors are given directions to perform or interpret *(Schnabel, 2007)*. Scripting languages are typically not technical but mathematical solutions that are define by set of rules and based on parameters. It is a programming language that controls a software application and often treated as distinct from programs which execute independently from any other application. As design computing is becoming powerful, scripting as a form of programming for architects have widespread in research and popularly known as 'Emergence' . The 'Theory of Emergence' looks up at natural phenomena *(Leach & Gou, 2007)* of any kinds like 'Genetic Space' *(Chu, 2000)* from biology and extracts their morphogenetic process and morphological formations as generator of design. Several applications of this theory are 'Morpho-Ecologies' *(Hensel, Menges et al 2004),* 'Biothing and Continuum' *(Andraseck, 2007)* and 'L-System in Architecture' *(Hansmeyer, 2003)* in which morphogenetic process is applied as form generators to architectural design. Its approach takes up from biological morphogenesis for which the process of evolutionary development and growth of organism is observe and apply as generative morphogenetic process to model building forms.

One project that have used scripting was Foster + Partners in their Great Canopy Project, a proposal for the West Kowloon Cultural District is to create a unique landmark of collection of visual arts, performance and leisure venues, on a dramatic harbour-front site in the heart of Hong Kong *(figure 4)*. The canopy flows over the various spaces that contained within the development to create a unique landmark. The sinuously flowing form of the site contours and the canopy produce a memorable effect.

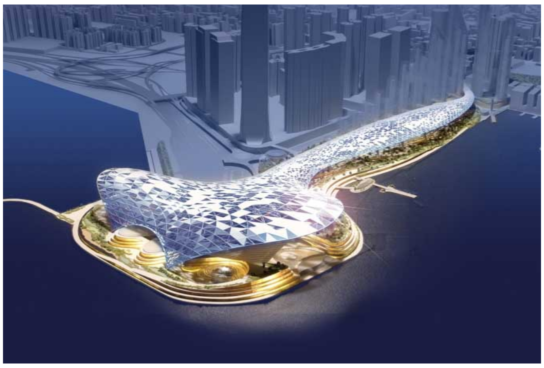

FIGURE 4 Digital models of the Great Canopy project used by Fosters and Partners

Scripting was used throughout the project to develop architectural ideas. They created algorithms and generative scripts to quickly create multiple structures and cladding options, it has proven to be a hugely successful and adaptable tool for skilled architectural designers to create their own design tools. A modular system was used to elaborate the complex design of the surfaces height, width and curvature that varies over its length, presenting smooth that can be viewed from above and beneath. Using generative scripts the canopy's structures produced three dimensions that was laser cut from digital files that produced seven glazing component, these elements was assembled by our in-house model shop.

3.6 Review of digital innovation tools

Summarizing the four (4) basic categories of digital tools i.e. non-parametric, parametric, building simulation tools and scripting, it has its common goal but different semantics, approaches and techniques that designer could use. Each method has its own weakness, strengths, and representational limitations and different capability in ways of generating different shapes-linear, curvilinear and free-forms. The first category is purely for drafting, object modeling, visualizations and the logic or the underlying factors of the object are less prioritized. However for the purpose of other disciplines like graphics, movies industrial design etc. wherein the underlying logic of object is not critical, it is vital and useful. On the other hand, the second and third category, parametric modeling and scripting is rigid and sometimes computationally tedious than traditional digital applications, but the synergy and flexibility of using the data to parametrically create and change a model is very powerful *(Hoffman, 2005).* In parametric modeling, it is the logic of the object that is being prioritized such as those of generating a performative architecture as building performance as guiding principles *(Burry, 1999).* The chart 1 below is a categorization of current CAAD tools that are used by several design practices.

