DIGITAL INNOVATION IN ARCHITECTURE: KEY DETERMINANTS AND BARRIERS IN THE CASE OF SMALL ARCHITECTURAL FIRMS

RUNDDY RAMILO AND MOHAMED RASHID BIN EMBI
Department of Architecture, Faculty of Built Environment
University of Technology Malaysia
Email address: rrunddy2@live.utm.my and b-rashid@utm.my

Abstract. 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 design practices wherein computer-based project plays a vital role. However, as these technologies rapidly develops and 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, Challenges, Barriers

1. Introduction

As the 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 (Luebkeman & Shea, 2005), enables to improved design quality in less time with reduced cost, and can make new levels of complexity and new aesthetics possible. These emerging digital technologies have led 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. As points out by Fallon (2004) the benefits of intelligent modeling to the design process are to increased productivity, reduced cycle time, better work flow and life cycle applications but these technologies are not fully utilized.

This paper investigates the key determinants that impede the effective adoption of digital innovation 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 (i.e. non-parametric, parametric and building performance simulation) used in architectural practices to successfully implement 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 affects small architectural organizations? Does years of practice experience has correlation with innovation adoption?

2. Computer-aided design tools in architectural practices

To some extent the design practices is dominated by the four high-end packages SketchUp from Last Software, AutoCAD from Autodesk, 3D Studio Max from Kinetix and Maya from Alias that is now owned by Autodesk. Some of the modeling tools with wider spread use are listed in table 1 below, and can be compared through downloading trial versions. Most architects and designers admit that in practice they use only a small fraction of their favorite tools modeling functionality (*Havenmann, 2005).* In practice, Sketch-up, AutoCAD, 3d Studio Max is the most designer’s favorite tools for its end-user ease of approach of modeling and lighting, easy to learn, and yields very clean meshes.

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.

TABLE 1. Non-parametric modeling tools that are used in design practice

Non-parametric modelling tools	Website
AutoCAD	http://www.autodesk.com
SketchUp	http://sketchup.google.com
Artlantis	www.artlantis.com
3D Studio Max	www.discreet.com
VectorWorks	www.victorworks.net
ArchiCAD	www. graphisoft.com/archicad
Cinema4D	www.maxon-computer.com
InteriCAD	www. yfcad.com

The table 2 below is a list of parametric-based software that is available in the market and is widely used in practice. They provide high end functionality at a high-end price but they also offer good conditions for academic and educational institutions.

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

With the demand of sustainability and green architecture, another kind of tools that is emerging is using building performance as guiding design principle adopting new performance-based priorities for the design of cities, buildings, landscapes and infrastructures. These new kind of tools interrogates broadly defined performative design above form making. According to Kolarevic *(2003),* 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. This emerging design methodology uses new information and simulation driven design process. Performance-based design is primary used to simulate environmental, thermal, climatic, acoustical etc. This involves finding sustainable strategies using building performance simulation tools or 4d modeling tools. 4d digital technologies are those software 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.

Related studies shows that performance simulation must be undertaken right from the very earliest stage of the project and then continued throughout the entire process to design completion and beyond. The detail and accuracy of the model should be developed in parallel with the design and all other performance analysis areas. Though the analysis at the early stage is dynamic, ball part figures is useful to check feasibility, quantity and inform design team decision making. It can help brainstorming issues on master planning, orientation, massing and form decisions justifying choices and differentiating for project proposals.

Building simulation software is currently dominated by the major CAAD companies Autodesk and Bently as listed in Table 3. They provide plug-inn that is linked with 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 modeling tools for environmental analyses

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

Another method used is Scripting or Algorithmic Architecture. It is used for various form finding through which the role of the designer can shift from 'space programming' to 'programming space'. As points out by Terzidis *(2006),* "it is an alternative choice which involves the designation of software programs to generate space and form from rule-based logic inherent in architectural programs, typologies and language itself. Instead of direct programming, the codification of design intention using scripting languages available in 3d packages can build consistency, structure, coherency, traceability and intelligence into computerized 3d form".

