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Impact of Technology on Designers' Cognitive Actions in Multireligious Collaborative Design

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ABSTRACT

Issues on collaboration and digital modality in design have continued to surface in modern construction research. The purpose of this study is to investigate how modality can support designer cognitive actions during collaboration in design. The study uses literature review to understanding the properties, usability and characteristics of collaboration in the context of design, to evaluate key component for cognitive actions in design and finally to established two existing design modalities (sketch and digital). Using protocol observation technique the study investigates the impact of the existing modalities on designers' cognitive actions during collaboration in design. The experiment consisted of eight design teams working with the two modalities. Coding schemes based on the four parameters of cognitive action namely; naming, framing, moving and reflecting were employed to generate empirical data from the protocols observation of the two modalities. Statistical analysis using Chi-Square cross tabulation established a significant degree of freedom among designer action in the two modalities. The results indicate that the cognitive actions of the two modalities are statistically different in their frequencies and duration. Higher framing actions were not affected by sketch modality but were affected by digital modality. Similarly, higher moving actions were not affected by sketch modality but were affected by digital modality. Thus, the study established that sketch is better cognitive action modality because of it important characteristics on naming, framing, moving and reflecting actions.Therefore, the study contributes in streamline collaboration in design process by establishing the sketch as the most appropriate modality that support designer cognitive actions during the process. Future studies can be carried out on the need to support and enhance the digital modality so that it can equally efficiently and sufficiently support designers' cognitive actions during collaboration in design.

1.0 Introduction

Teamwork in design is a fundamental activity that was described by Valkenburg and Dorst (1998) as a reflective process. The study explicitly established that naming, framing, moving and reflecting are the four major activities of design team work. The naming action is designers' act of looking for relevant information in the design brief. Framing action represents the act of problem and solution exploration in identifying something to hold on and focus while designing. Actions like generating ideas, making an inventory, sorting information, combining ideas, or comparing concepts are coded as moving action. Reflecting action is a critical revisit of earlier actions to test or clarify earlier actions about proceeding actions. Conversely, the study has established cognitive actions as a framework for measuring the activity of teamwork in design. Contemporarily, issue of collaboration is a more dominant research topic across different domains (Froese, 2010). However, one of the major problem facing contemporary design approach is the need to investigate designers' cognitive activities in a collaborative ecosystem. Even though literature presumed collaborative approach enhances building design (Garber, 2014), yet there is no clear theoretical or practical proving on how to collaborate in the context of a well-established problem-solving activity design teamwork. Therefore, there is the need to investigate the importance of cognitive actions during collaboration in design. Thus, this study will review relevant literature to identify and compare the modalities of collaboration in architectural design and the four classifications of cognitive actions.

2.0 Collaboration in the context of design

To understand collaboration in design, it is important to consider the underlying background of literature perspectives on the concept of collaboration and that of design. For example, theoretical design has been hypothetical described as a rational problem-solving process influenced by models of technical systems. However, these understanding of design received a lot of criticism due to its dependence on technical/scientific procedures instead of designer centered activities (Schon, 1983; Dorst and Dijkhuis, 1995). Consequently, many design authors circumscribed to the "reflective theory" that describes the design as when individual designers use their tacit knowledge to reason and act on design problems and solutions to generate the interpretations of new knowledge (Schon 1983, 1984, 1987). On the other hand, theoretically, the term collaboration means two or more people are working together (Hord, 1986; Gray, 1989; Wood and Gray, 1991; Mattessich and Monsey, 1992; Patel et al. 2012). Unequivocally Patel et al. (2012) point out that there are three major factors that constitute a collaboration, namely; context, team and strategy. Firstly, the context was described as the major factor that dictates the nature of the collaboration. This makes it a unique and complex to understand because many factors like teamwork, goal, external factors, working conditions and organizational structure within which the collaboration operates are all mixed into a single unit. Secondly, the team represents detail requirements of individuals sharing design tasks, goal, purpose, performance, and output. Their mutual work should cover individual, collective and interdependent tasks which will subsequently generate intra- and inter-group outcomes.