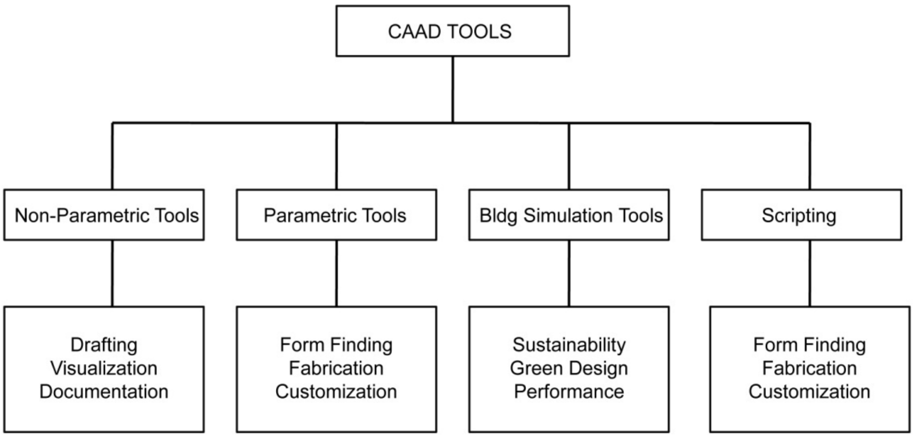

CHART 1 A diagram shows Categorizes of current CAAD tools that are used by architectural practices

4. CHALLENGES AND IMPEDIMENTS IN DIGITAL INNOVATION

Understanding the challenges and impediments digital innovation in architecture is difficult, and developing a single framework or model for digital innovation adoption is even more challenging. The reason for the difficulty of developing a single framework is that there is no available framework that discusses how architectural practices able to adopt the innovation process and how it affects the organization. Digital innovation is already happening in architectural practices but there are not enough research in digital innovation that tackles the barriers, impediments and challenges particularly in architectural practices. There has been relatively limited critical analysis of the practices of using digital technologies in building and infrastructure projects *(Whyte, 2011).* Literature in this subject is still very limited.

For the purpose of understanding the barriers and challenges that affect architectural organization in digital innovation adoption, a literature review of innovation in allied fields such as information science, business and organizational management, manufacturing, product design, engineering and construction was conducted. Though it is not specifically in architecture, it reveals several challenges and barriers to adopting digital innovation both of which has different views but shared common attributes that can be used for establishing the variables this research.

In digital innovation era, research focused on management information technology. Whyte *(2011)* elucidates that the new digital processes present a 'technological black box' with little visibility of the completeness of the design work represented in models and drawings. According to his research, this is a challenge because it makes it difficult to manage client expectations, especially where the completeness of design may have contractual implications. Boland et al. *(2007)* explore digital innovation on a project, arguing that the use of 3D digital technologies allows waves of innovation to propagate across the firms and have identified challenges relating to the use of digital technology and related processes.

From management perspective, it is claimed that organizations that are engaged in the design of buildings are often complex, having non-linear and multiple interdependencies between their sub-systems. They are considered as complex organizations whereby efficiency is important when using innovation. Digital technologies enable new forms of interaction and coupling*,* and increase the interactive complexity in complex organizations. Dossick and Neff *(2008)* have argued that it is a set of leadership skills that enables managers in design organizations to deal with the increasing tight coupling of technological solutions within loosely coupled organizational structures, and according to them it is important to analyze digital technologies, organizational structures and processes.

Whyte *(2011)* adds that information management has a strong relationship with the management of projects. His research suggests (1) that new digital tools and processes increase the coupling between the various disciplines involved in design, implying wider organizational changes across firm boundaries, (2) the process change challenges the currently institutionalized understandings of design stages and effective processes. He concluded that design organization operates within a wider set of institutionalized practices, which include formats for delivery, building regulations, local authority permissions and construction schedules. His research suggest that that to be effective 3D modes of working require a wider process of change, as this digital infrastructure for delivery challenges institutionalized understandings of the activities in and duration of different stages of the process *(Whyte, 2011).* Likewise as explained by Whyte *(2011),* this work has implications for practitioners, as work flow is changing the nature of professions. Figure 5 is the conventional process, and figure 6 is a useful of representation of new digital work flow in 3D centric way.