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.

The use of scripting in architecture was taken from the 'Theory of L-System' *(Lindemayer, 1968)* in which the simulation of plant growth is further experimented and applied as a process to generate objects *(Allen et al, 2004)*. The theory of L-systems has led to a well established methodology for simulating the branching architecture of plants. Many current architectural models provide insights into the mechanisms of plant development by incorporating physiological processes and had been an eye opener to architects and designers to use in form generation of buildings.

Summarizing the four (4) basic categories of CAAD 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 as points out by Burry *(1999)*, 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. The chart 1 below is a categorization of current CAAD tools that are used by several design practices.

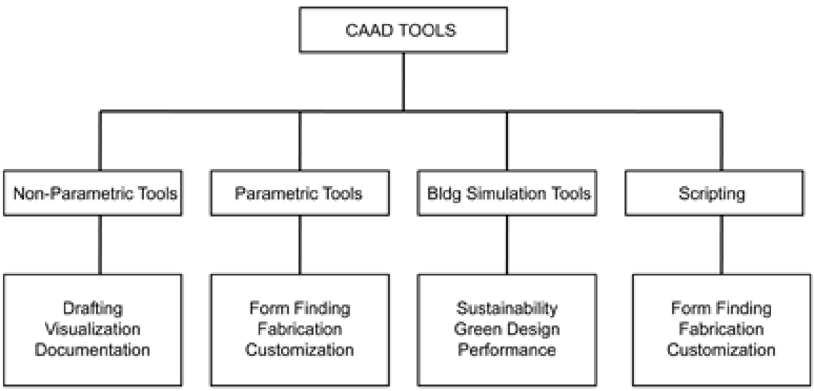

Chart 1. Categorization diagram of current CAAD tools that are used by several design practices

3. Digital innovation in architectural practices

Historically, innovation in architecture was initially adopted from industrial design. The CATIA (Computer Aided Three-dimensional Interactive Application) for example, has been in use for 20 years before it was discovered by Gehry's office *(Kolarevic, 2005).* A number of other recently completed projects, of widely varying scales and budgets made creative use shipbuilder's expertise. The NatWest Media Center at Lord's Cricket Ground in London designed by Future Systems was manufactured in a small shipyard and then transported in segments for assembly at the building site. Another example is the conference chamber in Frank Gehry's DG Building (2000) in Germany, with its complex curvelinear form, was clad in stainless steel plates produces and installed by skilled boatbuilders" *(Kolarevic, 2005).* Three-dimensional digital modeling software based on NURBS (Non-Uniform B-Splines), that is parametric curves and surfaces had been already used by automotive, aerospace, and ship building industries a long way before it was used by architects.

Gehry and Partners is the pioneer of digital innovation in Architecture. The firm uses powerful 3-dimensional representation tool, CATIA, to model the complex geometry of their buildings *(Yoo et al., 2006).* It has influenced the way the firm works with owners, contractors, subcontractors, engineers and fabricators. On their project they usually used CATIA 3-D representation tools focused on how the tool enabled Gehry to design more complex buildings.

According to Yoo et al. (*2006)* the firm uses of a centralized 3d model and database 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. 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. In this way, 3-D tools play an important role in connecting all the players and stimulating their joint and separate innovations. As a result, the project became a nexus of emergent and distributed innovations. In this process, the use of 3-D representations became a part of a larger process in which the whole project network became a vibrant source of innovations.

Frank Gehry's projects reveal how the use of 3D representations intensified the focus on form giving. According to Yong et al *(2006)* Even though form giving is an essential aspect of architectural design, a firm's ability to focus on form giving is often constrained by various forces. Gehry and his associates follow a design process that starts with his sketches and physical models at various scales and later adds 3-D digital models in order to incorporate the form giving energy of others throughout the project. The architectural vision provided by Frank Gehry in his initial sketches is carried forward throughout the project by using 3-D representations to enlist contractors and subcontractors in exploring and expanding upon his original architectural vision. What is striking in this process is how each building uniquely responds to clients' needs, local regulations, and the availability of talents and material and environmental conditions, but at the same time reflects his unmistakable design vocabulary.