Thirdly, the strategy is the instrument of coordination, communication, and decision-making where all the parties with a stake in the problem constructively explore their differences and develop a joint solution to problems, product development, and outcome. Thus, this study found Patel et al. (2012) factors of collaboration less useful in setting the frame of investigating collaboration in design. Therefore, we can finalize that theoretically, the framework of collaboration in the context of design should inculcate; shared reflective process within the same context, team and strategy. Therefore, we conceptualized and proposed to formulate a theoretical framework of collaboration in design from the initial understanding of design and collaboration theories. Thus, theoretically, collaboration in design should inculcate a shared reflective process within the same context, team and strategy while transforming the design problem into a solution that is beyond individual vision." (refer to figure 1)

Figure 1 A theoretical framework for collaboration in design

2.1 Cognitive Actions in Design

Grounded cognitive research stresses the importance of cognitive research approaches in accessing information embedded in human brain (LaBerge and Samuels, 1974; Norman and Shallice, 1986; Goodnow and Levine, 1973; Goodman, 1980). Similarly, design literature has established that designing is a complex activity that is strongly connected to cognition, (Kavakali and Gero, 2002; Goel, 1994; Schon, 1983; Dorst, 2011; Schon, 1984; Valkenburg and Dorst, 1998). Schon found that cognitive actions in design are agents of reflective practice that showcase designer's act of reasoning and behavior that uncovers meaningful ideas which suits the design problem under review. Schon (1983) explicitly classified cognitive actions in design as framing, moving, and evaluating. Framing is an action that uncovers design emergence, within which the design concept lies. Moving are actions that set the stage for adopting and implementing the design solution. Evaluation are designer actions through which consequences and implications are evaluated and subsequently reframe and implemented. Schon concluded that framing is a fundamental cognitive action in design because of its ability to peruse and strike design solutions through the use of themes derived from the design problems. Additionally, Hekkert et al. (2003) described the act of framing in design as the major activity designers use to perceive the situation in a certain way and adopt certain concepts which describe and associate it with their perception. The study concludes that in designing, the act of framing is the main structure under which other actions radiate from. However, Kolb (2014) highlighted time-consuming, psychological challenges and that content and substance are some of the major barriers hindering the act of framing in design. Nevertheless, as the design is reflective practice, the act of framing remain an integral part of the design, because it controls the invention of a move or hypothesis of the situations, settings or problems. Furthermore, as it can be seen in Figure 2, Valkenburg and Dorst (1998) promote cognitive actions in design as naming, framing, moving, and reflecting. Naming represents the act of mentioning the design brief when searching for relevant information. Framing is a way of scoping parameters that will form the basis for the design concept. Moving is making a change that will lead to a solution. Reflecting is the act of revisiting earlier moves and frames that can lead to reframing, new moves, or requesting new information.

2.1.1 Nature of Naming Actions in Design

In design, the design task is a vague requirement that indicates a problem often full of inner contradictions, and as a result, they are always open to interpretation. This process of interpretation and re-interpretation require the naming of the requirements of the crucial part of design creativity; it allows the design to take flight and move into framing, moving and reflecting. It provides the initial move that can provide some early solution proposals that drive the problem evolution show what solutions could realistically be achieved. There are different ways of dealing with initial design problem of which naming is one. Initially, designers will begin with the least effort and resources: they set out in a problem-solving manner to create a new 'something' that will save the day while keeping the 'how' 'frame' and 'value' constant. This is often the nature of the design situation as it first presents itself to a designer, implicitly framed by the client organization—and the designer has to explore whether the level at which the central design problem is perceived and understood by the client is right for the problematic situation to be fruitfully approached by the designer (Lawson 2012). Often, the problem-as-presented first needs to be 'deconstructed' (Hekkert et al. 2003) or opened up.

2.1.2 Understanding Framing Actions in Design

Framing is the term commonly used for the creation of a standpoint from which problematic situation is solved. This includes perceiving the situation in a certain way, adopting certain concepts to describe the situation, patterns of problem-solving that are associated with that way of seeing, leading to the possibility to act within the situation. In designing, the act of framing is the main structure which design lies and other actions radiate from. It is a term regularly utilized to represent a structure of designing. According to Schon, 1983 framing is a way of tackling design problem, and from the design, solution evolve. Mostly they are guided by primary knowledge and background experience through conventional representation and verbalization that portray the solution to a problem that supports a design concept. Design problems are solved through the guidance of designers framing. A designer's stance which is determined by training, personality, environment and culture. The use of the frame is characteristically connected to designers experience and the knowledge of the context. Framing is a fundamental method of adopting a problem-solving style in perusing and striking design solutions straight away. In framing, themes are general ramifications that are derived from design problems and specifically apply for the working of the solutions to the particular problem. There are two important reasons for designers to concentrate on the framing of a problematic situation: Experienced designers can be seen to do this by searching for the central paradox, asking themselves what makes the problem hard to solve, and only start working towards a solution once they have established the nature of the core paradox to their satisfaction (Dorst, 1997).