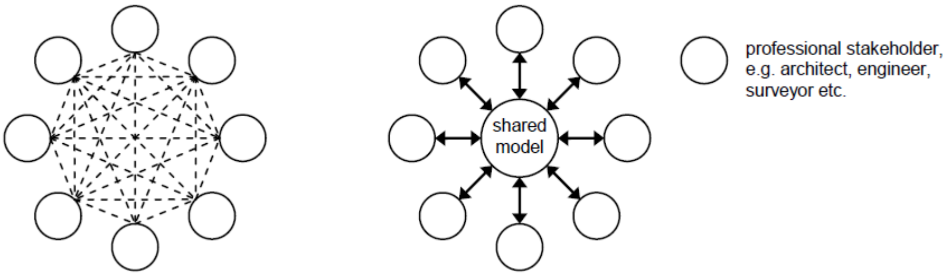

FIGURE 5 and 6 Idealized information flows between different professionals on a project, a) without a central project model and b) with a central model (Whyte, 2011).

In digital innovation research in architectural engineering and construction conducted by Johnson and Laepple *(2004),* they find out that when a company implement innovation, technical, financial and organizational barriers occur, and these such as:

- Additions of expertise
- Changes in company leadership and culture
- R&D software investment
- Work process changes and new marketing approaches.

In his technological innovation research, Inchachoto *(2002)* also indicated the following important technical, financial and organizational barriers:

- Innovation is best fostered by team members with prior work experience, as opposed to an assembly of individuals selected solely on the basis of expertise.
- Collaboration in innovation is useful and distinctively serve multiple functions such as technical-risk reduction, financial security, and psychological assurance.
- For the success of innovation, two key factors should be considered:
- Team dynamics and project logistics encompasses concurrent collaboration.

- Team relational competence and commitments.
- Project logistics is also important such as external funding, research collaboration, technical evaluation, demonstration and validation.
- Allocated budgets for research plays an integral role for technological innovations.

Such list of barriers is similar to the technical, financial and organizational barriers list that was elucidated by Jones and Saad *(2003)* in their innovation research in construction:

- Inherent problem in the innovation
- Lack of mutual recognition of the need for innovation
- Insufficient technical capabilities and skill levels
- Reluctance to change
- Inexperienced team members
- Lack of training
- Weak commitment and support by top
- Inadequate resources
- Lack of integration and collaboration
- Lack of learning environment
- Lack of incentives
- Difficult to comply with the existing regulations and established standard

Technical and financial barriers in AEC made are highlighted by Cory and Bozell *(2001)*. They claim that while the advent of digital technology have benefited the profession, practical issues occurs in utilizing new technologies and company should consider the following:

- Design costs and time
- Software learning curve
- Software costs
- Ability of the software to handle complex geometry performance of the software
- Level of detail needed and what the software can deliver
- Partition the model among multiple users
- Integrate model from multiple sources, tools for model review and web publishing
- Speed and working drawing extraction
- Maintenance both of which affect the profitability of the company.

In addition, technical and organizational barriers in digital innovation research of Whyte *(2011).* The author adds that the way in which digital innovation processes is configured and organized has a major impact on delivery. Organizational challenges related to process or performance management becomes an issue. He highlighted that on new digital processes, the team is under pressure to deliver to traditional timescales though it took longer to develop 3D information that could then add benefit at later stages. The new digital tools and processes implied wider organizational changes across firm boundaries. Furthermore, in digital innovation management research of Whyte *(2011)* indicates several technical barriers to the adoption of digital innovation such as:

- Coordination of digital package had consequential problems.
- Limitations of the 3D modelling package
- Challenges in finding staff that combined practical construction experience and digital technology.