3D representations played a critical role and were digital technologies is a central tool in exploring different project structures. The 3D tools and building information models is mainly used to experiment different patterns of communication and collaboration among project team, and to identify the areas where they will need innovations. Such a flexible approach to project structure, with the focus on form giving, challenges the team and in a way look for new innovations in their projects while at the same time continuing to carry forward their new ideas.

Another firm that is renowned for digital innovation is Foster and Partners in London *(Snoonian, 2005).* Some of their projects like the Greater London Authority Headquarters was created in Bentley Systems' MicroStation software, then rationalized into panels to refine the glazing and structural-steel systems. Fabricators and the construction contractor were required to develop their own digital models based on the firm's data to ensure that components would be machined to required tolerances and would be assembled correctly at the site. Instead of a traditional grid-line offset survey, the 3D building model was linked to known locations at the site. The builder even attached holographic targets to connections in the structural-steel systems, which were laser-scanned on-site so that steel beams were inserted in the correct position.

4. Challenges and impediments to digital innovation adoption

While global design practices have taken advantage of the new technologies, small architectural practices are facing challenges. This is because of the increasing new technology and the current demands of topologically non-linear building design and the issue of sustainability. Small design practices are indeed experiencing the challenges triggered by digital innovation. Constant introduction of new digital technology, increased global competitions, increasing client's demands and limited costs, limited software knowledge are among the challenges. Undeniably, the digitalization of design practices has not been trouble-free. Business profits as one of the major goals of design practice are at risk when implementing digital innovation. According to Davila et al (2006), innovation implies to newness of process, or new way of doing something, and therefore businesses are at risk of failure. 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.

Understanding digital innovation adoption in architecture is difficult, and developing a single framework or model for 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. Literature in this subject is still very limited.

For the purpose of understanding the barriers, challenges and key determinant factors that affect architectural organization in innovation adoption, a literature review in innovation in allied fields such as manufacturing, product design, engineering and construction was conducted. Though it is not specifically in architecture, it reveals several challenges and impediments in implementing digital innovation both of which has different views but shared common attributes that can be used for exploring the variables. It gives insights of the various barriers and impediments that are encountered when implementing innovation from allied disciplines.

A survey in manufacturing and product design innovation that was conducted by O'Sullivan *(2002)* reveals the following 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 digital innovation research in architectural engineering and construction conducted by Johnson and Laepple *(2002)*, they found out that when company is implementing innovation, organizational challenges and additions to resources happened such as:

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

Similar studies in AEC made by Cory and Bozell *(2001)* 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.

A research made by Civil Engineering Research Foundation *(1996)* reveals nine barriers to innovation in the building industry.

- Risk and liability
- Financial disincentives
- High equipment cost
- Inadequate technology transfer
- Inadequate basic and industrial R & D
- Adversarial relationships
- Poor leadership
- Inflexible building codes and standards
- Construction based initial costs

Inchachoto *(2002)* on his technological innovations research coined some important pointers on his research on technological innovation:

- 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.

Yo et al. *(2010)* on their digital innovations research focused on digital processes they coined some several barriers:

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

Such list of barriers is similar to the organizational barriers that were 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

These barriers of 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

Though, the application and multitude categorization of issues and barriers presented earlier are from different practices, common attributes are found (Table 4) from various research of innovation in different allied fields. 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 three (3) major barriers and challenges, elicited by O'Sullivan *(2002)*, Johnson & Laepple *(2002)*, Cory & Bozell *(2001)*, Civil Eng'g. Research *(1996)*, Inchachoto *(2002)*, Yo et al. *(2010)*, Jones and Saad (2003), it coincides with innovation research of Walcoff et al. *(1981)* are summarized in chart 2.