The word 'paradox' is used here in the sense of a complex statement that consists of two or more conflicting statements—true or valid in their right, but they cannot be combined. The core paradox is the real opposition to views, standpoints or requirements that require inventive design solutions or reframing of the problematic situation. This is a stark contrast to analytical problem solving, that takes place in a 'closed world' where there is no way to redefine the problematic situation (because the way in which the solution has to work is already set in stone). In her writings on Engineering Ethics, Caroline Whitbeck flags the way designers deal with paradoxes as a keyspecial element of design thinking (Whitbeck 1998).

2.1.3 Application of Moving Actions in Design

In the general perspective of design problem-solving, move refers to the designer's cognitive action that implements a meaningful idea that solves the design problem. The moving process transpires inset of solution that explicitly indicates the design outcome or product. The major factor that influence move action in the designers' understanding of the required explicit knowledge of the expected product. In the general perspective of utmost design problem-solving literature (Schon's 1984, 1987; Lawson and Dorst, 2009; Eckert et al. 2004), moving is regarded as one of the actions that represent the applicability of solution to design problem. Also, Schon (1984) describe the move action as the implementation of a solution to the design problem. Thus, designers move action generate the solution structure of the design problem. Another function of formulating action in design problem-solving in proving the integrated design outcome.

2.1.4 Reflecting Actions in Design Practice

According to Dewey (1933), reflective thinking is not imagination, but a widely discussed cognitive action applied and discussed in design-related disciplines. Dewey (1933) further explain reflective thinking as a persistent of knowledge ground that supports a conclusion. It is equally a state of doubt as well as an act of testing of the resolution of the doubt.Extensively Dewey (1933) argued that it is necessary to provide experience and some amount of knowledge dispositions at hand, to enhance reflective thinking for solving complex problems truly. On another layer of the understanding of reflective thinking Schön (1983, 1987) also finds the role of reflective thinking in solving design problems important, through problem situation. Design practitioners derive a new theory for a particular situation based on their previous experiences and already established theories. Thus Schon tagged reflection as reflection-in-action and reflection-on-action which is the interactive conversation between the practitioner and the situation. The practitioner reflection-in-action explains that how a practitioner's thought reshapes what he or she is doing while doing it while reflection-on-action when practitioner thinks back on what has been done and how the similar situations can be better solved in the future. Modification in design is a subtask input that generates changes which are regarded as closer to the specifications. What is required for changing or adding components that satisfy a solution required for a given design problem? The modification can be driven by a form of reasoning that relates to the desired changes in behavior to possible structural design change (Goel 1989). In this method, parameters are changed, the direction of improvement noted, and additional changes are made in the direction of designers' intention. The modification is straightforward which is a director backtracking change, or choosing a choice from a list of finite choices available. Some modification results from explicit knowledge about what to do under different kinds of trials. This information Criticism can reveal the need to modify and add new functions to proposed designs. Functions can be modified before they are added, that is, by creating and integrating separate substructures that deliver the functions, the design of the additional structures can simply be viewed as new design problems to be solved by all the methods available for design. The subtasks of generating specifications for these additional design problems and integrating their solutions were discussed in the section on problem decomposition and solution decomposition.

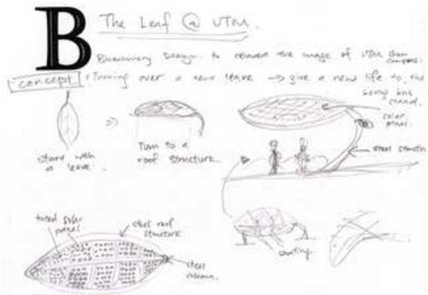

Figure 3a Naming and Framing Actions

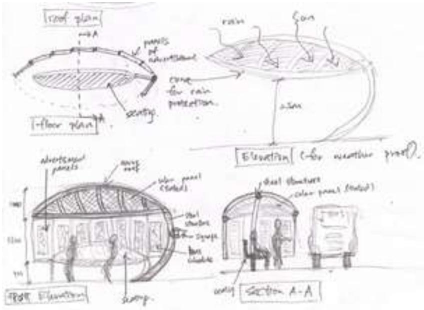

Figure 3b Moving and Reflecting Actions

2.2 Modalities of interaction during collaboration in design

As illustrated in Figure 3, one of the basic significant parameter related to the operability of collaboration in design is the modality of interaction. To date sketch, digital and physical models are the major design modalities known. On the other hand, discussions on collaboration have become prominent in present-day research. This study has identified digital modality as a major driver for building constructive collaboration research practices (Isikdag and Underwood, 2010). Therefore, this research aimed at testing collaboration in design from the perspective of how to determine the impact of the digital modality on cognitive actions in design (refer to Figure 4). Obviously, the sketch has proven to be a universal conventional design thinking tool, however, since 1990 to date research efforts on collaboration in the context of design have not addressed or investigated the actual impact the acclaimed digital modality can have design activities that are related to cognition. Therefore, this study will compare the impact of sketch and digital modality on designers' cognitive action during collaboration in design.