A survey in manufacturing and product design innovation that was conducted by O'Sullivan *(2002)* reveals the following organizational barriers:

- Several causes of failure in organizations are cited such as
- Poor leadership
- Poor organization
- Poor communication
- Poor empowerment
- Poor knowledge management.
- Failure is an inevitable part of the innovation process, and most successful organization factor in an appropriate level of risk.
- The impact of failure goes beyond the simple loss of investment.

- Failure can also lead the loss of morale among employees, an increase in cynicism, and even higher resistance to change in the future.
- Some causes are external to the organization and outside its influence of control.

In their digital innovations research, Yo et al. *(2010)* focus on digital processes they indicated some technical barriers:

- Performance of software
- Ability of software to handle complex geometry
- Integrations of model to multiple sources
- Speed and drawings extractions

These barriers to innovation coincide with process barriers elicited by Walcoff et al *(1983*) which are:

- Organizational barriers
- Technical barriers
- Financial barriers

5. COMMON ATTRIBUTES OF ORGANIZATIONAL BARRIERS

Upon analysis of the barriers presented earlier, common attributes are found such as technical, financial and organization barriers from various research of innovation in different allied fields *(chart 2)* elicited by Johnson & Laepple *(2004),* Inchachoto *(2002),* Jones and Saad *(2003)*, Cory & Bozell *(2001),* Whyte *(2011),* Yo et al. *(2010),* O'Sullivan *(2002.* These coincide with innovation research of Walcoff et al. *(1983)*. Recognizing these barriers as 'challenges' to innovation process, highlights the purpose of establishing a hypothesis. Upon analysis of the main of objectives and literature, the researcher have categorized the three major barriers and challenges and used it as variables of this research.

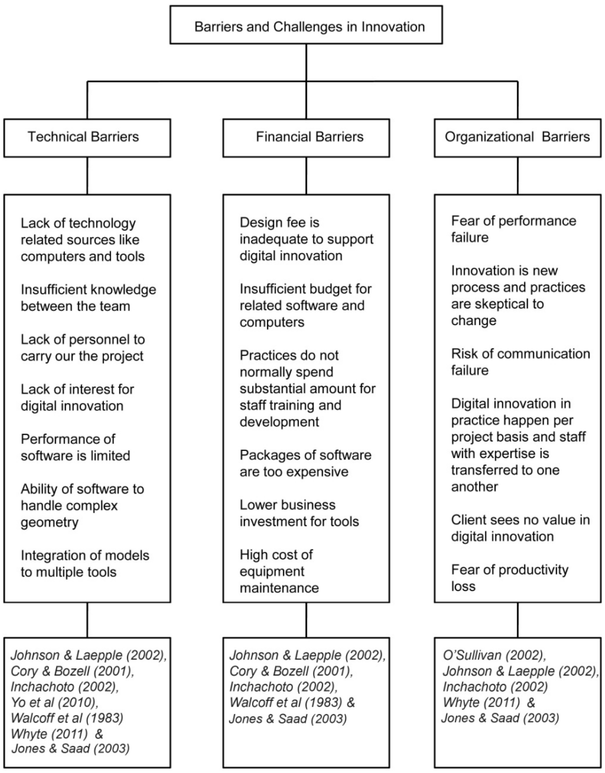

CHART 2. The three major barriers and challenges are summarized, elicited by Johnson & Laepple (2002), Inchachoto (2002), Jones and Saad (2003), Cory & Bozell (2001), Whyte (2011) Yo et al (2010), O'Sullivan (2002) & Walcoff et al (1981).