TABLE 4. Common determinants and barriers from innovation research in different allied fields

Researches from Allied Fields	Technical Barriers	Financial Barriers	Organizational Barriers
O'Sullivan *(2002)* Manufacturing & Product Design			●
Johnson & Laepple *(2002)*, AEC	●	●	●
Cory & Bozell *(2001)*, AEC	●	●	
Civil Eng'g. Research *(1996)*	●	●	
Inchachoto *(2002)* Arch'l. Technology	●	●	●
Yo et al *(2010)* Digital Innovation	●		
Walcoff et al *(1983)* Innovation Research	●	●	●

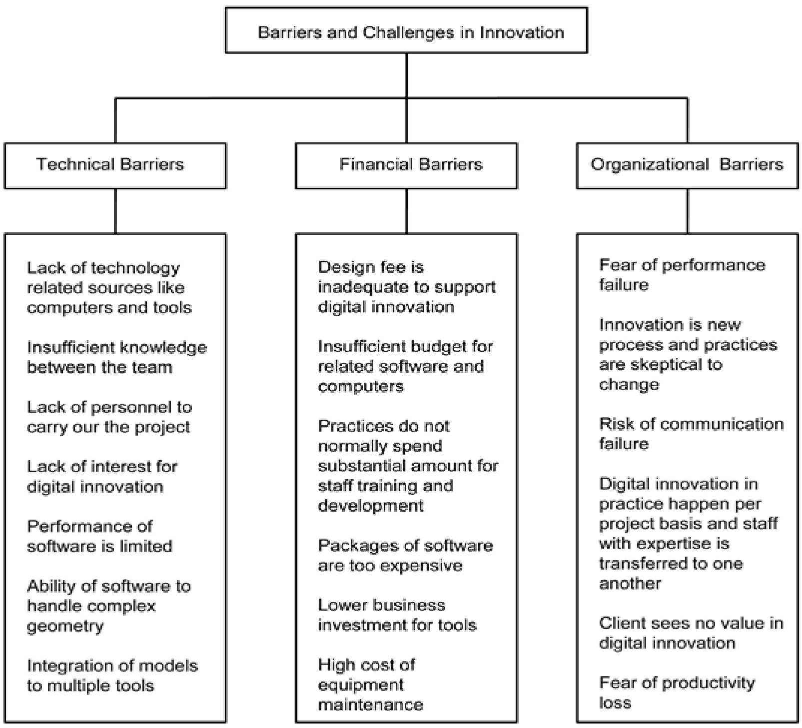

Chart 2. Three (3) major organizational barriers and challenges are summarized, elicited by O'Sullivan *(2002)*, Johnson & Laepple *(2002)*, Cory & Bozell *(2001)*, Civil Eng'g. Research *(1996)*, Inchachoto *(2002)*, Yo et al. *(2006)*, Jones and Saad (2003), Walcoff et al. *(1981)*. It was used as variables for this research.

6. Research methods 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 *(O'Sullivan, 2002), (Johnson and Laepple, 2002), (Cory and Bozell ,2001), (Civil Engineering Research Foundation, 1996, (Inchachoto, 2002), (Yo et al., 2010), (Jones & Saad, 2003) and (Walcoff et al., 1983).*

6.1 PROCEDURE

Using the identified variables, a survey through organized questionnaire was conducted on 39 small architectural organizations of different years of experience through interview to gather data for digital technologies used (i.e. non-parametric, parametric, building performance simulation tools) and technical, financial and organizational barriers when introducing digital innovations.

6.2 SURVEY RESPONDENTS

To ensure that correlation of years of experience and implementation of digital innovation was evaluated, the 39 respondents where group in three (i.e. junior practitioner, executive practitioner and expert practitioner). The purpose of this grouping is to find out whether years of experience in practice have correlations to digital innovation adoption.