Figure 4 Modalities for collaboration in design

2.2.1 Describing the role of Sketch in Design

Sketching is a specialized type of drawing, used for preparing and capturing fleeting subjects as a means of perfecting the design. In the early stage of the design process, thinking with sketches is the primary design activity that enables designers to manage, control, promote, and evaluate the design (Goel, 1995; Dorst and Cross 2001). According to Idi and Khaizir (2015) designer use sketches to enhance their thinking to discover new things, to see new ideas, and to share ideas. Similarly, Lawson (2002) stressed that in design problem-solving sketch is a tool that can facilitate the manifestation, evaluating and communication of the conceptual design idea from which the entire design process lies. Additionally, Lawson (2004) viewed sketching as a mental representation of the designer's mind, so that other parties can relate to the needed requirements. Also, Goldschmidt and Smolkov (2006), Goel (1995), Purcell and Gero (1998) attested that the sketch is a flexible, quick, and intuitive conceptual tool for supporting and stimulating creative ideas. In describing the characteristics of sketches, Gero et al. (2001) recognized that at the initial point, a sketch might have little or no meaning to outsiders, as only the author have little insight of what is happening in the sketch, this ambiguity is one of the major characteristics of the sketch. Equally, Fish & Scrivener (1990), Robbins (1994), Schön (1983), Goldschmidt and Smolkov (1994) established that to uncover and unidentified images of an object through the continuous thinking, regrouping, interpretation, reorganization and perpetuating of different kinds of the display until a convincing image is found, makes searching and communication as two important characteristics of the sketch. However, Suwa and Tversky (1997) highlighted that sketch might be limited to conceptual ideas with less detail, precision geometry and accurate dimensions. Still it leads to unexpected discoveries that generate new ideas. Therefore, it has a pivotal role in the initiation and development of creative ideas during the early design phase, but in some ways, it lacks the ability precisely detail these ideas. Therefore, there is the need to compare between sketch and digital modalities in a design setting to improve sketching precision. (Figure 5a-b illustrates the nature of sketch modality for design collaboration).

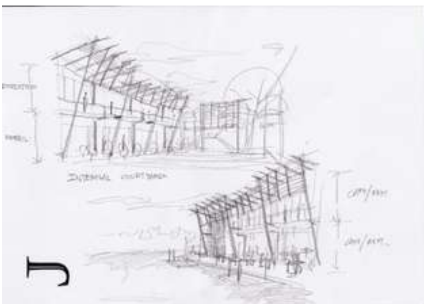

Figure 5a: The Sketch Modality

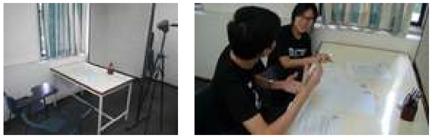

Figure 5b: Typical Sketch Modality setup and activity

2.2.2 Prescribing the Applicability of Digital Modality in Design

On the other and, for some time now, the construction industry has vigorously promoted digital modalities to remedy the notorious profligacy of the sector. The promotion of platforms that can enhance speed and accuracy has advanced the use of digital modalities in almost every aspect of building design, construction, and post-construction activities (MacLeamy 2004). For example, MacLeamy indicates that digital modalities can reduce design time and improve efficiency because of their ability to generate as-built virtual buildings and integrate stakeholders from different geographical locations. Similarly, the United States of America National Institute of Standard and Technology, concluded that with recent developments in Information Communication Technology (ICT) digital modality was set as a tool that improvises management, speed, and human capital in building design and construction (Gu et al. 2011, Delavari et al. 2013, Abrishami et al. 2015). One particular method that indicates how digital modality is applied in building design is driven by the Building Information Modeling (BIM) concept (Chi et al. 2013). According to Sabongi (2013), the BIM concept uses a digital-based modeling scale that has been approved by American Institute of Architects and BIM forum for the Level Of Detail (LOD) (Sabongi 2013). The application of the digital scale symbolizes design from level 100 (concept) to level 500. On the other hand, there are some concerns that digital modality might not necessarily support the complex nature of cognitive actions like the way conventional sketch modality does, even in collaborative design.