6. RESEARCH METHODOLOGY AND SCOPE

The scope of this pilot study deals with digital technologies and organizational barriers focused on small architectural organizations. Through its objectives, four general variables were tested-digital technologies, technical, financial and organizational barriers. Each of these has specific variables summarized in Table 1, 2, and 3 (for digital technologies) and chart 2 (for technical, financial and organization barriers) based on innovation research on construction, engineering, product design, industrial and manufacturing studies elicited by Johnson & Laepple *(2004),* Inchachoto *(2002),* Jones and Saad *(2003)*, Cory & Bozell *(2001),* Whyte *(2011),* Yo et al *(2010),* O'Sullivan *(2002) &* Walcoff et al *(1983)*.

6.1 Research methodology

Using the identified variables, a survey through organized questionnaire was conducted on 39 small architectural organizations in Singapore of various years of experience. This was through interviews to gather data for digital technologies used (ie non-parametric, parametric, building performance simulation tools) and technical, financial and organizational barriers when introducing digital innovations. Singapore was chosen because the country has innovative practices and digital innovation evidently in use. As soon as the data was collected, it was statistically analysed. Univariate Analysis of Variance and Multiple Regression Analysis were utilized to determine whether the differences in Mean value of the three groups is significant.

6.2 Survey respondents

Architectural practices with experience in digital innovation were only selected hence the relevant data needed in this study can be efficiently answered by those organizations who has the experience in digital innovation or at least have attempted to adopt digital innovation in their projects. They are small firms which have implemented digital innovations for the purpose of form finding, BIM, optimization or in different stages of design process using digital tools as stated in the review of literature. At least one manager or a senior architect in managerial level involved as a key player of the project was interviewed.

To ensure that correlation of years of experience and implementation of digital innovation was evaluated, the 39 respondents were grouped into three groups (i.e. junior practice, executive practice and expert practice). The purpose of this grouping is to find out whether years of experience in practice have significant correlations with digital innovation.

6.2.1 1-10 years in practice - Junior Practice

This type of practices are starting their architectural business and aiming to achieve stability and success.

6.2.2 10-20 years in practice - Executive Practice

This type of practices has already attained stability and maintained architectural office either in corporate or individual practice.

6.2.3 20 years in practice and up – Expert Practice

In this category the respondent has attained success as they already in practice for the past 20 years.

7. PRESENTATION OF DATA AND ANALYSIS

7.1 Utilization of digital technologies (i.e. non-parametric, parametric, and building performance simulation tools)

Distribution of Respondents answering item one-"What are the software or digital tools you used to successfully implement digital innovation?"

The result below indicates that all practitioners are significantly Autocad and SketchUp users. Junior and Executive Practice have been oftenly-using ArchiCAD than those of Expert Practice. The result is an evidence that Autocad and SketchUp, a non-parametric software are still the common software used in small practices (Table 4).

TABLE 4. Results of survey for the use of non-parametric digital tools

Non-Parametric	Junior Practice	Executive Practice	Expert Practice
	1-10 years	10-20 years	20 years up
	f	*f*	*f*
InteriCAD	0	0	0
ArchiCAD	7	5	2
Artlantis3	0	0	0
VectorWorks	1	0	0
SketchUp	10	12	5
Auto Cad	12	10	10
3d Studio Max	0	4	0
Cinema 4D	0	0	0

TABLE 5 Results of survey for the use of parametric digital tools

Parametric	Junior Practice	Executive Practice	Expert Practice
	1-10 years	10-20 years	20 years up
	f	*f*	*f*
Autodesk Revit	4	4	0
Grasshopper	0	0	0
Rhinoceros	0	0	0
Bently System	0	0	0
ParaCloud	0	0	0
CATIA	0	0	0
GenerativeCompts	0	0	0

TABLE 6. Results of survey for the use of building performance simulation tools

Building Simulation	Junior Practice	Executive Practice	Expert Practice
	1-10 years	10-20 years	20 years up
	f	*f*	*f*
IES	0	0	0
Ecotect	0	0	0
Radiance	0	0	0
Green Bldg Std	0	0	0
Energy Plus	0	0	0
Hevacomp	0	0	0

For parametric software the junior and executive practicing group are already using the Autodesk Revit for building information modelling. Other parametric-based tools are not being used us according to the respondents, they are unaware of it and knowledge of the software is very limited. The result also shows that Expert Practice is not using all of the parametric-based design tools (Table 5).