1-10 years in practice - Junior practitioner
The respondents are with one to ten years in practice are randomly selected and evaluated to represent the age bracket level.
10-20 years in practice - Executive practitioner
Selection in this particular group are between ten to twenty years in practice has been chosen to represent their age and practice bracket. This practice has already attained stability and maintained architectural office either in corporate or individual practice.
20 years in practice and up – Expert practitioner
In this category the respondent has attained success and already existing for the period of 20 years.

7. Presentation of Data and Analysis

7.1 UTILIZATION OF DIGITAL TECHNOLOGIES (IE 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?"

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

Non-Parametric	Junior Practitioner 1-10 years *f*	Executive Practitioner 10-20 years *f*	Expert Practitioner 20 years up *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

The result indicates that all practitioners are significantly Autocad and SketchUp users. Junior and Executive Practitioners have been more often using ArchiCAD than those of Expert Practitioners. The result is an evidence that AutoCAD and SketchUp, a non-parametric software are still the common software used in small practices.

TABLE 6. Results of survey for the use of parametric digital tools

Parametric	Junior Practice 1-10 years *f*	Executive Practice 10-20 years *f*	Expert Practice 20 years up *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

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 Practitioner is not using all of the parametric-based design tools.

TABLE 7 Results of survey for the use of building performance simulation tools

Building Simulation	Junior Practitioner 1-10 years *f*	Executive Practitioner 10-20 years *f*	Expert Practitioner 20 years up *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

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.

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 8. Frequency of respondents indicating technical barriers

Technical Barriers	Junior Practitioner 1-10 years *f*	Executive Practitioner 10-20 years *f*	Expert Practitioner 20 years up *f*
a. Lack of technology related like ›ftware, computers, and specialist digital ›ols.	10	8	8
b. Insufficient technical knowledge ›tween the team	10	6	6
c. Lack of appropriate personnel to carry ıt the project from design stage to ›nstruction	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 EC offices to software distributors, trainers ıd 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 9. Frequency of respondents indicating financial barriers

Financial Barriers	Junior Practitioner 1-10 years *f*	Executive Practitioner 10-20 years *f*	Expert Practitioner 20 years up *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
E. Design practice business profits are at risk, lower business return of investment	0	0	0
F. All of the Above	4	0	0

The results show that juniors got 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 startup 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.

The results show that expert group has more anticipation of business performance failure and skeptical about change partly 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 skeptical and fearful in adopting change.

TABLE 10. Frequency of respondents indicating organizational barriers

Organizational Barriers	Junior Practitioner 1-10 years *f*	Executive Practitioner 10-20 years *f*	Expert Practitioner 20 years up *f*
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
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 11. 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			

TABLE 12. Multiple comparisons between subjects on how they are correlated with technical barriers

Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
				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. This means that junior and executive group are strongly affected by digital innovations in terms of technological factors when compared to that of the expert group.

TABLE 13 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 14. 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 15. Multiple comparisons between subjects on how they are correlated to financial barriers

Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
				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

Significant result 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 16. 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 Descriptive Statistics for Organizational Barriers

TABLE 17. 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 Tests of between subjects on how they are affected with organizational barriers

TABLE 18 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

Multiple comparisons were utilized to evaluate which among the comparison groups are significant. 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.

New generation of architects is able to learn the new digital technologies and adopt the change evoke by the advent of the technology. 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.

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. The use of digital technology has a significant relationship on the technical barriers presented on this research. Knowledge of the technology and the awareness of technology can help improve projects plays a significant role.

Additionally, one reason of not using the new digital technology is partly because of the additional cost of the technology, insufficient budget for related resources like computers, software package which is very expensive and high maintenance cost. Furthermore, one of the major financial barriers is the design fee being inadequate to support digital innovations.

Organizational barriers are also present in small architectural organizations. Most of the managers are afraid of performance failure. They are skeptic to change and fear of quality failure and partly fear of productivity loss and most small organization is not interested with digital innovations.

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. Further study is needed to validate and test the presented variables in a bigger scale.

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