When the matter is viewed from the tacit perspective of design, sketch modality plays a vital, flexible role in processing designer tacit knowledge during design. Conversely, these tacit sketch properties might not be the same as in digital modality. Therefore, there is a need for comparisons between sketch and digital modalities in design. (Figure 6a-c illustrates the nature of sketch modality for design collaboration).

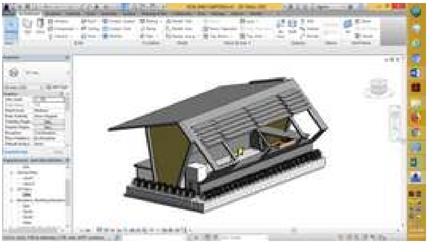

Figure 6a: Digital Modality output

Figure 6b: Digital Modality setup

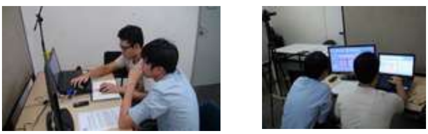

Figure 6b: Digital Modality setup

3.0 Methodology

This study employs theoretical framework discussed in section 2.0 to empirically (Creswell, 2013) investigate the act of collaboration in design involving eight different design teams working to solve a given design issue. The empirical study offers the opportunity to statistically compare the two selected variables from the framework namely; reflective cognitive actions and modalities (refer to Figure 7 and Table 1). Furthermore, the study of collaborative interactions mostly relies on concurrent protocol analysis; a technique originated from cognitive, conventional and linguistics sciences (Sonnenwald, 1996; Robillard et al., 1998). Robillard et al., (1998) attested the suitability of concurrent protocol analysis for gathering verbal conversation in a collaborative ecosystem. Generally, in this type of protocol analysis designers usually talk loudly during the design experiment so the observer can concurrently undertake the observation. Sometimes this method tends to be a bit biased on design context that can only be understood through nonverbal channels. Similarly, due to the salient and ambiguous nature of design problem-solving patterns, most methods tend to miss some aspects that lie in the designers' mental, cognitive space. For example, talking can support known and understood ideas as well as affect reasoning ability. Therefore, concurrent protocol analysis has some issues that undermine design thinking.However, even with the highlighted limitations, concurrent protocol analysis is still widely used for investigating design activities when collaboration is involved. In these cases, the design activities are naturally concurrent because stakeholders have to interact during the design process verbally. Therefore, collaboration in design is not about individual reasoning but integrated verbal conversations between participating stakeholders, which represents the protocol data of the design team. Thus, concurrent protocol analysis method is naturally suitable for studying collaborative design activities like this research (Gul and Maher, 2007; Dorst and Dijkhuis 1995, Schon, 1987; Lloyd, 1995).This study uses concurrent protocol analysis to provide a measurable cognitive action coding system for these interactions. Thus, this study selected and applied the use of concurrent protocol analysis to examine the influence of modalities on cognitive actions during collaboration in design.

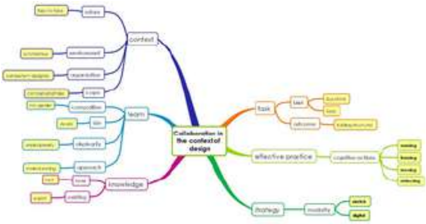

Table 1: Collaboration in design experiments using Digital and Sketch Modality

Sessions	Teams	Modality
1	Team 1	Sketch
2	Team 1	*Digital*
3	Team 2	Sketch
4	Team 2	*Digital*
5	Team 3	Sketch
6	Team 3	*Digital*
7	Team 4	Sketch
8	Team 4	*Digital*
9	Team 5	Sketch
10	Team 5	*Digital*
11	Team 6	Sketch
12	Team 6	*Digital*
13	Team 7	Sketch
14	Team 7	*Digital*
15	Team 8	Sketch
16	Team 8	*Digital*

Concurrent protocol data were obtained from eight design teams that worked twice. The first is the design of a bus stop stand (sketch), while the second is the design of a commercial prototype kiosk (digital). Considering the theoretical framework of collaboration in design, all designs observation were carried out in a face-to-face collocated synchronous setting. The designers were peered into eight teams to avoid the high level of conflicting interpersonal ideas that can be expounded through large team dynamism. In total 16 experiments were performed, 8 using digital modality and 8 using sketch modality. All 16 experiments were observed using two High Definition (HD) camcorders, a voice recorder, three tripod stands, one microphone, two computers installed with Revit software (digital modality), and manual drawing instruments (sketch modality). To control the originality of the conversational data, external sources were actively restricted. The designers worked collaboratively without interference from the researcher. At specific intervals, the observer carried out a routine inspection of the instruments to ensure optimum functionality and to capture static photographs, but the researcher did not contribute in any way to avoid distorting the process. This helped in providing uninterrupted team conversations. Table 1.0 and Figure 8a, b & c present schedules of collaboration design experiments carried out under their respective teams.