The result indicates that all of the software or tools being presented are not utilized in small practices. It is obvious that building performance simulation tools are still new to them and they are not aware of it (Table 6).

7.2 Test of respondents for technical, financial and organizational barriers

Distribution of Respondents answering item two-"What are the challenges and barriers you encountered in introducing digital innovation?"

TABLE 7. Frequency of respondents indicating technical barriers

Technical Barriers	Junior Practice	Executive Practice	Expert Practice
	1-10 years	10-20 years	20 years up
	f	*f*	*f*
a. Lack of technology related like software, computers, and specialist digital tools.	10	8	8
b. Insufficient technical knowledge between the team	10	6	6
c. Lack of appropriate personnel to carry out the project from design stage to construction	4	5	5
d. Lack of interest for digital innovation.	4	4	4
e. Unavailability of computing expertise	0	3	0
f. Performance of software	0	0	0
g. Industrial gap in digital tools between AEC offices to software distributors, trainers and Developer.	5	0	0
h. All of the above	7	0	0

The most common technological barriers indicated are the lack of technology related resources like software, computers, and specialist digital tools, insufficient technical knowledge between the team, lack of appropriate personnel to carry out the project from design stage to construction and lack of interest for digital innovation. These variables are present in all small practices. On these barriers it significantly indicates that there are a gap of the technical knowledge of the software because these technologies are new (Table 7).

The results shows that juniors have the highest score that responded in regards to design fees being inadequate to support innovation leading to an insufficient budget for related resources like software and computers. This would mean that start up architectural offices have insufficient income and have little capacity to engage software utilization and development for upgrading design services and presentation. Most of the executive and expert practicing group are indicating reluctance, having fear of profits are at risk and lower business return of investment (Table 8).

The result shows that expert group has more anticipation of business performance failure and sceptical about change partially because expert group gained stability and success in their practice already. Juniors and experts have also fears and lack leadership to guide and lead to the new technological leap of digital advancement. Organizationally, lack of technological information and training are the common factors why most of the architectural firms are sceptical and fearful in adopting change (Table 9).

TABLE 8. Frequency of respondents indicating financial barriers

Financial Barriers	Junior Practice	Executive Practice	Expert Practice
	1-10 years	10-20 years	20 years up
	f	*f*	*f*
a. Design fee is inadequate to support innovations.	10	10	10
b. Insufficient budget for related resources like software and computers.	10	9	9
c. Practices do not normally spend substantial amount for staff training and development.	8	0	0
d. Packages of software and devices are far too expensive.	2	6	0
e. Limited software knowledge	3	4	0
f. Design practice business profits are at risk, lower business return of investment	0	0	0
g. All of the above	4	0	0

TABLE 9. Frequency of respondents indicating organizational barriers

Organizational Barriers	Junior Practice	Executive Practice	Expert Practice
	1-10 years	10-20 years	20 years up
	f	*f*	*f*
a. Fear of performance failure.	6	10	11
b. Innovation is new process and practices are skeptical about change.	7	2	2
c. Fear of quality product failure.	9	2	12
d. Lack of leaders who has the interest of digital innovations.	8	1	1
e. Organization is afraid of business failure.	0	4	4
f. Global practices (multi-culture) are in risk of communication failure.	0	0	0
g. Digital innovations in design practices happen per project basis and staff with digital expertise is transferred from one project to another.	0	0	0
h. Client sees no value in digital innovations	0	0	0
i. Fear of productivity loss.	0	2	2
j. All of the Above	0	3	13

7.3 Mean Comparison of the Three Groups (Junior, Executive & Expert) to the extent to which digital innovation affects small design organization.