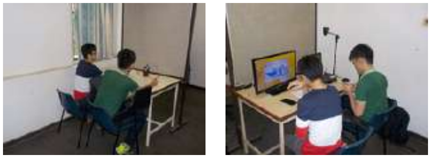

Figure 8a Collaboration in design using Digital and Sketch Modalities by Team 3

Figure 8b Collaboration in design using Digital and Sketch Modalities by Team 7

Figure 8c Collaboration in design using Digital and Sketch Modalities by Team 8

Retrospective protocol analysis to analyze the concurrent protocol data at a later time. The nature of analysis includes transcribing, segmenting, coding, and tabulation. The first stage of the analysis is data transcribing, then segmentation, and finally coding (Velkemburg and Dorst, 2011; Suwa and Tversky, 1997; Goldschmidt and Smolkov, 1994; Suwa et al. 1998).The tabulation was based on the frequency and time duration of cognitive actions as they unfolded during collaboration in design. Subsequently, the tabulated outcomes were used for statistical analysis using SPSS.

Through the analysis, we successfully uncovered and recorded stakeholders' salient and ambiguous information that transpires during collaboration in design. Next is to transcribe the verbal content of the data into textual information. For example, an hour of verbal data may take 6 to 10 hours to be fully transcribed, which can result in 15 to 50 pages of text before it is coded and reduced to a certain number of main samples (refer to Table 5.1). Even though transcription is not automated, this study used software (NVivo) for data transcribing, segmenting and coding. The segment is a conversational phase, unit, sentence or content of a protocol data that represent a coherent proposition about an entity that is being designed (Goldschmidt, 1991; Suwa and Tversky, 1997; Gero and McNeill, 1998; Ericsson and Simon, 1993). Similarly, in this study, conversational 'pauses' between designers' is regarded as a segment.

3.1 Coding

Most qualitative research investigations require data coding for timely data processing, analyzing, and managing (Velkemburg and Dorst 2011; Suwa and Tversky 1997; Goldschmidt and Weil, 1998; Suwa et al., 1998). This research deals with research constructs that unfold through the coding of verbal conversation from the design activities of 8 design teams. The research constructs and their relevant bases and classifications as already previously explained by Khaidzir and Lawson (2013) are coded using a cognitive actions coding matrix as shown in Table 4. The coding procedures are carried out on units of segments that represent different types of designers act. For example, designers activities related to the design brief are coded as a naming action. A typical example of a naming action is illustrated in Table 4. Framing is a fundamental method of adopting a problem-solving style for directly perusing and resolving design solutions. Segments coded as framing actions are those that represent designer acts of creation from a standpoint from which a problematic situation is solved. This includes perceiving the situation in a certain way, adopting certain concepts to describe the situation and patterns of problem-solving that are associated with that way of seeing. Some examples of framing action are illustrated in Table 4. In a general perspective of design problem-solving, moving refers to designer cognitive actions that uncover a meaningful idea that suits the issue under review. Therefore coded segments that fall under the move action are referred to designer acts that uncover an important idea that suits the solution for the issue under review. Some examples of move actions are illustrated in Table 4. Reflecting differs from other types of actions, because it deals with the imagination of a persistent idea space that supports a conclusion. This study coded segments of designer conversations that indicate the testing of an initial outcome as reflection. Some examples of reflecting actions are illustrated in Table 4.

Table 2: Transcribing of Verbal Conversation in Architectural Design Collaboration (Team 1 Digital Modality)

Time (m)	Transcribing Verbal Protocols
00.00.24 00.00.34	Z; it seems we are dealing with a bigger area S; yes it is big almost about 55m² Z; yes 55m² can be considered as big, and that will be around 11x5m S; okay 11x5m is our floor area
00.02.17 00.03.17	Z; the kiosk is for one working staff and among other requirements is to provide a space for freezer, fridges, ice cream machine, kitchenette, W/C and some advertisement signboard on the exterior of something like that (reading from the design brief) S; with WC and what else? Z; freezer, ice cream machine, freezer (reading from the design brief)
00.03.41 00.03.48	Z; I think freezer and fridge are referring to the same S; same right but I do not believe so Z; it should be same
00.04.22 00.04.50	S; so what do we have in the toilet and front elevation? Z; we may have some wash basin and water closet in the toilet and then the signboard should be clearly visible on the front elevation
00.06.34 00.06.45	Z; I think the entrance and opening in the front view should be clearly defined and presented S; okay
00.06.34 00.07.06	Z; probably the only entrance will be the staff entrance at the back so that means customers cannot go in then they will need to have eating space outside S; yeah okay eat outside Z; eat outside okay Z; where is the staff entrance? S; it will be placed somewhere at the back as you just mentioned
00.11.42 00.11.51	S; let's see the elevations Z; ehrr so here is the toilet from outside
00.15.05 00.15.20	S; okay, I think it is finish or any other thing Z; may be the signboard S; where should I put it Z; at the top of the front view S; okay here at the top
00.17.12 00.17.20	S; shall we name it UTM kiosk Z; sure S; okay
00.24.00 00.24.00	S; ooh Z; done.
02.59.00	