TABLE 10. Tests of subjects on how they are affected with technical barriers

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	108.154[a]	2	54.077	3.483	.041
Intercept	16947.923	1	16947.923	1091.609	.000
GROUP	108.154	2	54.077	3.483	.041
Error	558.923	36	15.526		
Total	17615.000	39			
Corrected Total	667.077	38			

On the above table, Univariate Analysis of Variance was utilized to determine if the mean difference of the three comparison groups is significant. The result above confirmed a significant value (F (2, 13) = 3.48, p= .041) (Table 10).

TABLE 11. Multiple comparisons between subjects on how they are correlated with technical barriers

				95% Confidence Interval	
Group	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
Executive	1.9231	1.54550	.469	-2.0229	5.8691
	-2.1538	1.54550	.388	-6.0998	1.7921
Expert	-1.9231	1.54550	.469	-5.8691	2.0229
	-4.0769*	1.54550	.042	-8.0229	-.1309
Junior	2.1538	1.54550	.388	-1.7921	6.0998
	4.0769*	1.54550	.042	.1309	8.0229

The mean difference is significant at the .05 level. The table above shows that the mean scores of the junior and executive groups are significant to each other. It can be gleaned that junior and executive group are strongly more affected by digital innovations in terms of technological factors when compared to that of the expert group (Table 11).

TABLE 12. Descriptive Statistics for Financial Barriers

Group	Mean	Std. Deviation	N
Executive	26.3077	2.13638	13
Expert	20.6923	3.54459	13
Junior	23.8462	4.33678	13
Total	23.6154	4.09503	39

The above result shows that Executive Group are not that affected by digital innovations (M=26.31, SD = 2.145), Junior Group followed (M = 23.85, SD = 4.34) and the Expert Group (M=20.69, SD = 3.54) are likely affected by digital innovations (Table 12).

TABLE 13. Tests of between subjects on how they are affected with financial barriers

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	206.000[a]	2	103.000	8.599	.001
Intercept	21749.769	1	21749.769	1815.714	.000
GROUP	206.000	2	103.000	8.599	.001
Error	431.231	36	11.979		
Total	22387.000	39			
Corrected Total	637.231	38			

TABLE 14. Multiple comparisons between subjects on how they are correlate to financial barriers

				95% Confidence Interval	
Group	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
Executive	5.6154*	1.35752	.001	2.1493	9.0814
	2.4615	1.35752	.207	-1.0045	5.9276
Expert	-5.6154*	1.35752	.001	-9.0814	-2.1493
	-3.1538	1.35752	.081	-6.6199	.3122
Junior	-2.4615	1.35752	.207	-5.9276	1.0045
	3.1538	1.35752	.081	-.3122	6.6199

A significant result in table 14 was found in between Executive and Expert groups. Executive group are greatly affected by financial barriers compared to expert group, F(2, 13) = 8.59. p = .01) (Table 14).

TABLE 15. Descriptive statistics for organizational barriers

Group	Mean	Std. Deviation	N
EXECUTIVE	9.4615	2.18386	13
EXPERT	10.5385	.87706	13
JUNIOR	13.0769	1.60528	13
Total	11.0256	2.21819	39

TABLE 16. Tests of between subjects on how they are affected with organizational barriers

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	89.590[a]	2	44.795	16.559	.000
Intercept	4741.026	1	4741.026	1752.60	.000
GROUP	89.590	2	44.795	16.559	.000
Error	97.385	36	2.705		
Total	4928.000	39			
Corrected Total	186.974	38			

TABLE 17 Multiple comparisons between subjects on how they are correlated to organizational barriers.

Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
				Lower Bound	Upper Bound
Executive	-1.0769	.64512	.261	-2.7240	.5702
	-3.6154*	.64512	.000	-5.2625	-1.9683
Expert	1.0769	.64512	.261	-.5702	2.7240
	-2.5385*	.64512	.002	-4.1856	-.8913
Junior	3.6154*	.64512	.000	1.9683	5.2625
	2.5385*	.64512	.002	.8913	4.1856

Table 17 revealed the multiple comparisons to evaluate which among the comparison groups are significant for organizational barriers. It was found out that the mean differences of the two comparisons between expert group and junior group and executive group were found significant. However, junior group are significantly affected by organizational factors than expert and executive groups.

8. CONCLUSION

This pilot study was conducted to test the four general variables-digital technologies, technical, financial and organizational barriers when introducing digital innovation focused on small architectural organizations have found out significant results.

In testing the digital technology used in digital innovation, it was found out that new generation of architects are able to learn the new digital technologies and adopt the change evoke by the advent of the technology than older practices. They are willing to explore and experiment new design ideas taking advantage of the new technology while the older small practice is resistant to change and lack of appreciation to the new digital technology. Statistically almost all the parametric based tools (except Autodesk Revit) and building performance simulation tools is not being utilized yet in small practices. This is mainly due to the lack of knowledge of the software and the awareness of the availability of these digital tools which boils down to technical and financial barriers. This is because of the additional cost of the technology to be incurred, insufficient budget for related resources like computers, software package which is very expensive and high maintenance cost. Additionally, one of the major barriers is the professional fee being inadequate to support digital innovations.

Technical barriers are signicantly present and observed to be crucial in small architectural organizations. Significant result shows that inadequate maintenance of equipment, and inadequate technology transfer is not that crucial on all architectural organizations. The most common technological barriers indicated are the lack of technology related resources like software, computers, and specialist digital tools, insufficient technical knowledge between the team, lack of appropriate personnel to carry out the project from design stage to construction and lack of interest for digital innovation.

Financial barrier is the most crucial factor in small architectural organizations because they have small projects and consequently their professional fee is not adequate to support innovation. All variables are common barriers such as inadequate design fee to support digital innovation, insufficient budget for digital innovation, the practice doesn’t want to spend much for digital tools, digital tools are expensive to set-up equipment , lack of budget for training the team, high equipment (computer) maintenance cost, practice-based cost doesn’t support digital innovation, lack of R and D budget, expensive salary to hire knowledgeable staff that know the new digital tools.

Similarly, organizational barriers are signicantly present and observed to be small architectural organizations. Significant result shows poor leadership towards digital innovation, poor organization attitude to innovation, lack of empowerment and support to digital innovation construction and lack of interest for digital innovation. Organizational barriers significantly indicate a significant gap between small, medium and big organizations. The more the leadership and support from organization the more the adoption to digital innovation is observed. It can be concluded that small architectural firms is substantially affected by technical, financial and organizational barriers. These barriers impede small architectural practices to innovate.

Holistically, by using Univariate Analysis of Variance it concluded that years of experience in architectural practice are not significantly correlated with digital innovation.

With this results, it is interesting to note that the findings of this study differs from Clayton Christensen *(Christensen 1997)* research*,* which elucidates that major innovations are not likely to be developed by large, established organization. His research indicated that truly revolutionary innovation those that could change industries are most likely to come from small companies who do not have an established market with established customer expectations. Christensen findings were based on business context but may not be applicable in architectural organizations. This is because of the use of innovation technologies for digital innovation in architectural firms is dynamic, and the complexity is uniquely based on the merits and parameters of each project.

Research for digital innovation in design practices is still very limited, and evaluating the challenges and barriers in related fields are significant. The wide variety of barriers presented earlier, indicates series of problems in introducing digital innovations in small design practices, it should be considered by the architectural organizations. The new digital technology is proven to improve productivity and design quality but it is not used in its potential.

Another interesting research area to explore is how small and big architectural firms differ in terms of barriers to digital innovation adoption. Further studies are needed to validate and test the variables presented in this research, to compare larger sample of small and big architectural firms.

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