Table 1: Collaboration in design experiments using Digital and Sketch Modality

Segment	Designers (D1, D2)	CA	Description	Time (mins)
-	-	NAM	When the team is explicitly pointing to parts of the design task as being important, we code the activity as 'naming.' During the naming-activity, the team is looking for relevant objects in the design task.	-
-	-	FRM	This is designers' action that uncovers meaningful idea that suits the issue under review. This is the team action of settings a problem or solution boundaries to explore further on; then we code the context as a 'frame.' The frame is a context for the next activities; something to hold on to and to focus on while designing.	-
-	-	MOV	Experimental actions like generating ideas, making an inventory, sorting information, combining ideas, or comparing concepts are coded as 'moving.' During the 'moving'-activity, the team not only tries to solve the problem but at the same time also explores the suitability of the frame. The move is always characterized by a verb, identifying the activity, complemented with the content of the activity.	-
-	-	REF	This is a pattern of action that represents the application of designers' experience and knowledge of the situation to validate, test or understand a situation to generate some analytical assumptions to support the adoption, improving or optimizing a situation.	-

Note:
Designer 1 – **D1**; Designer 2 – **D2**; Cognitive Action – **CA**; Naming Action – **NAM**; Framing Action – **FRM**; Moving Action – **MOV**; Reflecting Action - **REF**

Table 1: Collaboration in design experiments using Digital and Sketch Modality

3.2 Tabulation

This section presents the analysis of the tabulated frequencies and time durations of cognitive actions during collaboration in design as shown in Tables 5 and 6. In the columns are the teams, framing (FRM), moving (MOV), naming (NAM) and reflection (REF). Whereas in the rows are frequency and time duration. The sketch teams recorded a total frequency of 24 for NAM, 62 for FRM, 220 for MOV and 310 for REF. on the other hand; the digital recorded 17 for NAM, 5 for FRM, 204 for MOV and 360 for REF. Similarly, while using the sketch modality designers spent 14.8mins on NAM, 19.5mins on FRM, 44.9mins on MOV and 88.4mins on REF. However, spent 4.0min on NAM, 0.9min on FRM, 35.3mins on MOV and 89.6mins on REF while using the digital modality

Table 5: Frequency Tabulation of Sketch and Digital Modalities

Sketch					**Digital**				
Teams	**NAM**	**FRM**	**MOV**	**REF**	**Teams**	**NAM**	**FRM**	**MOV**	**REF**
T1	1	2	10	14	T1	2	0	12	20
T2	0	3	18	25	T2	1	1	14	18
T3	2	8	49	67	T3	4	0	43	78
T4	0	5	22	35	T4	1	0	25	34
T5	4	12	21	30	T5	4	1	14	29
T6	5	8	22	33	T6	1	1	20	31
T7	4	11	20	35	T7	2	2	26	45
T8	8	13	58	71	T8	1	0	50	105
Total	**24**	**62**	**220**	**310**	**Total**	**17**	**5**	**204**	**360**

Table 6: Duration (mins) Tabulation of Sketch and Digital modalities

Sketch					**Digital**				
Teams	**NAM**	**FRM**	**MOV**	**REF**	**Teams**	**NAM**	**FRM**	**MOV**	**REF**
T1	0.1	0.1	1.2	1.9	T1	0.0	0	0.4	1.5
T2	0	0.3	3.0	5.3	T2	1.1	0.3	2.4	9.6
T3	0.1	0.7	4.0	6.9	T3	1.0	0	8.1	17.3
T4	0	0.8	3.2	11.0	T4	0.4	0	5.5	8.7
T5	4.9	4.2	3.4	8.2	T5	0.5	0.1	1.1	6.7
T6	6.4	3.1	6.1	11.1	T6	0.4	0.1	3.5	6.7
T7	0.5	7.4	6.7	9.6	T7	0.2	0.4	3.6	13.5
T8	2.54	2.5	15.0	33.9	T8	0.08	0	10.5	25.2
Total	**14.8**	**19.5**	**42.9**	**88.4**	Total	**4.0**	**0.9**	**35.3**	**89.6**

3.3 Results

This subsection presents the chi-square results and discusses differences between the sketch and digital teams. The results of the Chi-Square two-way crosstabulation presented in Figure 10 established that design modality has a highly significant association with cognitive actions during collaboration in design (x2 = 1202.000a, p = .000, df 7). The number of counts and their percentages are shown in the rows labeled cognitive actions (NAM, FRM, MOV, and REF). Similarly, the distribution of the counts and their percentages according to their modalities as shown in the columns labeled modalities (Sketch and Digital). For example, Sketch modality produced actual counts of NAM=24, FRM=62, MOV=220, and REF=310. On the other hand, Digital modality produced actual counts of NAM=17, FRM=5, MOV=204, and REF=360. The values of the counts established that the assumption of the chi-square that postulates that all expected counts must be greater than five was achieved. This evidence shown in Figure 10 indicates the smallest expected count is 20.00, which exceeds five as stipulated by the assumption. Similarly, the Pearson Chi-Square value for a significant association between measured variables was established within a range of $p < .001$ within a rounding error of 1665.577/89.970, which is a highly significant value. Therefore, it is significant (refer to Figure 10). A detailed description of the result and its implication will be discussed in the subsequent section.

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	1202.000[a]	7	.000
Likelihood Ratio	1665.577	7	.000
Linear-by-Linear Association	89.970	1	.000
N of Valid Cases	1202		

a. 2 cells (12.5%) have expected count less than 5. The minimum expected count is 2.44.

Figure 9: The P-value between Cognitive action and Modalities

4.0 Finding and Conclusion

Even though the chi-square indicated a significant difference between the two modalities, there is a very negligible margin between the total frequency and duration of the two modalities. In total, the sketch recorded 51% and the digital recorded 49% of the total frequency and duration of cognitive actions. Therefore, concerning the total frequency and duration of all the four parameters of cognitive actions, the differences are very negligible therefore not very significant (refer to table 7 and figure 9).

Table 7: Frequency/Duration of Cognitive action in Modality-based Collaboration Design

Modalities	Frequecy (count)	Duration (mins)
Sketch	613	166
Digital	586	130

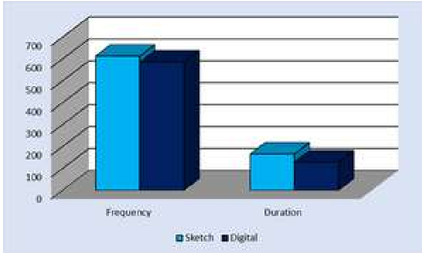

Figure 10: Frequency/Duration of Cognitive action in Modality-based Collaboration Design

On the other hand, a microscopic view indicated that the sketch yielded more frequency and duration of framing actions than the digital. This implies that digital modality for collaboration in design impedes a particular way of seeing the problem and solution that facilitates the communication and evaluation of abstract ideas and concepts (Valkenburg and Dorst, 1998; Schon, 1983). Even though there are global application and adoption of digital modality for collaboration in design, we strongly advocate the need to improve the digital modal with the properties of the sketch. The detailed illustration of the test was presented in Figure 11 and 12. The results affirmed that a sketch modality is a cognitive tool that supports framing actions in design (Gero et al. 2001; Fish and Scrivener, 1990). However, the findings contradict the assumption of most contemporary research that opts for the adoption of digital modality for design. The contradiction can be justified by the inability of digital modality to effectively support key cognitive actions like framing during collaboration in design. Consequently, it can be suggested that there is a need to improve digital modality with the properties of the sketch. Finally, this indicates that the sketch can still play a vital role in collaboration in design (refer to figure 10 and figure 12).

Table 8 Frequency of Cognitive action

Modalities	Framing Action	
	Frequency (count)	Duration (mins)
Sketch	62	20
Digital	5	1

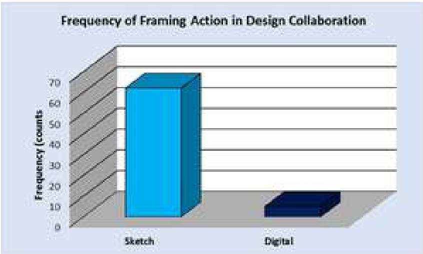

Figure 11 Frequency of framing between sketch and digital

Figure 12 Time duration of framing between sketch and digital

5.0 Reference

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